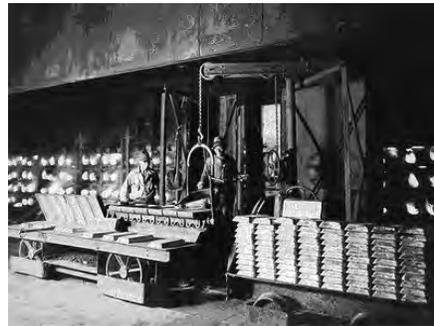
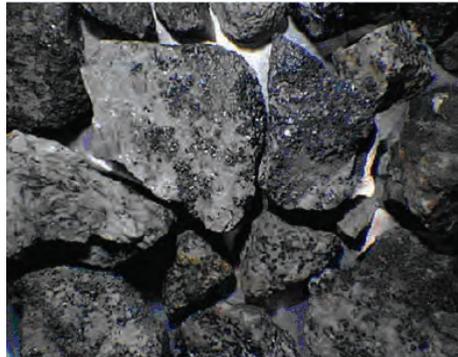


Historical Zinc Smelting in New Jersey, Pennsylvania, Virginia, West Virginia, and Washington, D.C., with Estimates of Atmospheric Zinc Emissions and Other Materials



Open-File Report 2010–1131

On the cover: Top left: Photograph of smithsonite (USGS, 2009). Top center: Photograph of mixed franklinite, willemite, and zincite (USGS, 2009). Top right: Photograph of sphalerite (USGS, 2009). Bottom left: Photograph of an 1868 advertisement for zinc oxide [Library of Congress, 2009 ([http://lcweb2.loc.gov/cgi-bin/query/r?pp/PPALL:@field\(DOCID+@lit\(2006679062\)\)](http://lcweb2.loc.gov/cgi-bin/query/r?pp/PPALL:@field(DOCID+@lit(2006679062))))]. Bottom center: Photograph of molten zinc being poured into molds at the Donora Zinc Works, circa 1920 (Courtesy of Scott Beveridge and the Donora Historical Society, 2009). Bottom right: Photograph of the Palmerton Zinc Smelter, circa 1965 (Courtesy of Arthur W. Larvey, Consulting Chemical Engineer, 2009).

Historical Zinc Smelting in New Jersey, Pennsylvania, Virginia, West Virginia, and Washington, D.C., with Estimates of Atmospheric Zinc Emissions and Other Materials

By Donald I. Bleiwas and Carl DiFrancesco

Open-File Report 2010–1131

**U.S. Department of the Interior
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Conversion Factors

Multiply	By	To obtain
mile (mi)	1.6093	kilometer (km)
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
pound avoirdupois	0.4536	kilogram
ton, short (2,000 pounds)	0.9072	metric ton

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

Historical Zinc Smelting in New Jersey, Pennsylvania, Virginia, West Virginia, and Washington, D.C., with Estimates of Atmospheric Zinc Emissions and Other Materials

By Donald I. Bleiwas and Carl DiFrancesco¹

Executive Summary

Introduction

The metallurgical industry can be broadly divided into metal production from feedstock consisting of primary and secondary sources. Primary production refers to the extraction of metal derived from ores and concentrates. Secondary production refers to the recovery of metal from materials such as alloys, electric arc furnace dust, ingots, and scrap. The foci of this study are the histories of selected pyrometallurgical plants that treated mostly primary zinc feedstock and the atmospheric emissions, primarily zinc, generated by those plants during the course of producing zinc and zinc oxide in New Jersey, Pennsylvania, Virginia, West Virginia, and Washington, D.C.

Pure zinc metal, commonly known as native zinc, does not occur as an ore in nature, but occurs in, or in association with, minerals that can contain elements such as arsenic, cadmium, calcium, copper, fluorine, iron, lead, manganese, mercury, silica, and sulfur. Dust, fumes, and gases containing various combinations of these materials are generated at zinc smelting facilities by mechanical and pyrometallurgical processes that convert ore and concentrates into marketable zinc products and byproducts. The combination of dust, fumes, and gas, is referred to in some of the historical literature as metallurgical smoke (Fulton, 1915). The distribution of dusts, fumes, and gases are affected by point of origin, distribution by ceiling vents and stacks, weather patterns, and geography. The amount and chemistry of atmospheric emissions produced by zinc smelters reflect the amount and composition of the feedstock processed, amount and types of products and byproducts produced from primary and some secondary sources, technologies employed, and the operators' environmental practices and compliance with regulatory policies relating to human health and the environment.

The atmospheric emissions produced from the smelting practices used at some of the plants included in this study have been associated with causing or contributing to environmental and human health. The materials contained in the emissions included arsenic, cadmium, carbon, lead, fluorine, mercury, sulfur, and zinc. From the early 1870s, operations at zinc smelters in the study area were affected by community resentment of sulfurous emissions to the atmosphere in areas of population growth (Miller, 1941, p. 349) and contributed to the decision to cease mining sulfide ores in the Friedensville District in Pennsylvania (Miller, 1941; p. 349). Evidence of the harmful effects had shown that heap roasting, a practice used in the Friedensville District before the 20th century, was a nuisance and caused damage to livestock, indigenous vegetation, and crops (Austin, 1909; p. 84) and resulted in action by the courts. In 1875, the Jersey City smelter discontinued processing sulfide ores shipped from Pennsylvania because of the generation of a large amount of "sulfur fumes in populated areas" (Dunn, 1995; p. 780). In the late-1890s, roasting of zinc sulfide ores in Kansas were reported to have produced "sulfur vapors destructive to the vegetation around the smelters" (Grimsley, 1903) contributed to concerns.

In 1948, atmospheric emissions produced by zinc smelting activities are thought to have contributed to the deaths and illness of residents of Donora, Pennsylvania. This particular occurrence was considered pivotal in the development of the Clean Air Act of 1970 (Clean Air Trust, 1999, p 2).

Three U.S primary zinc smelters included in this study appear on the U.S. Environmental Protection Agency (USEPA) National Priority List, commonly known as federal Superfund sites. They include the Palmerton Plant, which was placed on the list in 1983. Evidence shows that the facility's smelting-related activities in the past contributed to forest defoliation and anomalously high levels of metals in surrounding soils. The plant's roasting activities were reported to have released an average of 3,300–3,600 pounds of sulfur per hour to the atmosphere from 1918 to 1970, when additional equipment was added to reduce emissions. From 1970 to 1980, when the practice of roasting ore and concentrate ceased,

¹Retired

2 Historical Zinc Smelting in New Jersey, Pennsylvania, Virginia, West Virginia, and Washington, D.C.

sulfur emissions were determined to have dropped to about 1,400 pounds of sulfur per hour (Flowers, 2005, p. 2; Oyler, 1997, p. 5). The two other Superfund sites at Langeloth, Pennsylvania and Meadowbrook, West Virginia required remediation long after the smelters closure at considerable cost.

Many of the plant sites examined in this study have been partially or completely demolished leaving little or no visible physical evidence of the original structures. Industrial ecologists can use data relating to historical zinc smelting activities, to account for the presence of certain materials at various scales and timeframes and can further the understanding of the possible causes environmental and health effects.

During the last 150 years, increased material recoveries resulting from improvements in, and the introduction of new technologies, changes in the types of feedstock, greater knowledge regarding human health and the environment, and more-stringent environmental regulations at various levels of government have reduced greatly the amount of potentially harmful emissions per unit of zinc recovered in the United States.

Study Area and Smelter Site Locations

The 19 zinc smelting sites included in this study are located in the District of Columbia, and the States of Pennsylvania, New Jersey, Virginia, and West Virginia. In 2009, only 2 of the 19 sites continued to produce zinc products (Monaca and Palmerton), but neither site uses primary zinc ore or concentrate as feedstock, rather consuming only secondary feedstock, primarily dust recovered from electric arc furnaces (EAF) that melt scrap for steel production.

Table 1 includes the names of the plant sites studied and other general information related to the sites. Figure 1 illustrates their approximate location. Specific information related to each site is presented in Appendix 2.

Synopsis of Historical Zinc Smelting in the Study Area

The following synopsis is a general description of the history of the U.S. zinc industry with a focus on the plants evaluated in this study. Figures showing the changing geographic pattern of zinc production, through closures and openings among the plants studied are illustrated in figures 2 through 6. It is not intended to be a comprehensive history of the domestic zinc smelting sector. A general description of technologies employed in the recovery of zinc from ore, concentrate, and some secondary materials is presented in Appendix 1. Details relating to specific occurrences that affected individual plants evaluated in this study are provided in the profile reports in Appendix 2.

Although large-scale smelting of zinc ore was practiced in China during the 7th century, India beginning in the 13th

century, and in Europe by the early 18th century (Deshpande, 1996), it was not practiced in the United States until the 1830s when zincite mined in New Jersey was smelted in Washington, D.C. Small furnaces containing horizontal retorts operated on a limited basis for the purpose of producing brass for the first United States' official weights and measures ordered by Congress.

It was not until the 1850s that commercially successful smelting operations were established in the United States using a newly developed pyrometallurgical process to produce zinc oxide using furnaces to vaporize zinc metal from ores and baghouses to capture the reacted zinc oxide. The first plants to employ this process were constructed in New Jersey and Pennsylvania. Soon afterward, zinc metal was produced in the same states by an established method of furnaces containing horizontal retorts charged with a mixture of zinc ore and a carbon source, usually coal. In this process, zinc contained in the ore was vaporized in an oxygen-depleted atmosphere and condensed to a molten zinc metal.

Most of these early plants were constructed in or close to industrialized population centers, that possessed an available labor force and well-developed infrastructure such as ports on the Atlantic coast, canals, rail lines, rivers, and roadways. Pre-existing electricity, natural gas, and water supplies were available also for some plants. Other smelting sites were constructed in or near zinc mining districts or in proximity to a coal source. Coal was a major consumable for fueling furnaces, producing gas and generating steam for driving equipment and generating electricity; and as a reductant in the pyrometallurgical processes for producing zinc. Some of the early smelting facilities required bringing in skilled smelter operators from other cities and from overseas.

The first commercial smelter, constructed in Newark, New Jersey and placed into operation in 1852, used the zinc ores from the Franklin and Sterling Hill zinc deposits in northern New Jersey. The smelter produced zinc oxide, mostly for use as a pigment in paints as part of a growing trend to replace lead, owing to the potentially toxic effects of the metal. Advances in technology, such as magnetic separation and gravity separation of ores, permitted the development of additional zinc oxide smelters at Bergen Point and Passaic, in New Jersey in the 1850s.

During the early 1860s, the recovery of zinc metal at the South Bethlehem, Pennsylvania plant was initiated using sulfide ores from local deposits considered worthless 20 years earlier because of technological problems. The zinc metal was used for galvanizing steel and as a component in the manufacture of brass. The extraction of zinc sulfide ores increased as ore from previous discoveries and subsequent zinc exploration successes were developed as the oxidized portions of sulfide ore bodies became exhausted and operating mines extracting ore from zinc oxide deposits could no longer meet the rising demand for zinc. A number of small roasting facilities for the pretreatment of sulfide ore and smelters to treat locally mined ores from the Friedensville deposits were constructed in the Lehigh Valley in eastern Pennsylvania (most of them short

Table 1. Facility name, city, state, map number, and latitude and longitude.

Map number ¹ (See fig. 1)	Facility name	City	State	Latitude (Degrees, minutes, seconds)	Longitude (Degrees, minutes, seconds)	Latitude (Decimal degrees)	Longitude (Decimal degrees)
1	Bergen Point Zinc Works	Bayonne	New Jersey	40°38'51" N	074°08'30" W	40.647500	-74.141667
2	Passaic Zinc Works	Jersey City	New Jersey	40°42'46" N	074°03'44" W	40.712778	-74.062220
3	Newark Zinc Works	Newark	New Jersey	40°43'59" N	074°08'27" W	40.733012	-74.140829
4	Bamford Spelter Plant	Bamford	Pennsylvania	40°05'05" N	076°23'23" W	40.084726	-76.389882
5	South Bethlehem Smelter	Bethlehem	Pennsylvania	40°36'39" N	075°22'00" W	40.610833	-75.366667
6	Keystone Zinc Works	Birmingham	Pennsylvania	40°38'56" N	078°12'46" W	40.648889	-78.212778
7	Donora Zinc Works	Donora	Pennsylvania	40°10'24" N	079°51'28" W	40.173333	-79.857780
8	Florence Zinc Works	Freemansburg	Pennsylvania	40°37'35" N	075°20'46" W	40.626389	-75.346111
9	Lehigh Zinc and Friedensville Zinc Companies (combined)	Friedensville	Pennsylvania	40°33'16" N	075°24'18" W	40.554444	-75.405000
10	Monaca Zinc Smelter	Monaca	Pennsylvania	40°40'16" N	080°20'50" W	40.671111	-80.334736
11	Langeloth Zinc Works	Langeloth	Pennsylvania	40°21'54" N	080°24'51" W	40.363506	-80.414167
12	Palmerton Zinc Smelter	Palmerton	Pennsylvania	40°49' 59" N	075°40'00" W	40.833333	-75.666667
13	Austinville Furnace	Austinville	Virginia	36°51'04" N	080°54'44" W	36.851111	-80.912220
14	Bertha Zinc Works	Pulaski	Virginia	37°02'52" N	080°46'47" W	37.047778	-80.779722
15	Grasselli Chemical Company	Anmoore	West Virginia	39°15'25" N	080°17'33" W	39.256846	-80.292602
16	Clarksburg Zinc Company	Clarksburg	West Virginia	39°17'15" N	080°20'56" W	39.287504	-80.348815
17	Moundsville Zinc Smelter	Moundsville	West Virginia	39°55'13" N	080°44'36" W	39.920278	-80.743333
18	Meadowbrook Zinc Smelter	Spelter	West Virginia	39°20'54" N	080°18'59" W	39.348349	-80.316375
19	United States Arsenal	Washington	District of Columbia	38°51'42" N	077°01'04" W	38.86167	-77.017780

¹Map numbers are assigned alphabetically by state (first order) and city (second order). Washington, D.C., was placed last.

4 Historical Zinc Smelting in New Jersey, Pennsylvania, Virginia, West Virginia, and Washington, D.C.

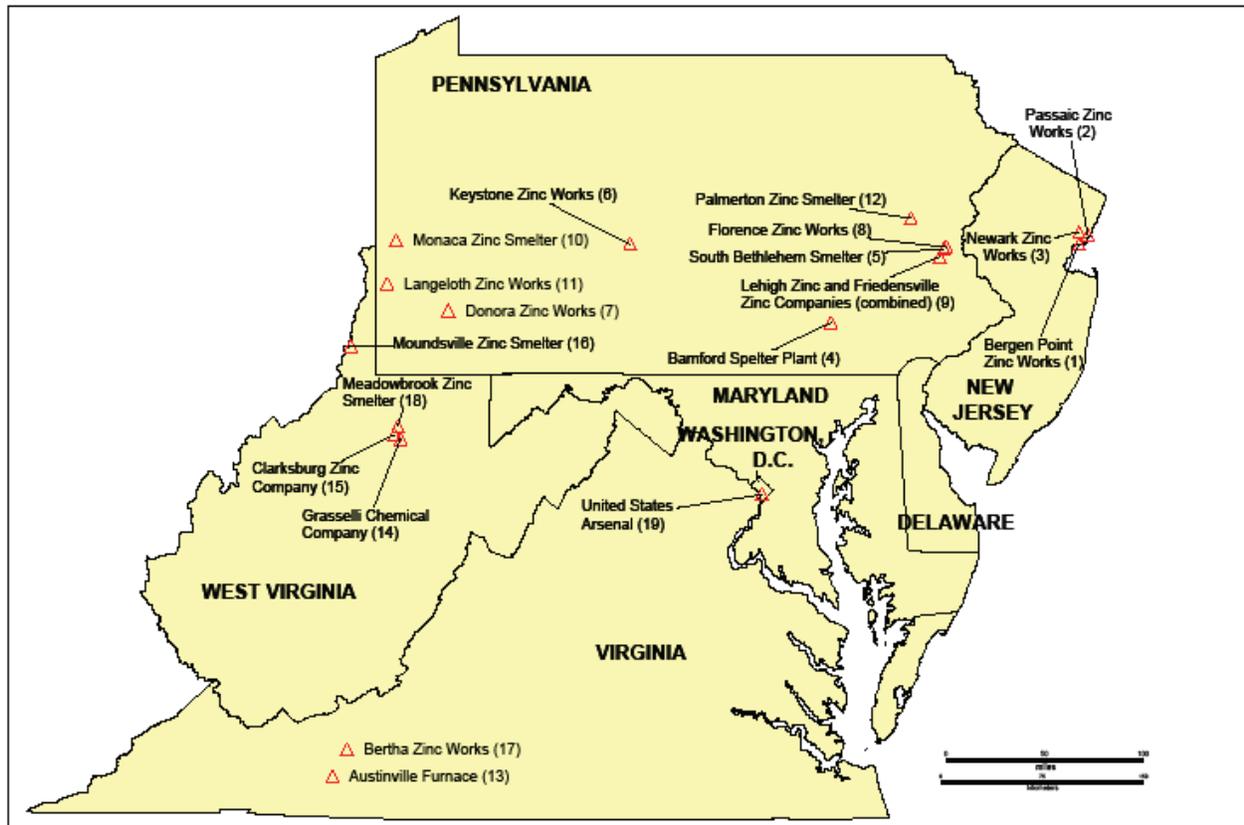


Figure 1. Locations of zinc smelters evaluated in this study. Numbers in parentheses correspond to table 1.

lived). Most of the zinc smelters were initially constructed close to the sources of ore to reduce transportation costs and other logistical costs associated with transporting and processing the ore.

Beginning in the 1870s, ore, and later concentrate, from the Franklin and Sterling area of New Jersey were shipped to Pennsylvania for smelting. The practice continued for nearly 150 years (Jolly, 1994, p. 65). Previously known deposits containing zinc near Austinville, Virginia, were exploited and new deposits discovered, resulting in the construction of smelters in Pulaski, Virginia to treat these ores in the late 1870s (Whisonant, 1996).

In the 1880s, the principal zinc products were zinc oxide for the zinc-based paint industry, zinc metal, and pig iron, referred to in the industry at the time as spiegeleisen (Dunn, 1995, p. 214). Zinc oxide generated the most revenue in the industry (Dunn, 1995, p. 214). Around 1895, a geographic shift in the mining and smelting of zinc ores from the eastern states to the Tri-State District in Illinois, Kansas, and Missouri occurred resulting from the discovery of large polymetallic ore bodies and abundant natural gas in the region, particularly in Kansas (McMahon and others, 1974, p. 41). The development

of essentially free-flowing gas wells gave a significant production cost advantage to these operations and contributed to the permanent shut down of higher-cost operations, such as the South Bethlehem facility in Pennsylvania.

A major restructuring of the zinc industry occurred when the New Jersey Zinc Company purchased several zinc companies in what is referred to as the “Great Consolidation” (Dunn, 1995).

By 1910, all three zinc smelters in New Jersey; the Bergen Point, Newark, and the Passaic Zinc Works, had permanently closed because of a combination of competition, increasing costs, and obsolete technologies. From this time forward, newly constructed plants in Pennsylvania using improved technologies and local coal reserves processed most of the zinc ores and concentrates recovered from the zinc mines in New Jersey, until the last of the New Jersey mines closed in 1986. During the same time period, smelters were constructed in the vicinity of Clarksburg, West Virginia to take advantage of abundant coal and natural gas reserves in the area. The ores that originated from the Tri-State District, some of which were roasted in Ohio, were a principal feedstock to the plants in West Virginia.

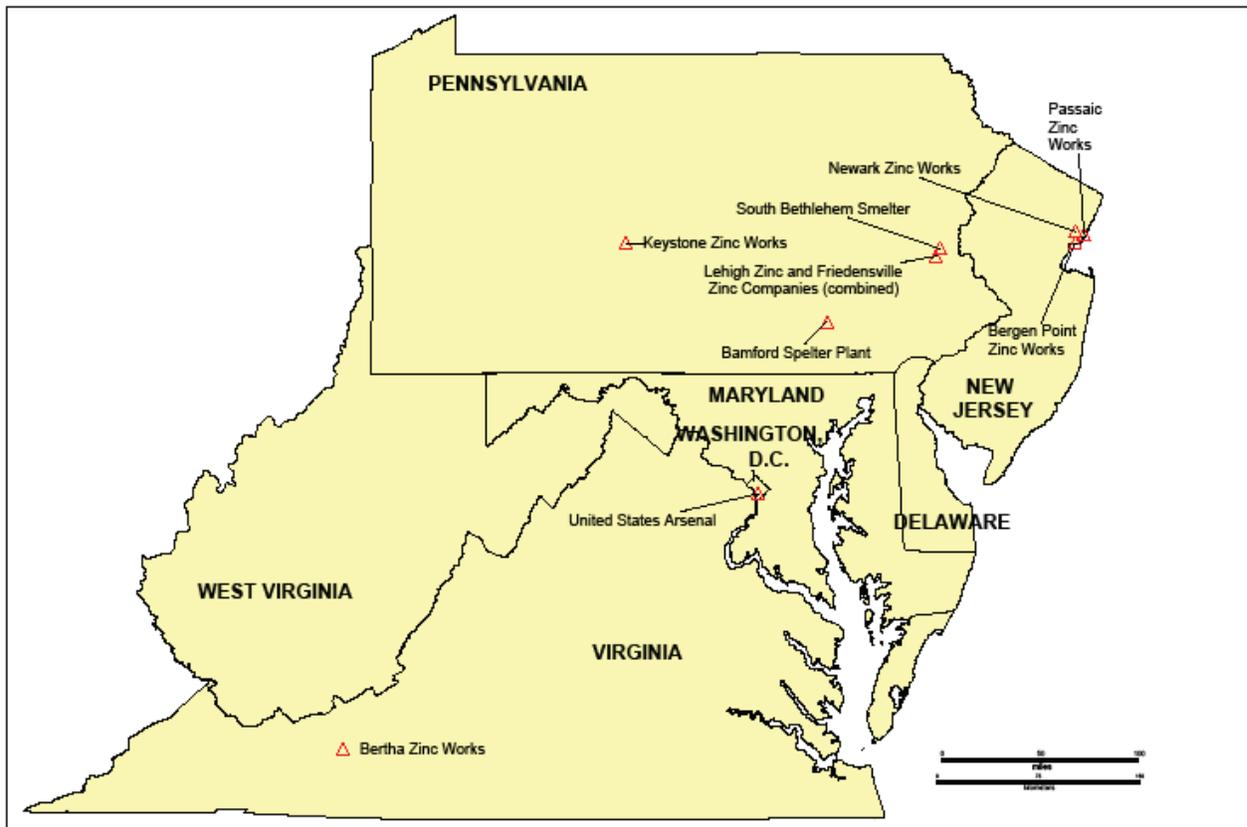


Figure 2. Zinc smelters operating during 1830 through 1890.

During World War I, the smelting facilities of Belgium, France, Germany, and Poland were unavailable to the Allies. This spurred the construction of new zinc smelters in the United States, such as the Donora and Langeloth plants in Pennsylvania, and expansions at other U.S. plants (McMahon and others, 1974, p. 42). Following the war, excess global plant capacity caused metal prices to fall dramatically resulting in numerous mine and smelter closures. The permanent closure of the Clarksburg Zinc Company's smelter in West Virginia was among the casualties of the low metal prices.

In the 1920s, exploration to test for the potential for zinc sulfide ore reserves lying below the exhausted zinc oxide deposits near Austinville, Virginia, resulted in the discovery of rich zinc sulfide ores and justified the construction of several mining operations that treated milled sulfide ores by flotation, a relatively new technology for that time period to produce high-grade concentrates. Flotation could accomplish much of the work previously done by hand sorting and selective mining of ores and could recover zinc as a mineral concentrate. A portion of this new feedstock supply was directed to the Palmer-ton smelter and other plants in the region.

Improvement in pyrometallurgical technology led to higher recoveries of zinc from ore. A total smelter recovery of 62 percent of contained zinc in ore was noted in 1844, 75 percent in 1880, and 87-90 percent around 1920 (Hofman, 1922, p. 166).

In the late-1930s and into the early-1940s, U.S. smelters expanded their zinc production capacity initially in response to orders for the metal from Great Britain and France and later to support the U.S. World War II effort (McMahon and others, 1974, p. 44). It was during this time also that a major technological transition occurred in the zinc smelting industry with the introduction of more efficient electrothermic vertical retorts as a replacement of horizontal retorts. The Monaca and Palmerton plants were among the first zinc smelters to install the new type of retorts. During World War II, the U.S. smelters absorbed much of the foreign trade that was shipped to European smelters, but during this period were in territory occupied by the German military (McMahon and others, 1974). During this period sources of feedstock to the smelters evaluated in this study included the countries of Australia, Canada, Chile, Ireland, Mexico, Peru, Spain, and Thailand; and in the United States; Colorado, Kansas, Missouri, New Jersey, New Mexico,

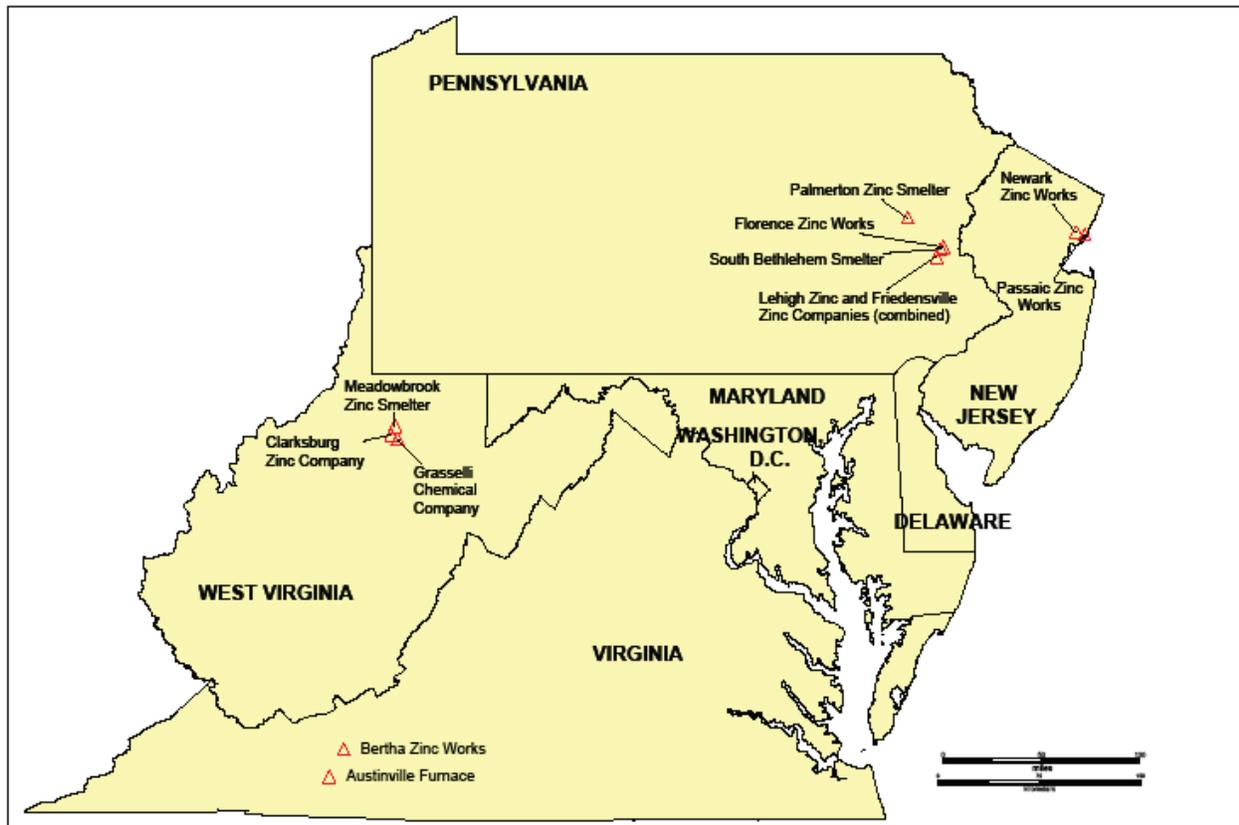


Figure 3. Zinc smelters operating during 1891 through 1913.

New York, Oklahoma, Ohio, Pennsylvania, Tennessee, and Virginia. The increase in domestic and foreign sources of zinc ore and concentrate during this time period is reflected in the amounts and types of feedstock treated at the Meadowbrook and Palmerton smelters in Pennsylvania, in particular. During the 1940s, the Palmerton plant treated sulfide ore and concentrate from operations in Colorado and perhaps 40 other operations elsewhere in response to the need for zinc during World War II (Oyler, 1997).

Within 2 years following World War II, the Florence, Langeloth, and Moundsville plants permanently closed because of excessive global zinc smelting capacity, weak zinc prices, aging technology, and relatively high production costs.

In 1957, U.S. Steel, owners of the Donora Zinc Works, in Donora, Pennsylvania, permanently closed the plant because of depleted ore reserves, high operating costs, and obsolete equipment (Beveridge, 2007). Claims of environmental degradation and negative effects on human health caused by the plant, new laws limiting plant emissions, and potential litigation also contributed to the closure. The effect of air pollution

generated by the Donora Zinc Works was instrumental in the passage of the Federal Air Pollution Control Act of 1955 also referred to as the Clean Air Act (Davis, 2003; Hess, 1995).

Following the closure of the Donora plant, only the Meadowbrook, Monaca, and Palmerton smelters in Pennsylvania remained in operation among the plants evaluated in this study. By 1970, anticipated costs for meeting regulatory compliance with enacted environmental regulations contributed to the closure of the Meadowbrook plant in 1971. In the year 1980, the USEPA listed Electric Arc Furnace (EAF) dust, as a hazardous waste because of its potentially toxic components, which included cadmium, calcium, chlorine, fluorine, lead, and zinc. Around 1990, a ban was placed on disposing untreated EAF dust in landfills (James and Bounds, 1990). These regulatory actions stimulated interest in development or improvement of existing technologies to recover metal values, such as cadmium, chromium, iron, and zinc, contained in EAF dust through recycling.

To comply with new regulations and improve their competitive position in the industry, the Monaca and Palmerton

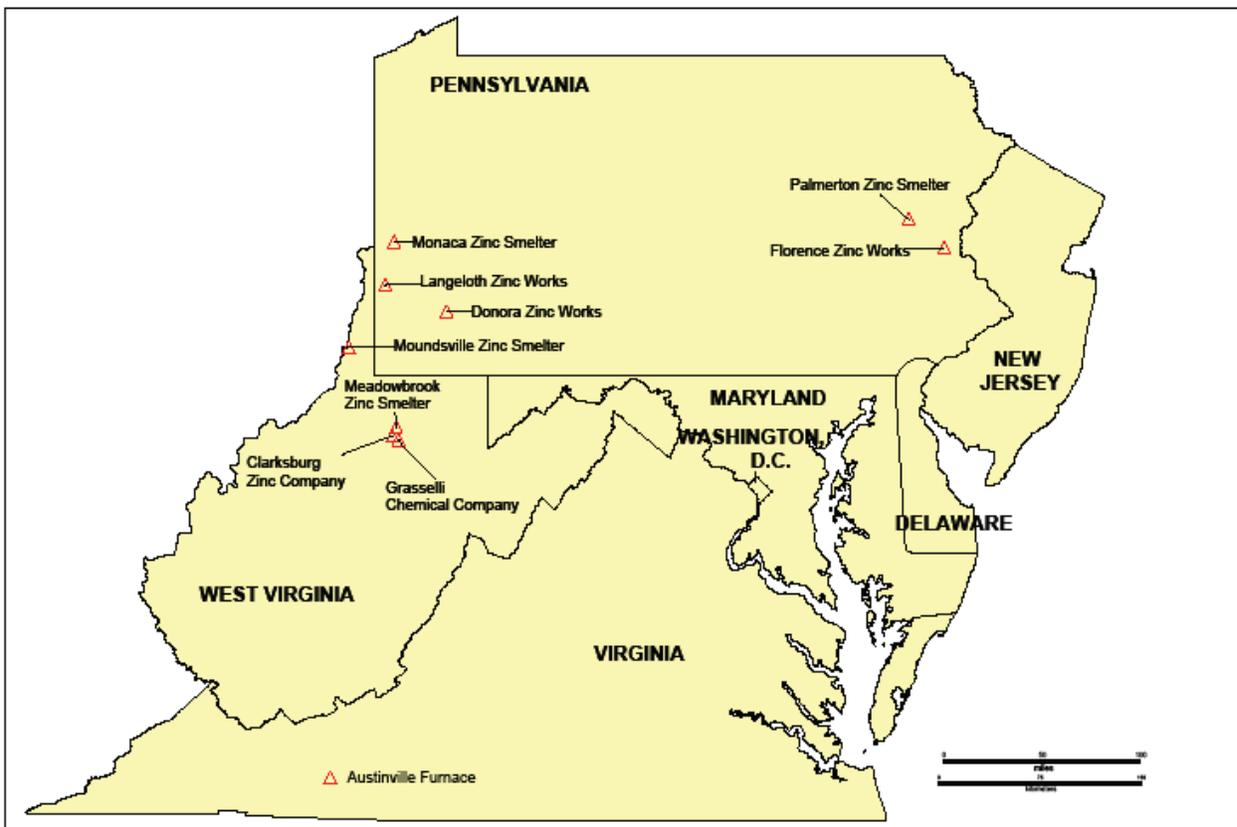


Figure 4. Zinc smelting facilities operating during 1914 through 1950.

plants increased the proportion of secondary zinc feedstock material, including EAF dust, and eventually treated secondary feedstock exclusively, a practice the company continues to follow.

Methodology

This study focuses on selected zinc smelting operations in the eastern United States over a period of approximately 150 years, with an emphasis on the feedstock, production, processing technology, and the atmospheric emissions of zinc, and in some cases other materials, generated by the plants. The authors report previous and ongoing research activities pertaining to the analyses of emissions such as fate, dispersion and distribution; and environmental or health effects attributed to specific facilities or facilities, but these types of site-specific analyses were considered to be beyond the scope of this study.

Statistical data specifically relating to atmospheric zinc emissions generated by individual plants were published

rarely. However, some generalized data pertaining to process losses for the various stages of treatment required for recovering zinc metal, and to a much lesser extent zinc oxide, were published in the literature. For example, in 1917, approximately 4.1 percent of the zinc contained in horizontal retorts was estimated to have been emitted through chimneys and other avenues of escape to the atmosphere (Hofman, 1922, p. 166) during the production of zinc metal. A photograph, taken around 1916, shows zinc fumes escaping from the horizontal retorts at the Donora zinc smelter in Pennsylvania.

In the early 1940s, approximately, 2.5 percent to 4 percent of the zinc contained in the charge processed in horizontal retort furnaces was lost to the atmosphere by diffusion through retorts, broken retorts, and through chimneys (Liddell, 1945, p. 458). A test performed on air emissions at the Donora Zinc Plant in 1949 determined that the amount of zinc emitted to the atmosphere annually was approximately 5 percent of the plant's zinc production capacity (Schrenk and others, 1949), lending further support to the estimated zinc losses to the atmosphere calculated for this study.

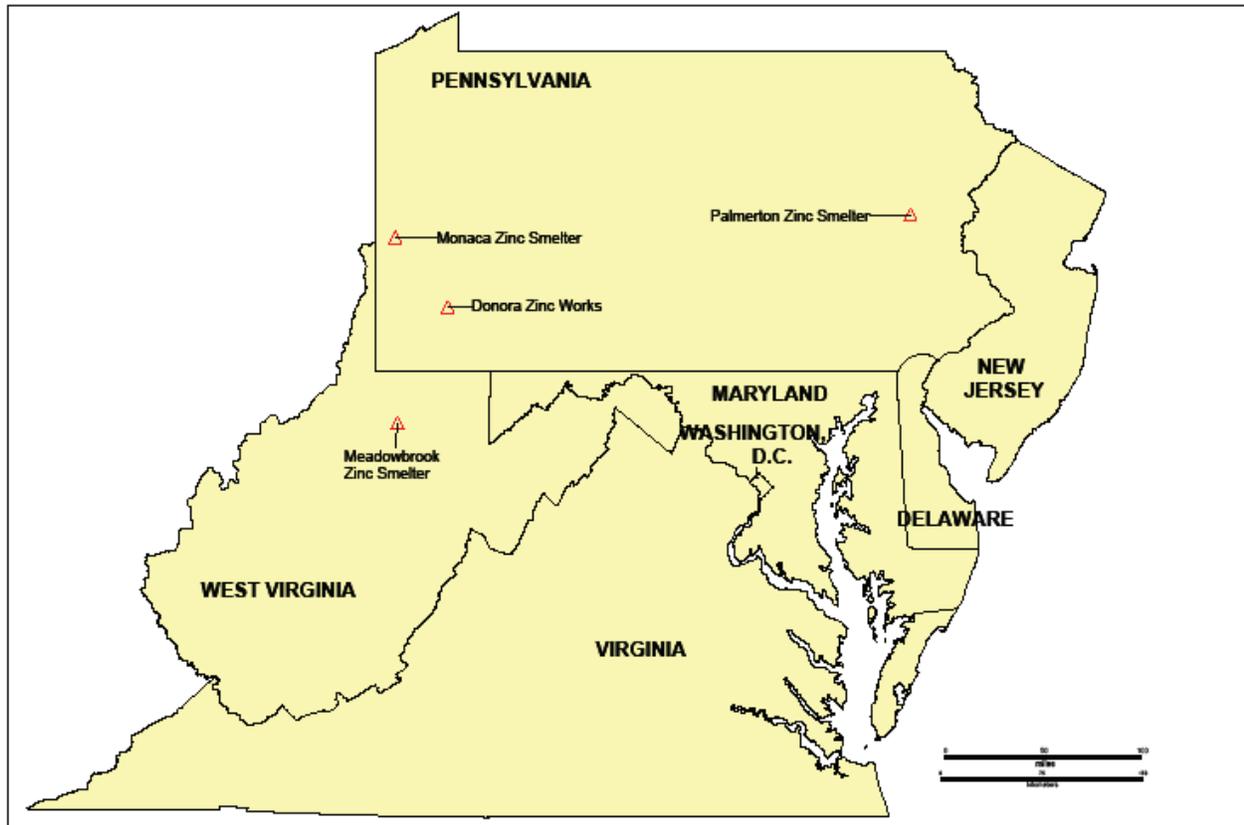


Figure 5. Zinc smelters operating during 1951 through 1975.

Additional losses also occurred during charge preparation, material handling, and during the roasting and sintering of feedstock. In the late 1940s and early 1950s, zinc recovery in vertical retorts was 92–94 percent with residues containing approximately 3 percent zinc (U.S. Bureau of Mines, 1951, p. II-42). The balance of the losses was contained in releases to the atmosphere as dust, fumes, and gas. Losses from plants varied and depended on numerous factors including individual plant practices, state of technologies, and regulatory requirements.

In the mid-1970s, plant-specific data became more available because of the implementation of stricter federal, state, and local regulatory reporting requirements and greater public interest in the environment and human health. By this time, only two of the evaluated primary zinc sites, the Monaca and the Palmerton plants in Pennsylvania, were still active. These plants had undertaken major modifications to comply with the newly emplaced regulations. All other operations evaluated

in this study had permanently closed previously for various reasons.

In the absence of site-specific emission data, it was necessary to reconstruct operational details for the selected smelters over the length of time they were active. These details included annual production, plant capacity, capacity use, the number of years of production, the chemistry and proportions of various feedstock materials, product types, regulatory policies, and the types and effectiveness of technologies employed at the facility. Most of these factors varied over the plants' operating life. These data were collected and developed from numerous sources that included annual publications of the U.S. Bureau of Mines and U.S. Geological Survey reports, newspapers, professional journals, and reference books, and annual stockholder reports, and internal company reports. Industry experts with historical and current knowledge of zinc smelting practices, and in some cases for specific operations, were consulted and provided assistance in developing estimates.

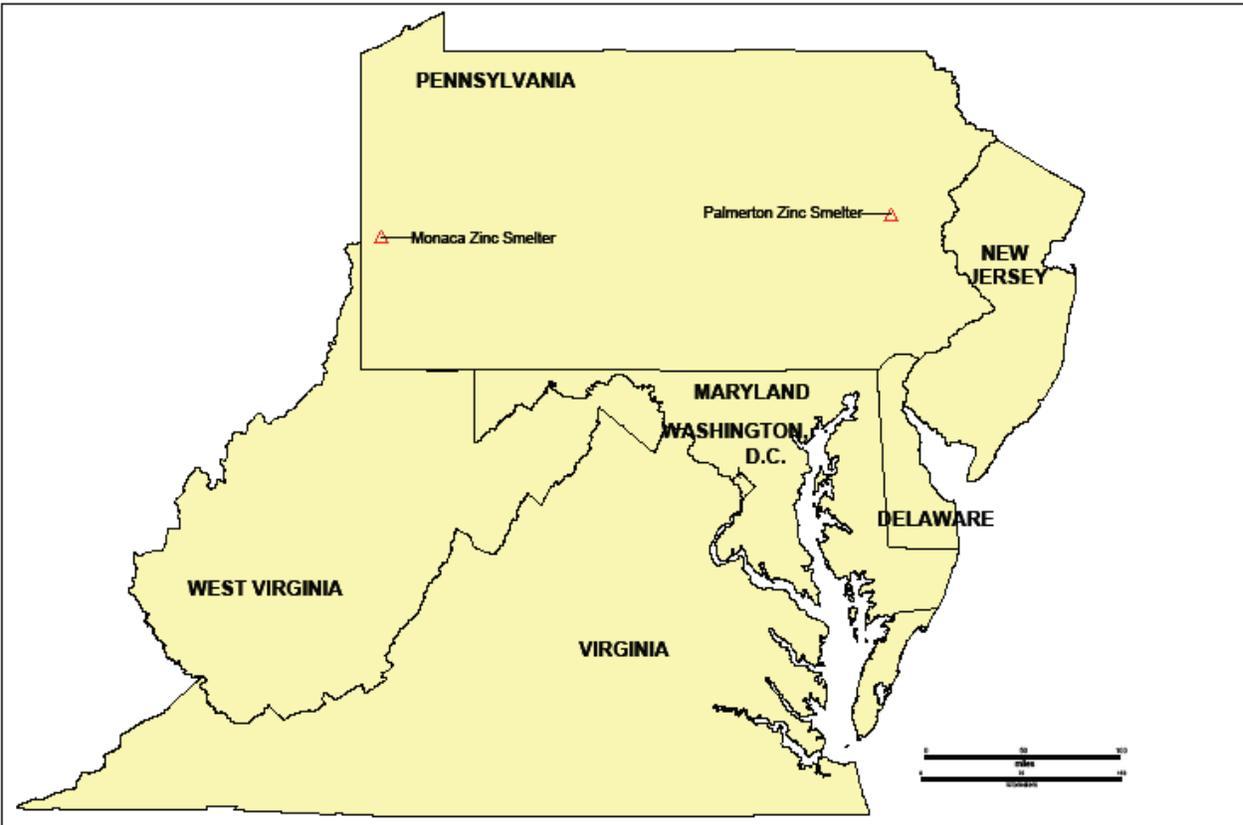


Figure 6. Zinc smelting facilities operating during 1976 through 2009.

Lastly, assumptions were sometimes necessary to develop estimates in the absence of actual data. Emission estimates should be considered broad approximations because site-specific data were incomplete, and the compounding effects of combining estimated factors used in the calculations can significantly affect results.

Most values reported in this study are presented in English units, the original form of the referenced data, rather than metric units.

Summary of Atmospheric Fugitive and Stack Emission Estimates

Table 2 summarizes atmospheric zinc emission estimates for individual plants studied in this report. Figures 7, 8, 9, and 10 illustrate the estimated total and average annual zinc production and zinc emissions and zinc emissions on a

plant-by-plant basis. Atmospheric emissions generated from wind-blown smelter slag and from fumes and vapors from freshly poured slag were not included in the estimates. Emissions generated from the consumption of materials used in the processes required to recover zinc, such as reagents and coal (used as a reductant and to generate steam and producer gas) also were not considered in the estimates. Some of these materials contained sulfur and heavy metals. Zinc emission estimates were not quantified for two sites owing to insufficient data. Profiles describing the individual sites and atmospheric emissions associated with the plants are provided in Appendix 2.

It is estimated that approximately 863,000 short tons of zinc, contained in various forms, were possibly emitted through fugitive and stack emissions during the production of an estimated 23.6 million short tons of zinc contained in products. This is equivalent to about 3.7 percent of the estimated zinc production from the plants listed in table 2.

Table 2. Facility name, location, years of production evaluated, estimated zinc contained in atmospheric emissions, in descending order; estimated average annual zinc production, estimated total zinc production.

[Tonnage values are expressed as 1,000 short tons.]

Facility Name	Operational Status (as of 2009)	Years of operation evaluated	Primary zinc product(s) ² ³ (zinc metal and/or zinc oxide)	Average estimated annual atmospheric zinc emissions ^{4,5}	Total estimated atmospheric zinc emissions ⁴	Average estimated annual zinc production ⁷	Total estimated zinc production ⁷	Atmospheric zinc emissions as a percentage of total zinc production ⁸	Elements comprising feedstock, and likely or known to be contained in atmospheric emissions ⁹
Monaca Zinc Smelter	Producer	1931-2002 ¹	Zinc metal, zinc oxide	3.6-4.4	260 –318	122–133	8,800 – 9,600	3	Cd, Cu, Hg, F, Pb, S, Zn
Palmerton Zinc Smelter	Producer	1898-1986 ¹	Zinc metal, zinc oxide	3.2	286	93	8,200	4	As, Cd, Cu, Hg, Mn, Pb, S, Se, Zn
Meadowbrook Zinc Smelter	Past producer	1911-71	Zinc metal	0.97-1.3	60–80	33	2,000	3-4	As, Cd, Cu, F, Hg, Pb, S, Zn
Donora Zinc Works	Past producer	1915-57	Zinc metal	1.7	73	35	1,500	5	As, Cd, Cu, F, Pb, S, Zn
Langeloth Zinc Works	Past producer	1914-47	Zinc metal	1.1	36	27	900	4	As, Cd, Cu, Pb, S, Sb, Zn
Grasselli Chemical Company	Past producer	1904-27	Zinc metal	0.67	16	17	410	4	As, Cd, Cu, Hg, Pb, S, Zn
Newark Zinc Works	Past producer	1852-1910	Zinc metal, zinc oxide	0.26	15.5	4.6	272	6	Mn, Zn
Passaic Zinc Works	Past producer	1854-1901	Zinc metal, zinc oxide	0.26	12.5	4.4	216	6	Mn, S, Zn
Moundsville Zinc Smelter	Past producer	1918-45	Zinc metal	0.32	9.0	6.5	183	5	As, Cd, Cu, Pb, S, Zn
South Bethlehem Smelter	Past producer	1853-1911	Zinc metal, zinc oxide	0.11	6.7	2.5	146	5	Mn, S, Zn
Clarksburg Zinc Company	Past producer	1907-18	Zinc metal	0.29	3.5	7.0	84	4	As, Cd, Cu, Pb, S, Zn
Bertha Zinc Works	Past producer	1880-1910	Zinc metal	0.11	3.5	2.2	67	5	Pb, Zn
Florence Zinc Works	Past producer	1891-1945	Zinc oxide	0.04	2.0	1.2	68	3	Zn
Bergen Point Zinc Works	Past producer	1875(?) -86	Zinc metal, zinc oxide	0.10	1.2	2.3	27	4	S, Zn
Austinville Furnace	Past producer	1904-15; 1922-25	Zinc oxide	0.03	0.40	0.47	7.40	6	Pb, S, Zn
Bamford Spelter Plant	Past producer	1855-56; 1873-76	Zinc metal, zinc oxide	0.01	0.04	0.08	0.50	8	Cd, Pb, S, Zn

Table 2. Facility name, location, years of production evaluated, estimated zinc contained in atmospheric emissions, in descending order; estimated average annual zinc production, estimated total zinc production.

[Tonnage values are expressed as 1,000 short tons.]—Continued

Facility Name	Operational Status (as of 2009)	Years of operation evaluated	Primary zinc product(s) ² ³ (zinc metal and/or zinc oxide)	Average estimated annual atmospheric zinc emissions ^{4,5}	Total estimated atmospheric zinc emissions ⁴	Average estimated annual zinc production ⁷	Total estimated zinc production ⁷	Atmospheric zinc emissions as a percentage of total zinc production ⁸	Elements comprising feedstock, and likely or known to be contained in atmospheric emissions ⁹
Keystone Zinc Works	Past producer	1864-70	Zinc oxide	0.004	0.03	0.06	0.40	8	Pb, S, Zn
Lehigh Zinc and Friendsville Zinc Companies (combined)	Past producer	1885-1900 (intermittent)	Zinc oxide, zinc metal	Less than 0.01	Less than 0.06	Less than 0.20	Less than 1.0	N/A	S, Zn
United States Arsenal	Past producer	1830s	Zinc metal	Less than 0.001	Less than 0.003	Less than 0.01	Less than 0.05	N/A	Zn
Total (nearest 100,000 short tons)	---	---		--- ⁶	785 – 863	--- ⁶	22,881 – 23,681	---	---

¹The Monaca and Palmerton plants continue to operate, but process secondary zinc feedstock exclusively since 2003 and 1987, respectively.

²May include zinc metal of various grades such as Prime Western and zinc oxide products, such as high-purity zinc oxide and high lead zinc oxide.

³Products listed in descending order of contained zinc tonnage produced over the facility's life.

⁴Zinc contained in atmospheric fugitive and stack emissions.

⁵Estimates represent simple averages. Production and emissions for some operations may have changed significantly from year to year or over a time period as a result of factors that include market conditions, expansions, and plant technology. Palmerton did not include the year 1898 in annual estimate because the plant initiated production in October of that year.

⁶Values are not averaged because plants did not operate concurrently.

⁷Zinc contained in various product types, such as zinc metal and high purity and low purity zinc oxide.

⁸Rounded to the nearest whole percent.

⁹Not inclusive of all materials contained in feedstock that were emitted to the atmosphere. The list does not include elements contained in other materials used in smelting and can be present in atmospheric emissions such as combustion gases, fluxes, fuels, oxidants and reductants; reagents, and refractories.

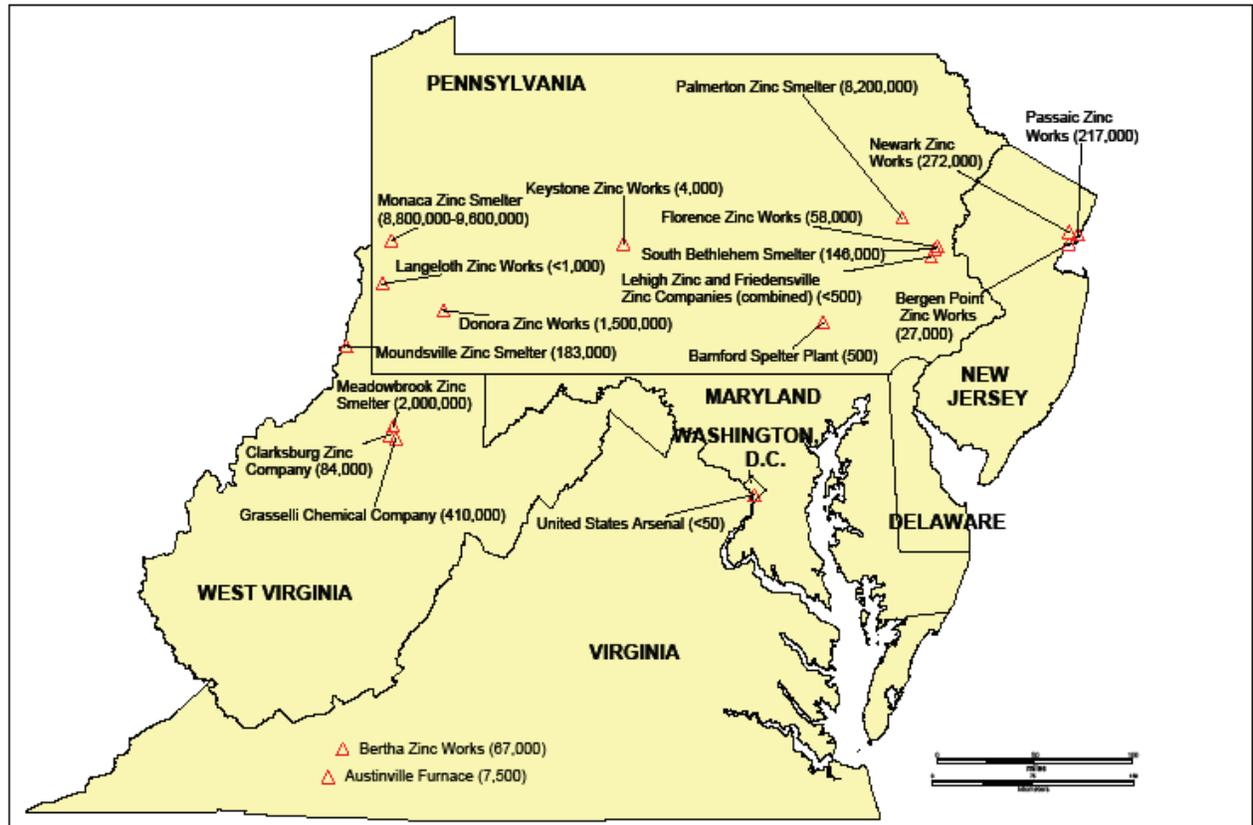


Figure 7. Total estimated zinc production (short tons) contained in zinc metal, zinc oxide, and other products, by smelter site.

As a percentage of zinc production, the highest levels of atmospheric zinc emissions among the sites studied occurred prior to and into the early 20th century, when the domestic zinc smelting industry was dominated by operations in New Jersey and Pennsylvania. The loss of zinc during this period was primarily attributed to limited dust control measures and relatively inefficient pyrometallurgical technologies. It is estimated that about 6-8 percent of the tonnage of recovered zinc was dissipated as dust, fumes, and gas to the atmosphere from the point of delivery to the point of shipping product. Photographs and observations of furnaces with horizontal retorts have shown imperfect recovery of zinc in condensers which lead to the escape of fumes containing zinc and other materials to the atmosphere (Circuit Court of Harrison County, WV 2008; Dunn, 1995, p. 786.) Figures 11 and 12 and other photographs of horizontal retort furnaces and the buildings that housed them, show fumes escaping.

Although some of these early plants had long production histories, their annual production was low compared to plants that succeeded them. Also, the amount of cadmium, lead, sulfur, and other potentially harmful materials emitted by some of the early facilities, was relatively low because the sources of predominantly oxide feedstock sourced from New Jersey and Pennsylvania were free relatively of these materials.

In the early 20th century, advancements in mineral separation technologies, such as the development of flotation (a beneficiation method used to separate ore minerals from gangue minerals and other ore minerals), resulted in a greater proportion of zinc feedstock derived from polymetallic sulfide ore bodies reporting to zinc smelters. The technology resulted in a significant transition in the amount and character of feedstock processed in the zinc industry as the concentrate derived from these deposits contained, in addition to zinc, materials such as arsenic, cadmium, copper, fluorite, lead, mercury,

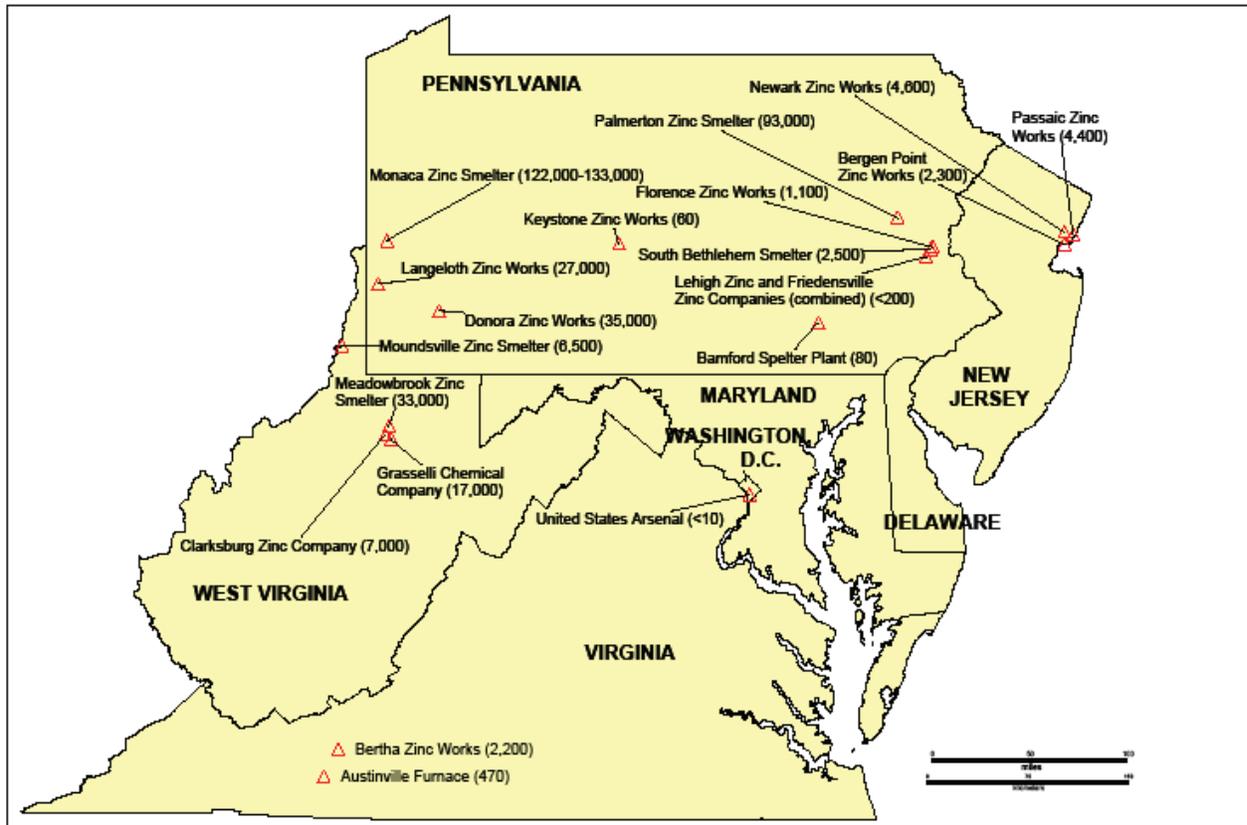


Figure 8. Estimated average annual zinc production (short tons) contained in zinc metal, zinc oxide, and other products, by smelter site.

and sulfur. The increase in the amount of concentrate derived from flotation in the United States for 1921 through 1928 (see table 4) was significant as the technology's use gained acceptance (American Bureau of Mining Statistics, 1929). Also, the amount of lead contained in zinc concentrates decreased over time as the technology used in the flotation process improved. In general, the content of the atmospheric emissions generated by the smelters activities reflected the chemistry of the feedstock and the materials used in the facilities. Some of the elements contained or likely contained in emissions to the atmosphere from feedstock supplied to these plants are shown in table 2. It also was during this period that the construction of sulfuric acid plants, using captured sulfur produced during roasting, were included with new smelter complexes. Some established smelters were fitted also with acid plants. In general, the production of sulfuric acid generated additional revenue and resulted in a reduction in sulfur contained in

atmospheric emissions where roasting was ongoing, except in those places where roasting plants had not existed previously.

Two zinc smelting operations in particular stand out among all of the plants evaluated from a perspective of annual and total zinc emissions. On an annual basis, the Monaca and the Palmerton smelters in Pennsylvania released about 4,400 short tons and 3,600 short tons of zinc contained in fugitive and stack emissions per year averaged over the lives of the plants. The total atmospheric zinc emissions generated at the Palmerton and the Monaca smelters in Pennsylvania were estimated to contain about 300,000 short tons each. Together, the two operations made up nearly 70 percent of the total amount of zinc contained in atmospheric emissions estimated in this study. The comparatively high emission tonnages are a combined result of the plants' relatively high annual zinc production, lengthy operating period (each exceeding 70 years), and the types of feedstock and technologies that were employed.

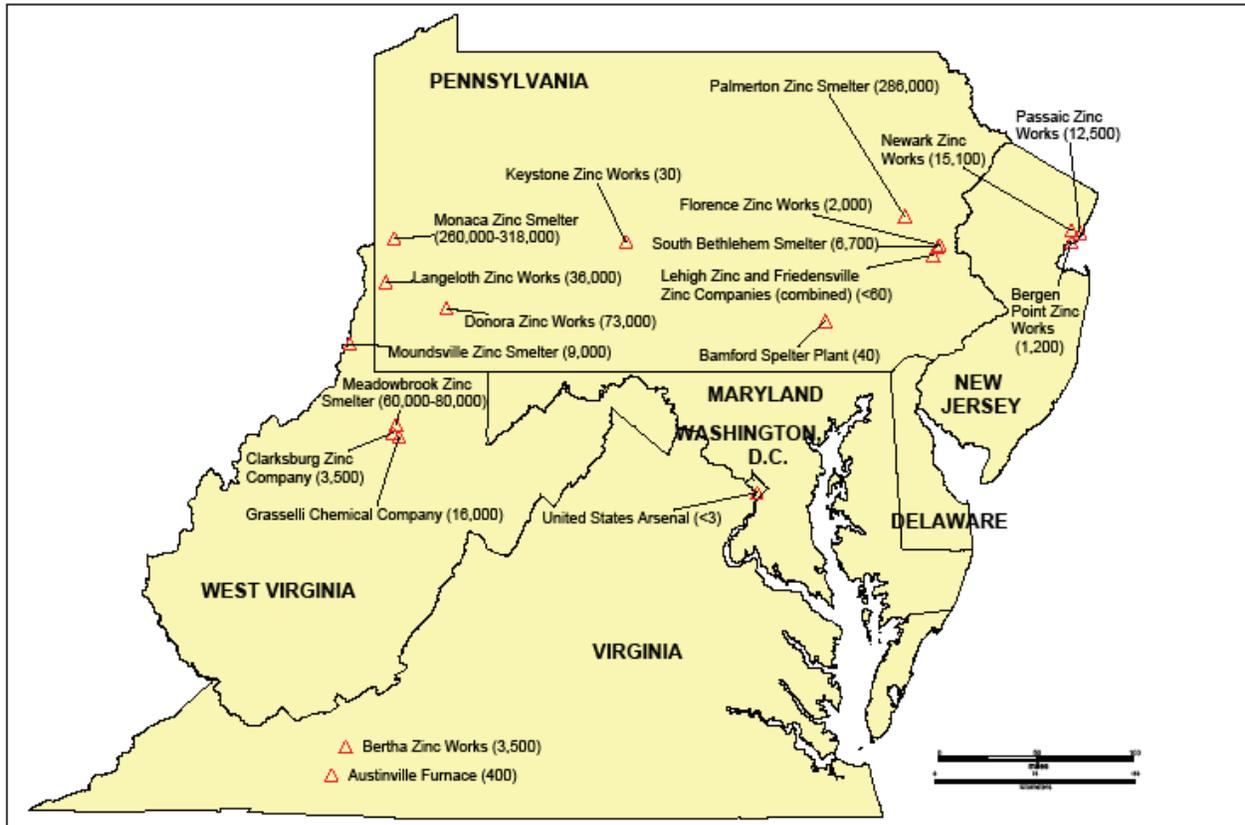


Figure 9. Total estimated atmospheric zinc emissions (short tons) contained in zinc metal, zinc oxide, and other products, by smelter site.

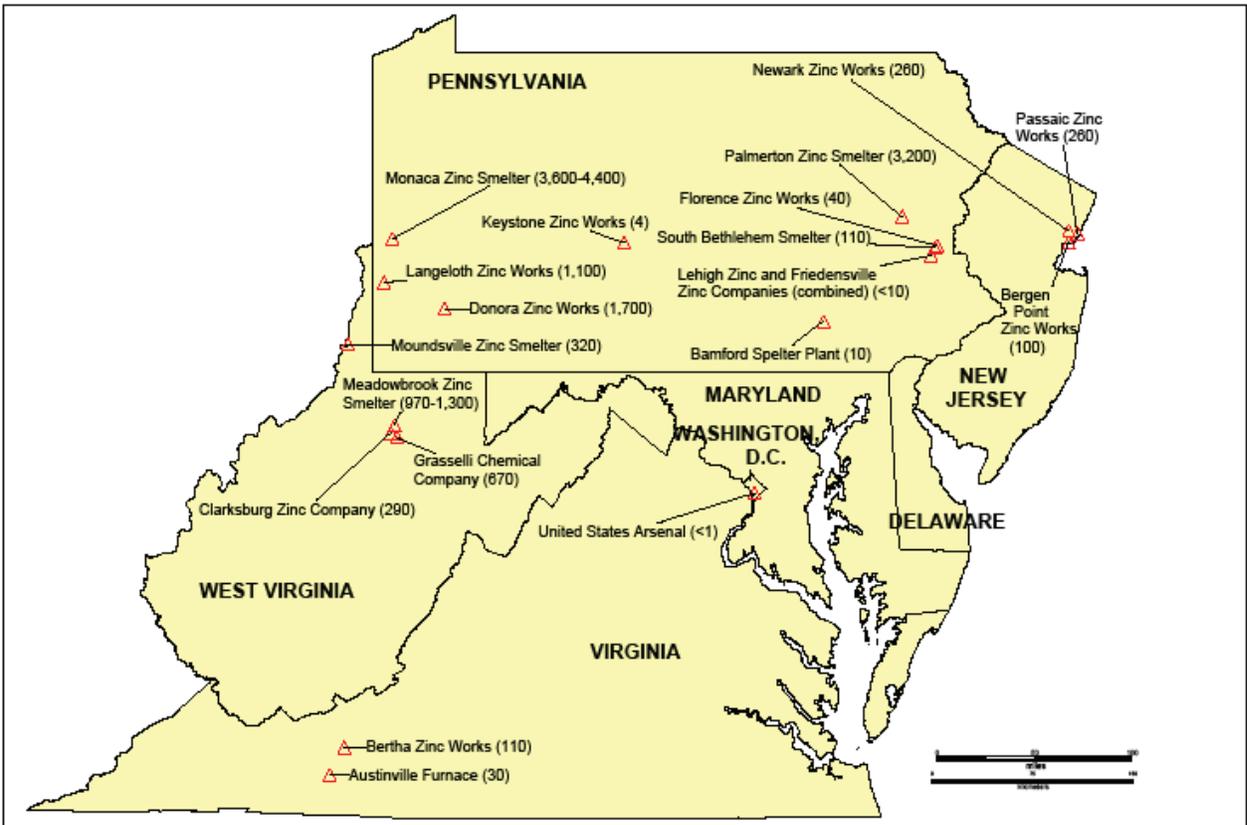


Figure 10. Estimated average annual tonnage (short tons) of zinc contained in atmospheric emissions from the production of zinc metal, zinc oxide, and other products, by smelter site.



Figure 11. Furnace section at the Donora Zinc Works heating zinc ore contained in horizontal retorts (circa 1915–17). Note the zinc fumes escaping from the openings at the ends of the retorts. They were exhausted generally to the atmosphere with roof fans. Photograph provided courtesy of the Bruce Drisbach Collection, Archives Service Center, University of Pittsburgh, 2009.



Figure 12. Photograph of a spelter worker collecting molten zinc from horizontal retorts at the Donora Zinc Works. Note the white zinc fumes escaping and the spelter worker for scale. The cart travelled along tracks and the worker would collect molten zinc in a ladle and pour it into the kettle. Shielding protected the worker. The actual date of when the photograph was taken is unknown, but it was probably taken in the mid-1920s. Permission for the publication of this photograph was granted by the Donora Historical Society and the California University of Pennsylvania, Library of Congress, Teaching with Primary Sources Program, 2009.

Table 3. Average grade of sphalerite shipments from the Joplin, Missouri Mining District, 1897-1906 (The Mineral Industry, Its Statistics, Technology, and Trade During 1905, edited by Walter Renton Ingalls, v. XIX, p. 590, Engineering and Mining Journal, New York, 1906).

Year	Number of shipments ¹	Zinc, percent	Iron, percent
1897	600	56.64	N/A
1898	1,299	56.99	N/A
1899	3,715	56.67	N/A
1900	3,500	57.36	0.22 ²
1901	3,683	57.53	2.02
1902	5,776	57.08	2.24
1903	6,014	57.30	2.0
1904	6,220	57.24	2.1
1905 ³	4,628	57.97	1.84
Weighted average zinc grade (percent)		--	--

¹Size of shipments were not provided.

²Iron assay was likely a misprint.

³In 1905, the shipments also contained 1 percent lead, 0.198 percent cadmium, and 0.001 percent copper.

Table 4. Zinc flotation concentrates produced in the United States, exclusive of the Tri-State Mining District, 1921-1928¹.

Year	Concentrates (short tons)	Zinc content		Lead content	
		Short tons, contained	Grade, percent	Short tons, contained	Grade, percent
1921	38,433	15,311	39.84	4,457	11.60
1922	82,121	37,116	45.20	6,105	7.43
1923	169,496	83,778	49.43	11,181	6.60
1924	227,955	109,005	47.82	14,368	6.30
1925	253,989	130,594	51.42	11,064	4.36
1926	404,485	208,834	51.63	16,722	4.13
1927	500,675	265,702	53.07	12,298	2.46
1928	551,187	294,522	53.43	17,267	3.13

¹American Bureau of Metal Statistics (AMERICAN BUREAU OF MINING STATISTICS), 1929, Yearbook of the American Bureau of Metal Statistics, Ninth annual issue - 1928, Maple Press, York, PA.

²U.S. Bureau of Mines, Department of Commerce, 1931, Mineral Resources of the United States 1928, p. 377, Washington Printing Office, Wash. D.C.

Table 5. Assay data of representative sphalerite ore samples in the Tri-State Mining District, Missouri prior to the year 1900. Zinc concentrate from Joplin during this time assayed on average about 60 percent zinc, 0.5-1 percent lead, 1-2 percent iron, 30 percent sulfur, and cadmium and silica (no percentages given). No arsenic was detected. (Taken from Ingalls, Walter, 1902).

Locality	Zinc, percent	Cadmium, percent	Iron, percent	Silica, percent
Joplin	65.92	0.509	0.32	0.25
Joplin	64.87	0.723	0.37	1.41
Granby	64.67	0.53	2.05

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Appendix 1. Types of Smelter Feedstock and Applied Technologies

Feedstock

The feedstock treated at the smelters evaluated in this study can be broadly categorized into two main groups; primary and secondary materials. The chemistry of feedstock dictates the technologies applied and the types of zinc products and byproducts produced. Brief descriptions of the major zinc ore minerals and types of secondary materials received by smelters included in this study follow.

Primary Zinc Feedstock

Primary zinc feedstock includes direct shipping ores extracted from mineral deposits and concentrates produced by beneficiating ores, either by gravity or flotation methods. The naturally occurring minerals containing zinc can be further divided into mineralogical groups with which zinc has a natural affinity to combine with other elements under certain conditions.

Zinc ores, and the concentrates produced from the ores, occur as carbonates, oxides, silicates, and sulfides. Native zinc occurs only rarely and has never been found in sufficient quantities to be considered an ore mineral. The chemistry of the zinc ore minerals dictate to a great extent the technologies used to produce either zinc metal or zinc oxide.

Zinc Carbonate Ore Mineral

Smithsonite

Zinc carbonate (ZnCO_3) or smithsonite, is the most significant zinc carbonate ore mineral and can contain up to 52 percent zinc. It is a desirable, although minor, zinc ore mineral and is most often associated with zinc deposits formed in limestone. Historically, smithsonite was collectively identified as calamine with hemimorphite, a silicate ore, before it was realized in the late 19th century that they were two distinct minerals. The two minerals are very similar in appearance, and the term calamine was sometimes used for describing both ore minerals in early literature; although calamine survived as an alternate, although rarely used name for hemimorphite. Smithsonite is a secondary ore mineral, produced as an alteration product of zinc sulfide minerals, chiefly sphalerite. As an alteration of deposits containing sulfide minerals, smithsonite can also contain cadmium, cobalt, lead, sulfur, and other materials. Zinc carbonate ores can be treated solely or in combination with other ores. When heated in furnaces or retorts, smithsonite decomposes into zinc oxide and carbon dioxide. Smithsonite is suitable for producing zinc metal and zinc oxide and does not need to be roasted, unless sulfur is present in some form. Domestic sources of zinc carbonate ores and

concentrates for some of the smelters included in this study included Missouri, New Jersey, Pennsylvania, Tennessee, and Virginia.

Zinc Oxide Ore Minerals

The ores or concentrates used to produce zinc oxide, popularly known at the end of the 19th century as zinc white, generally contain much less sulfur and less subordinate metals, such as arsenic, cadmium, lead, and mercury, than ores comprised predominantly of sulfide minerals. Zinc oxide ores or concentrates are generally less problematic from a smelting and environmental perspective than zinc sulfide-based ores because of the absence of, or relatively small amounts of materials such as arsenic, cadmium, lead and sulfur. Most of the zinc oxide ores treated by smelters included in this study consisted of franklinite and zincite that originated from mines in New Jersey.

Franklinite

Franklinite [$(\text{Zn}, \text{Fe}, \text{Mn})(\text{Fe}, \text{Mn})_2\text{O}_4$], is a relatively rare oxide mineral, but occurred in large mineable quantities at the Franklin-Sterling Mining District in New Jersey. Although it was the most abundant of the three economic zinc ore minerals (franklinite, willemite, and zincite) mined in the district (Dunn, 1995), it had the lowest zinc content. Chemical analysis data showed that the mineral's composition could vary, but generally contained about 17 percent zinc (Dunn, 1995). The mineral was used to produce three marketable products: zinc metal (as component in concentrate with willemite and zincite), zinc oxide, and spiegeleisen. Spiegeleisen, also known as pig iron, is an alloy of iron, manganese, and carbon; generally used as a component in steelmaking. It was produced from residues remaining from the spent charges placed in the zinc oxide furnaces. The use of the franklinite ore was not conducive as a primary source of zinc metal because of its zinc content and reaction between the iron oxide in the franklinite with the silicate minerals contained in the clay retorts resulting in retort failures (Miller, 1941, p. 329).

Zincite

Zincite (ZnO) is a rare mineral and has only been mined as an ore in the Franklin-Sterling Hill, New Jersey Mining District. It was sometimes referred to as "ruby" in the district, a term usually reserved for sphalerite at other mines (Dunn, 1995). Zincite was the least abundant of the three principal zinc ore minerals (franklinite, willemite, and zincite); but at 80.3 percent zinc, it contained the highest zinc percentage content and no deleterious elements. Although some zincite ore was used directly for producing zinc, especially in the earliest

part of the district's history, most of the zincite processed in smelters was contained in a willemite-zincite concentrate.

Zinc Silicate Ore Minerals

Hemimorphite

Hemimorphite ($\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2\cdot\text{H}_2\text{O}$) is a hydrated zinc silicate mineral that contains up to 54.2 percent zinc. Hemimorphite is a desirable ore mineral because of its high zinc content and high purity, and because roasting is not required. The mineral was referred to as calamine in the early literature until the distinction with smithsonite was understood. Afterwards, calamine was reserved as an occasional alternate name for hemimorphite to avoid confusion. Like smithsonite, hemimorphite most often forms as a secondary alteration product of sphalerite, and although economically important as an ore mineral, it did not comprise the bulk of ore deposits that supplied feedstock to the smelters evaluated in this study. The mineral was mined in PA, VA, and NJ and shipped as feed or as a component with other zinc ore minerals to some of the smelters included in this study.

Willemite

Willemite (Zn_2SiO_4) was supplied to smelters as untreated ore and as a concentrate. It was used primarily for the production of zinc metal. Willemite was associated with franklinite and to a lesser extent zincite. Willemite, extracted from ore bodies in the Franklin-Sterling, New Jersey Mining District, played an important role as a feedstock in the early development of the domestic zinc industry in the 1860s and continued to be an important ore mineral for the Palmerton smelter until the closure of the New Jersey mines in the mid-1980s. Although the mineral can contain approximately 54 percent zinc, willemite ores and concentrates produced in the District assayed approximately 47 percent zinc (Ingalls, 1908; 1916; Pierce, 1917).

Zinc Sulfide Ore Mineral

Sphalerite

Sphalerite, $(\text{Zn}, \text{Fe})\text{S}$, is the most common primary zinc sulfide ore mineral. Zinc content in sphalerite can range from about 38 to 67 percent, with the other major constituents being iron and sulfur. Other elements often associated with sphalerite ore and concentrate are arsenic, cadmium, copper, iron, lead, mercury, and sulfur. Some of these are potentially recoverable as byproducts, but can also be contained in emissions that are potentially harmful to human health and the environment. The manufacture of sulfuric acid from sulfur

Zinc smelter emissions generated from ores extracted from the Franklin and Sterling Hill Mining District, New Jersey

Dunn, (Dunn, 1995; p. 213) reported that the total ore output from the mines making up the Franklin and Sterling Hill District, for the approximately 135-year production period that the District produced, was on the order of 34 million short tons averaging about 20 percent zinc, 8 percent manganese, and 17 percent iron. The author advised that the estimate should be considered with caution because of numerous factors that included incomplete historical records, reporting methods that varied over time, and because statistics were considered proprietary in some years and not released (Pete Dunn, 1995, oral communication, 2008). Applying Dunn's, 1995 total ore production estimate, roughly 180,000 short tons of zinc could have been emitted to the atmosphere by plants in New Jersey and Pennsylvania based on the additional assumptions that 65 percent of the zinc contained in ore was recovered in zinc metal and zinc oxide and an amount equivalent to about 4 percent of the recovered zinc was lost as a component of fugitive dust and plant emissions.

dioxide produced from the roasting of the mineral sphalerite was especially important as a revenue producer and in limiting potential damage to the environment.

The sphalerite ores, concentrates, and roast used by some of the smelters included in this study originated from Colorado, Missouri, New Mexico, New York, Pennsylvania, Virginia, Tennessee, West Virginia, and foreign imports from Canada, Mexico, and overseas.

Secondary Zinc Feedstock

Secondary materials treated at the plants evaluated in this study included dross and skimmings, mostly derived as a waste product from galvanizing; electric arc furnace (EAF) dust generated during steel making, scrap generated during cutting and machining from manufacturing of products, and old scrap such as recycled zinc metal, and die cast products.

Zinc Dross and Skimmings

Zinc dross is defined for this study as the material that accumulates at the bottom of zinc galvanizing baths. Skimmings are zinc oxide accumulations that form at the top of galvanizing baths (Galvanized Rebar Resource Center, 2005). Dross assays were as high as 95 percent zinc. Varying amounts of aluminum, cadmium, iron, and lead made up most of the remaining 5 percent (Struthers, 1902; Ingalls, 1903). The zinc content in skimmings ranges from 65-85 percent (Ingalls, 1903, p. 579). These waste products, generated in the steel galvanizing industry, were used at several smelters analyzed in this paper to produce slab zinc and are still used as feedstock at many smelters worldwide. At some smelters, the terms

“skimmings” and “dross” were used also to describe crusts and coatings recovered from retorts and zinc oxide furnaces that were recycled for zinc and zinc oxide production.

Electric Arc Furnace (EAF) Dust

EAF dust is the product of condensed fumes of volatilized metals and minor amounts of other materials recovered in the extractive air flow exiting electric arc furnaces during steel making and recycling metals. In 1980, the USEPA listed the material as a hazardous waste because of its potentially toxic components. EAF dusts typically contain cadmium, calcium, chlorine, chromium, fluorine, iron, lead, and zinc as well as other materials. The composition and proportion of the individual elements in EAF dust reflects the metallic charges used in the process, reagents, and the degradation of refractories.

EAF dust typically contains from 10 to 20 percent zinc. In approximately 1990, the USEPA placed a ban on disposing untreated EAF dust in landfills (James, 1990). This regulatory action stimulated the development or improvement of existing technologies used to recover the contained metal values, such as cadmium, chromium, iron, and zinc contained in EAF dust through recycling. Residues can be put in a landfill following treatment. In 1988, the zinc smelter in Monaca, PA initiated the treatment of EAF dust for the purpose of recovering zinc and other materials (Don Freshcorn, Senior Process Engineer; and James Reese, Director, Environmental Health and Safety, Horsehead Corporation, written communication, 2008). Figure 13 is a flow diagram showing the process of treating EAF dust at Palmerton and Monaca and recovering byproduct materials from the company’s Bartlesville plant.

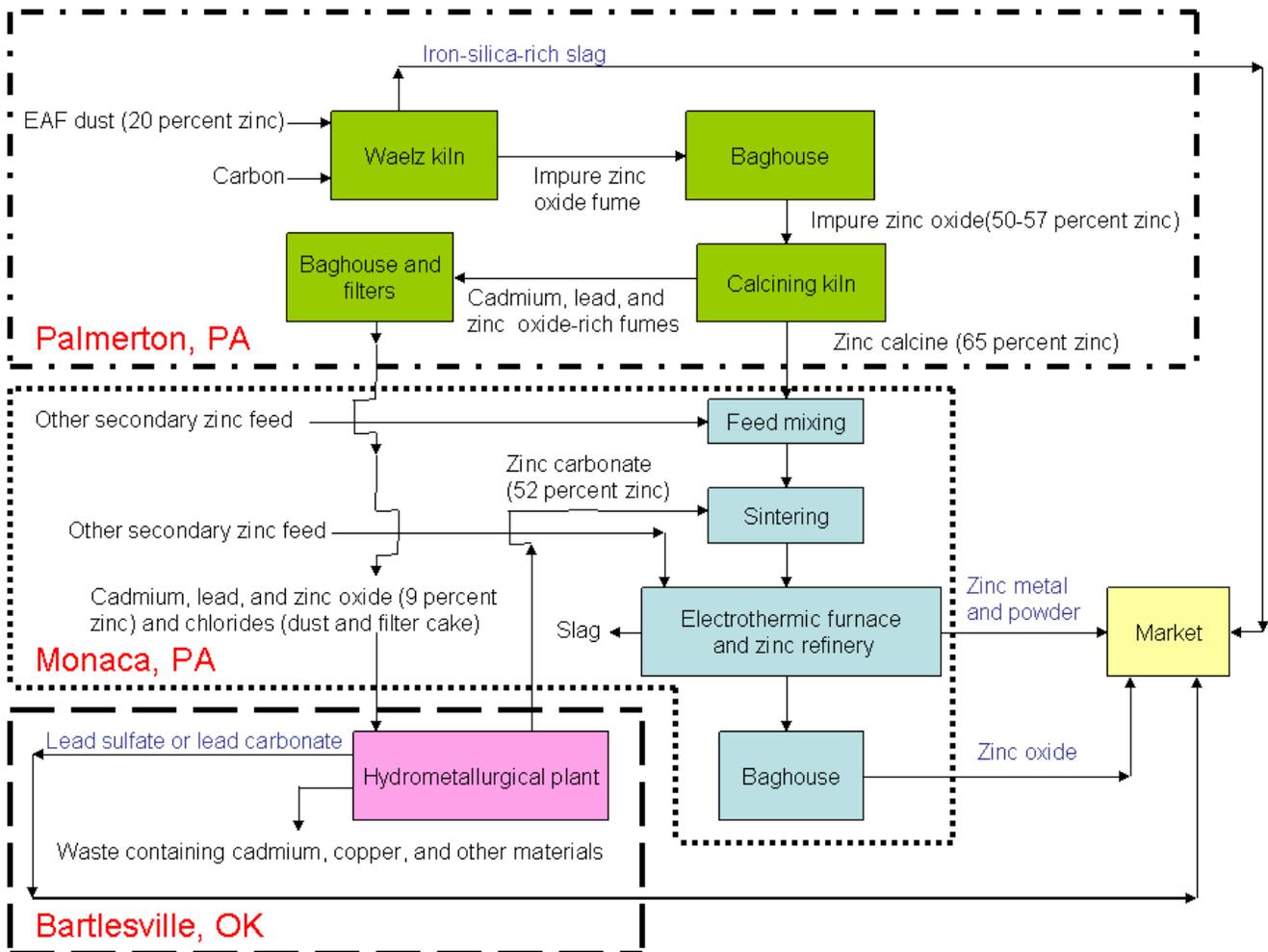


Figure 13. Process flow of electric arc furnace dust (EAF) through the Palmerton, Monaca, and Bartlesville plants as of March 2009. Production from Bartlesville reflects commodity prices. Cadmium and other metals may be recovered during periods of favorable prices and contained in plant waste during periods of low prices. The form of lead produced at the Bartlesville facility depends on the cost of production and customer preference.

Other Dusts

Other dusts that are high in zinc content, which are chiefly recovered by air pollution devices such as in the course of tire burning and recycling metals also are components of the feedstock treated at some zinc smelters.

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Zinc Smelting-Process Descriptions

In this study, zinc smelting is applied broadly to the treatment of zinc ores, concentrates, and recycled materials delivered to a roasting plant and smelter, or both to produce zinc metal, zinc oxide, and other zinc-based marketable materials from primary and secondary feedstock. The major post-beneficiation activities for producing zinc metal that are addressed in this study include: (1) roasting (calcining); (2) sintering; (3) retorting; and sometimes refining. The major steps to produce zinc oxide addressed in this study may include (1) roasting; (2) furnacing; and (3) recovery in the baghouse. The chemical composition of feedstock and the desired product were the primary determinants for selecting the appropriate treatment.

General descriptions of the most commonly employed processes follow, and when available, detailed descriptions of technologies are included in the individual smelter profiles (Appendix 2). Process flow diagrams for the Donora, Monaca, and Palmerton plants are provided also.

Zinc Metal Production

Roasting, sintering, retorting, and refining may be required to produce zinc metal, also known as slab zinc and spelter, from primary zinc ores and concentrates. Secondary materials, such as dross and zinc scrap, have high zinc content with low impurities and low sulfur content and do not usually require roasting and sintering. A generalized flow for recovering zinc metal is shown in figure 14a and discussed in the Roasting section of this report.

Roasting

Roasting, also referred to as calcining, is a pyrometallurgical process applied to primarily sulfidic zinc feedstock, mostly sphalerite. The primary purpose of roasting is to convert zinc sulfide to zinc oxide by means of heat. Historically, the most common zinc sulfide mineral making up the feedstock is sphalerite and has been smelted as direct-feed ore, and more commonly, as a major constituent of flotation and gravity concentrate.

Direct feed sulfide ores and some concentrate produced by hand sorting and gravity methods dominated the feedstock sent to roasters in the United States up until the early 1920s. Beginning in the 1920s, direct feed ore became increasingly uncommon with the development and acceptance of flotation technology by the zinc industry. The zinc content of sphalerite ore and concentrate can vary significantly, but generally ranges from 55-65 percent. A major grade determinant is the amount of iron in the mineral's crystal lattice, which can substitute for zinc. The sulfur content in ore and concentrate generally is about 30 percent. Roasting techniques can convert up to 97 percent of the captured sulfur contained in the feed to sulfur dioxide and the same amount of zinc to zinc oxide at temperatures more than 1,800 degrees Fahrenheit (McMahon and others, 1974, p. 33). Using current practices, the amount

of sulfur in the calcine can range 1-3 percent, but is usually less than 1.5 percent; prior to the 1930s the sulfur content in the calcine tended to be higher, ranging as high as 5 percent (Fairlie, 1936).

Depending on the chemistry of the ores extracted from mineral deposits, primary sulfidic feedstock may include other materials such as arsenic, cadmium, calcium, copper, indium, iron, lead, mercury, and silica. In the course of converting the zinc sulfide to zinc oxide, significant amounts of dust, fumes, and gas, containing sulfur dioxide and the aforementioned materials also are commonly produced. In addition to sulfuric acid produced from sulfur dioxide captured at plants equipped with roasters, other components of the feedstock are recovered also by emission control devices and often reprocessed through the smelter. Until the 1950s and 1960s the decision to recover sulfur dioxide and other materials usually was based on the economic benefits received from the recovery of the materials and from concerns of lawsuits from the local populace because regulatory legislation was not in place.

Sintering

A sintering machine's primary purpose is to produce a charge of relatively coarse-zinc-rich agglomerated material as a suitable feedstock for reduction in retorts and electrothermic furnaces. Sintering was practiced to a limited degree in the zinc industry prior to the introduction of electrothermic vertical retorts in the 1920s, mostly because most feedstock was suitably sized for established methods. However, with the increased supply of zinc concentrates brought about by the advent of concentration of ore minerals by flotation, further development of the sintering process was required. The fine-grained nature of calcine or roast derived from treating concentrates hindered zinc recovery in the retorts by impeding circulation and transference of fumes and gases. The coarse-hard sinter product resolved the problem to a great degree by allowing "pathways" through the furnace feedstock.

A general description of the sintering process follows. The first step required to produce sinter entails the preparation of a controlled mixture that consists of zinc calcine and nonsulfurous primary or secondary feedstock or both; coal or coke, silica, and in some instances, furnace residues and other zinc-rich material. Moisture is added pressure applied to the mixture enabling it to be formed into briquettes or pellets which are placed on a continuous feed conveyor belt to the sintering machine. In the sintering machine, the feedstock is subjected to downdraft of air heated to about 2,000 degrees Fahrenheit which converts coal to coke, removes most of the remaining sulfur, and volatilizes the majority of cadmium, lead, and other materials contained in the zinc feedstock. As a result, the sintering step can be the greatest source of air emissions at a zinc smelting facility (USEPA, 1975). These materials are deleterious to the quality of the zinc product. In addition to metal fumes and dust, the emissions contain about 2 percent sulfur dioxide (McMahon and others, 1974). The hard nature of the sintered material, which sometimes needs to

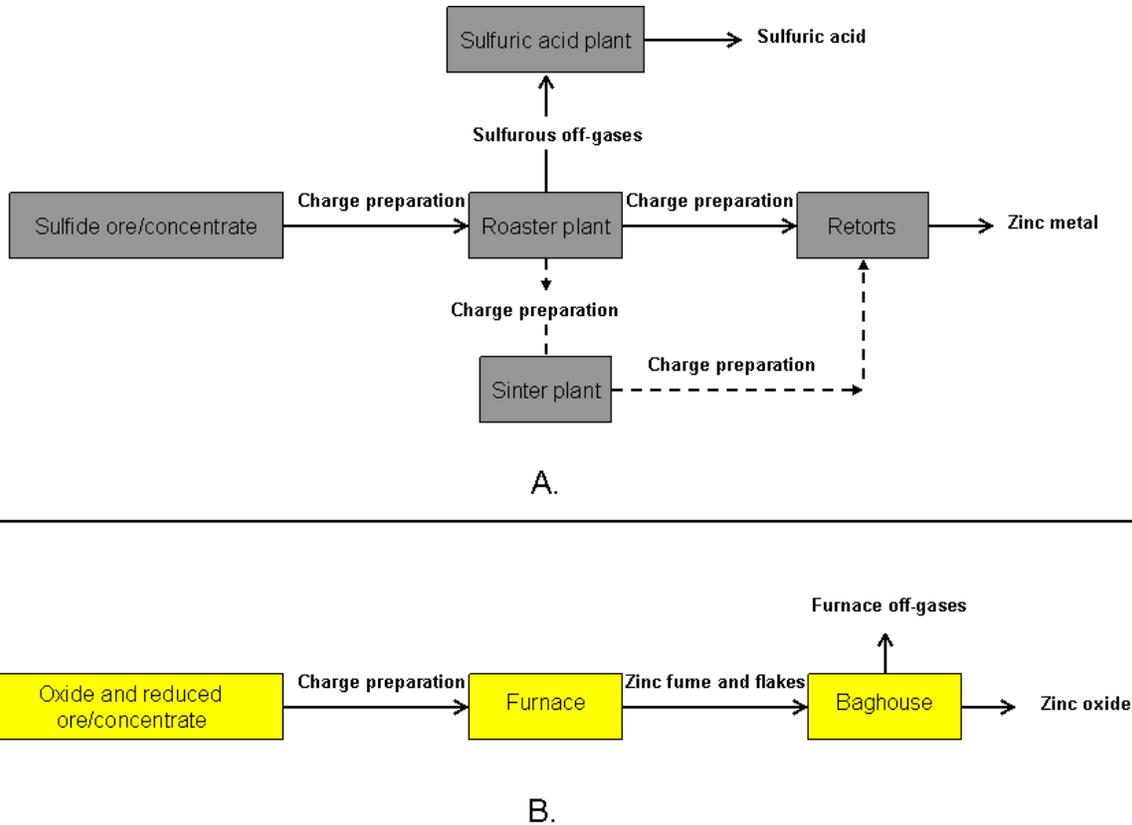


Figure 14. Generalized flow illustrating the production of zinc metal (a) and zinc oxide (b).

be crushed into smaller fragments, benefits the volatilization of zinc in the retort by permitting better flow of heat throughout the retort and providing channels for zinc fumes to escape more efficiently. Depending on its composition, secondary material also can serve as feed to the sinter plant. Sinter produced from primary sources evaluated in this study generally ranged from 55 to 72 percent zinc. Beginning in about 1930, sintering was practiced on virtually all primary and secondary feedstock used to charge electrothermic retorts, and to a lesser extent in operations employing externally-heated vertical retorts.

The placement of sintering in the process flow of producing zinc is illustrated in the flow sheet for the Donora, Monaca, and Palmerton plants in Appendix 2.

Retorting

In general terms, retorting is the pyrometallurgical process of reducing zinc oxide contained in roast and sinter in the presence of carbon to zinc vapor and carbon dioxide. The reduction process is performed by externally heating a vessel (usually a retort) and its calcine-carbon mix content to a temperature of about 2,200 degrees Fahrenheit. The resulting zinc vapor is condensed as zinc metal and tapped, and carbon

dioxide is vented to the atmosphere (see figure 14). The zinc industry of the United States used three basic types of retorts to produce zinc metal; horizontal, electrothermic, and vertical. The horizontal furnaces were first used around 1859. The introduction of more efficient vertical retorts in the 1930s marked the rapid decline of using horizontal retorts in the U.S. zinc industry. Electrothermic retorts, or furnaces, are still in use in the U.S. zinc industry, while the use of all horizontal and externally-heated conventional vertical retorts for primary zinc feedstock has been discontinued (U.S. Environmental Protection Agency, 1995, p. 6).

Horizontal Retorts

Although a zinc oxide industry had been established in the United States, the first commercially successful zinc metal production in the United States did not occur until the late-1850s and was based on the reduction of zinc using horizontal retorts (Miller, 1924). The use of horizontal retorts remained the dominant method of reducing zinc until the 1930s when an industry-wide conversion to vertical retorts began to supplant horizontal retorts. The smelter at Donora, PA was the last to use horizontal retorts exclusively and closed in 1957. Figures 15-18 are photographs of the horizontal retorts

employed at Donora. In the 1950s the practice of using horizontal retorts had changed little from 30 years earlier. Although improved over time and no longer used in the United States, horizontal retorts are still used to a limited extent in other countries. Horizontal retorts are ceramic cylinders (although some were oblong) made from fired clay that varied in dimensions, but generally were about 5 feet in length with an inside diameter of about 9 inches and closed at one end. Some plants included in this study contained up to 900 retorts in a single furnace; some smelters were equipped with multiple furnaces. A mixture of sinter or calcine (and sometimes secondary zinc-rich material and minor amounts of zinc residue) and a reductant high in carbon, such as low-sulfur coal or coke, made up the charge in the retorts. A plug consisting of wet coal was placed at the mouth of a condenser that was slipped over the open end of the retort. In the furnace, heat was applied externally to the retorts until the contents reached about 2,200 degrees Fahrenheit. At this temperature, the reduction of the zinc oxide progresses as the carbon, made available from burning of the reductant, combines with oxygen in the zinc feedstock resulting in the production of zinc vapor, carbon monoxide and carbon dioxide. The zinc vapor

condensed in ceramic condensers as molten zinc was manually collected with ladles, and poured into molds as shown in figure 18. The coal plug was broken each time the molten zinc was tapped; and replaced if retorting the charge was to continue. Each tapping marked the end of a cycle of about 8 hours (retorting time could vary based on grade and nature of the charge). Three cycles was usually sufficient to maximize the recovery of zinc in the charge, encompassing a period of about 24 hours. Afterwards the retorts were cleaned out manually and scaled of residue, repaired, or replaced (breakage was commonplace with commensurate zinc losses), recharged, and placed in the furnace for the next cycle. Zinc recovery estimates and zinc content in the primary zinc product from the smelters evaluated which employed horizontal retorts depended on factors such as technology of the time period, grade and composition of the feedstock, and the furnace-cycle time. Zinc recoveries generally ranged from 80 to 95 percent (McMahon and others, 1974, p. 36) of the zinc contained in the charge. Zinc content in slab zinc varied, but nearly always exceeded 98 percent. The balance could include cadmium, iron, lead, and trace amounts of other elements.



Figure 15. Photograph of furnaces containing horizontal retorts at the Donora Zinc Works (circa 1925). Note that in the background, the furnace is heating the retorts containing zinc ore with a resulting loss of zinc as fume. Permission for the publication of this photograph was granted by the Donora Historical Society and the California University of Pennsylvania, Library of Congress, Teaching with Primary Sources Program, 2009.

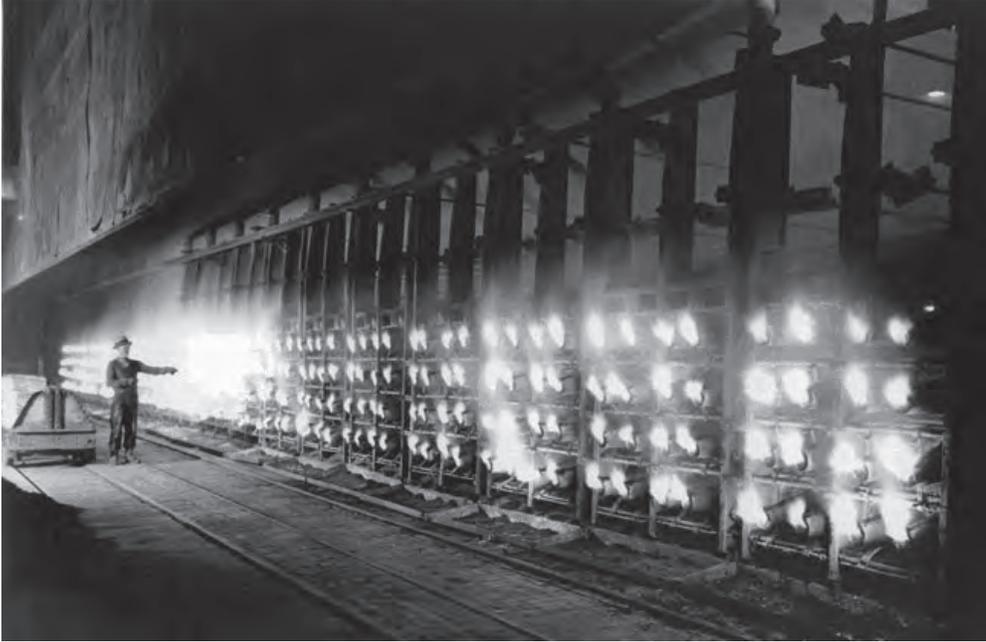


Figure 16. Horizontal retorts in use at the Donora Zinc Works. Note white zinc fumes escaping and spelter worker for scale. The actual date of photograph is unknown, but it was probably taken in the mid-1920s. Permission for the publication of this photograph was granted by the Donora Historical Society and the California University of Pennsylvania, Library of Congress, Teaching with Primary Sources Program, 2009.



Figure 17a. Photograph taken circa 1915-17 of a "cold" furnace at the Donora Zinc Works containing horizontal retorts stacked 6 high. Photograph provided courtesy of the Bruce Drisbach Collection, Archives Service Center, University of Pittsburgh, 2009.

Figure 17b. View of a 4-row horizontal retort zinc furnace at the Donora Zinc Works, Donora PA, taken in 1945. Note the fumes escaping from the open end of the retorts containing zinc and other materials. As seen in figure 17a and other figures showing horizontal retorts, the technology employing horizontal retorts to recover zinc metal did not change significantly at Donora or other facilities over a period of about 25 years. (Image donated by Corbis – Bettmann, 2009).



Figure 18. Photograph taken circa 1920 at the Donora Smelter showing spelter workers pouring molten zinc collected from retorts into molds (indicated by white arrow). Note the stacked slab zinc in the foreground and the furnace containing horizontal retorts in the background. Photograph courtesy of Scott Beveridge and the Donora Historical Society, 2009.

The last of the operating horizontal retorts were phased out in the United States in the late 1970s, because of high costs and unacceptably high zinc losses of zinc particulates, specifically fugitive zinc oxide dust; a component of severe air pollution problems associated with the technology (U.S. Environmental Protection Agency, 1975; McMahan and others, 1974, p. 35). During the early 1970s it was estimated that with a 95-percent dust-collection efficiency, approximately 0.3 metric tons of cadmium were released to the atmosphere for every 100,000 of zinc produced during horizontal retorting (U.S. Environmental Protection Agency, 1975). Other materials were also released. Although the metal content of the retort charge was not provided, it was probably around 0.02 percent cadmium, 0.4 percent lead, and 53.5 percent zinc (U.S. Environmental Protection Agency, 1975).

Vertical Externally-Heated Retorts

Although small closed-end ceramic vertical retorts were used to a limited extent in the domestic zinc industry, it was not until 1929 when the New Jersey Zinc Company introduced the commercial-scale continuous process vertical retorts as replacements for existing operations using horizontal retorts or as new construction. Vertical retorts were constructed of refractory brick and measured approximately 25 to 35 feet in height, 5 to 7 feet in horizontal length and about 1 foot in width. A retort of this size could produce 8 tons per day of zinc (McMahan and others, 1974).

Retorts were externally heated using natural or producer gas. Vertical retorts offered several advantages over the horizontal type. Among the greatest advantages was that they could be mechanically loaded with feedstock from the top and emptied of residue from the bottom on a continuous basis, thereby being more efficient and less labor intensive. They also did not require frequent replacement resulting from cracking and breakage resulting in loss of zinc, a common occurrence using horizontal retorts. The new and improved technology was met with industry-wide acceptance.

In general, the charge to the top-loaded retorts consisted of briquettes composed of briquetted or sintered calcine and coked coal. The retort design directed zinc vapor as the sinter was heated through the top of the retort where it was condensed by one of several methods that included cooling by contact with a spray of molten zinc or by bubbling the zinc vapor through a zinc bath. Other methods resulted in heating the sinter causing molten zinc to run out the bottom of the retort into a pool of water where it cooled to a solid. Zinc recoveries generally exceeded 95 percent (McMahan and others, 1974, p. 36). Figure 19 is a generalized diagram of a vertical zinc retort.

Electrothermic Vertical Retorts

At about the same time that externally heated vertical retorts were commercially introduced by the New Jersey Zinc Company, experiments by the St. Joseph Lead Company using electrothermic reduction were being carried out. In 1936, the

first commercial vertical retort furnaces using heat generated by thermal resistance was constructed by the company (Porter, 1991). Electrothermic retorts or furnaces used at smelters evaluated in this study ranged from 25 to 40 feet in height, a cross section of 5-8 feet in length, and about 1-foot in width. The electrothermic retort shared the same advantages of the externally-heated furnace over horizontal retorts because they can be fed continuously, can accommodate relatively large amounts of feed, and are less prone to failures because of the refractory lining. The primary difference between the externally heated vertical retorts and the electrothermic vertical retorts is that the heat required for volatilizing the zinc contained in the charge (composed of zinc sinter produced from primary zinc ores, concentrates, and also secondary materials, in combination with coke) was accomplished by passing an electric current through the material between two carbon electrodes and using the natural electrical resistance to produce heat and cause melting and fuming of the zinc. The zinc vapor was condensed by contact with cooler, molten zinc; frequently tapped, and poured into forms to produce slab zinc. Residues were removed from the bottom of the furnace. The excess carbon monoxide, produced from the burning of coke, was used as a fuel in other operations or recycled back to the retort to contribute to the reduction process. Electrothermic reduction of primary zinc feed and secondary materials offered two major advantages over externally-heated retorts because they were more energy efficient and could accommodate a wide variety of materials including scrap and other zinc-bearing materials (U. S. Environmental Protection Agency, 1995, p.6).

Since the early 1970s a typical vertical electrothermic furnace is approximately 8 feet in diameter, 50 feet high, and a distance of about 32 feet between the upper and lower electrodes. This type of unit produces about 50 tons of zinc per day. The feed must be relatively clean and metals such as lead and cadmium must be removed prior to being placed in the retort (McMahan and others, 1974, U.S. Bureau of Mines IC8629, 1974, p. 36–37).

In modern electrothermic furnaces, more than 95 percent of the zinc entering the retort is recovered (U. S. Environmental Protection Agency, 1995, p. 6). Other materials captured through the use of emission control equipment are processed into saleable byproducts and include cadmium, lead, and zinc (Williams, 1990, p. 448).

Zinc Oxide Production

The commercial production of zinc oxide in New Jersey in the 1850s marked the beginning of the domestic commercial zinc industry. Zinc oxide, originally known as “zinc white” until the 1920s, was first used as substitute for lead pigment in the paint industry. Its use widened in the early 20th century as new applications, especially as a component of rubber in tires, played an increasing role in the world’s economy. The technology used to produce zinc oxide relies on reduction of zinc contained in feedstock in the presence of heat and a carbon source. The greatest distinction between the processes

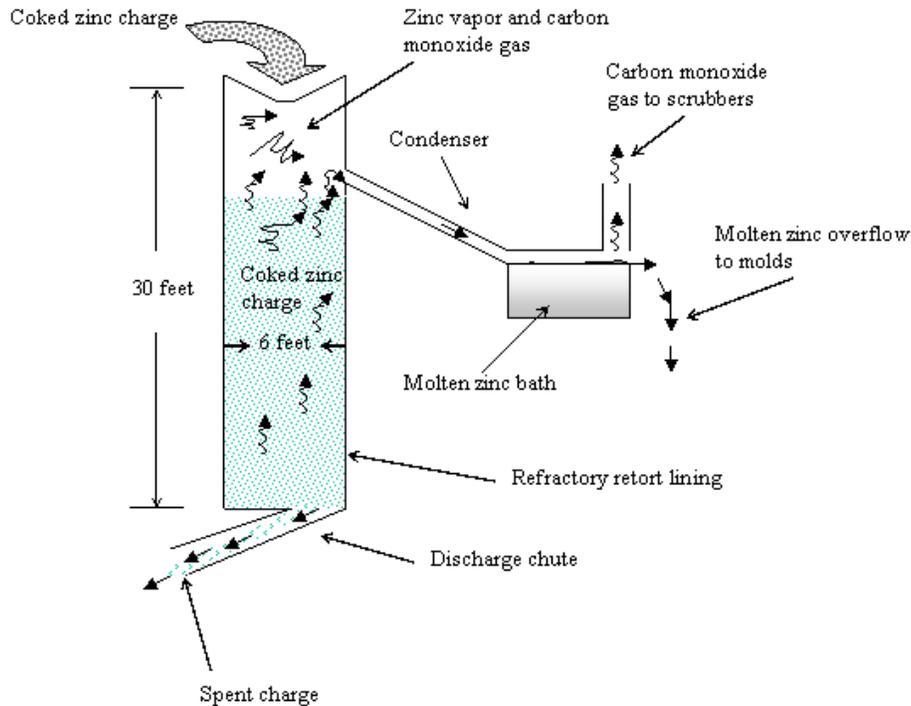


Figure 19. Generalized diagram (not to scale) of a continuously-charged vertical zinc retort. Specific technologies varied over time, and from company to company, but the principle remained the same. The primary zinc-sourced sinter-coke charge was loaded through the top of the retort and the spent charge extracted from the bottom. The carbon monoxide generated from the burning of coke was cleaned and recycled as fuel and the zinc fumes were drawn off, condensed into a molten zinc bath, and then poured into molds. (Modified from Rosenqvist, 2004).

to produce zinc oxide and zinc metal is that the former is produced by exposing zinc vapor to an oxygen-rich atmosphere to form zinc oxide, while zinc metal is condensed in an oxygen-deficient atmosphere. In this study, zinc oxide production was limited to basically two pyrometallurgical processes: (1) the “direct process,” also known as the American process; and; (2) the indirect process, popularly known as the French process. Overall, the great majority of zinc oxide produced in the United States has been by the American process.

American or Direct Process

In the American (direct) Process, marketable zinc oxide produced in the plants evaluated in this study was produced from primary feedstock by volatilizing zinc contained in carbonate, oxide, silicate, and to a lesser extent, well-roasted sulfide ore minerals. Secondary feedstock from recycled materials was used in increasing amounts in the latter half of the 20th Century. Figure 14B is a generalized flow diagram of the pyrometallurgical process used to produce zinc oxide using the direct or American Process.

The early method of furnacing to volatilize zinc and produce zinc oxide required mixing the ore and a reductant, usually anthracite, in proportions of up to 1:1. The mixture was loaded manually onto a grate in a furnace. When the zinc began to fumes, a flue was opened that directed the volatilized zinc and permitted oxygen to combine to form zinc fumes as excess air was blown into the furnace. The zinc oxide gas was cooled to a temperature that caused it to form zinc oxide flakes which were directed by fans to a bag room. In the bag room the mix of air, combustion gases, and zinc oxide flakes were passed through cotton bags measuring up to 50-feet long. The finely-woven cotton captured the zinc flakes and permitted the gases to be vented to the atmosphere. Bags were emptied about every 24 hours. Some baghouses contained up to several hundred bags. After a furnace charge was exhausted, it was emptied and recharged. Until the 1920s, virtually all of the furnacing process activities were carried out by manual labor. Beginning in the 1920s, zinc oxide production became more mechanized with the commercial establishment of the traveling grate which supplied feed to the zinc oxide furnaces on a continuous basis using metal conveyor belts.

The value of the zinc oxide product produced at a given plant was determined by its purity, which reflected, in part, the composition of the feedstock and could contain arsenic, cadmium, lead, sulfur, and water (Dunn, 1995; Dunn, 1996; Hofman, 1922). Although the highest quality and highest valued product created using the American process could attain the pharmaceutical standard of 99-percent zinc oxide, the nature of most feedstock resulted in a content of about 95 percent, highly suitable as an additive for rubber, as pigment in paints, and other uses. Some zinc oxide produced by the American process, termed “leaded zinc oxide” could contain up to 35-percent lead (Hofman, 1922).

French or Indirect Process

The French process, also known as the indirect process, produces the purest forms of zinc oxide. This method produces zinc oxide essentially the same way as that used in the direct process, but with the distinction of using zinc metal as the feedstock instead of primary feedstock. By using zinc metal, the zinc oxide produced using the French process has exceptional and consistent purity, usually exceeding 99 percent ZnO, and is more desirable in certain applications, such as in pharmaceuticals, than standard zinc oxide produced by the direct method. Historically, while some plants produced zinc oxide using the French process as a part of their product line, very few plants produced it as the sole product.

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Atmospheric Emission Controls

Emissions of fumes, gas, and vapor to the atmosphere are generated through the mechanical and pyrometallurgical processing steps employed during the conversion of feedstock to marketable products. The major incentives to limit emissions include, in alphabetical order: (1) avoidance of lawsuits and judgments; (2) concern for the environment and human health; (3) maintaining a healthy labor force and plant efficiency through industrial hygiene; (4) maximizing revenue through greater recoveries of primary and secondary products; and (5) meeting regulatory requirements.

Pyrometallurgical processes during zinc smelting often generate emissions containing potentially harmful constituents. Federal, State, and local regulatory legislation have been effective at reducing the amount released to the environment by setting limits which result in the use of various devices. However, in the past, releases to the atmosphere typically were not well controlled, and emissions were carried downwind. Some emissions, such as sulfur dioxide, affect downwind environments through acid precipitation and deposition of particulates, or both. From the mid-1800s through the beginning of the 20th century, the abundance of sulfurous emissions produced during open-air-heap-roasting of sphalerite caused concerns in communities resulting in reducing or eliminating the practice in some areas. The construction of sulfuric acid plants, beginning with the development of the Hegeler roaster in the late-1880s, removed most of the sulfurous gases out of necessity to produce a marketable and profitable product (sulfuric acid) and also served to greatly reduce the amount of sulfur-rich gas emissions, fumes, and dust to the atmosphere (Grimsley, 1903; p. 1).

In the late-1890s, the roasting of zinc sulfide ores in Kansas was reported to have produced “sulphur vapors destructive to the vegetation around the smelters” (Grimsley, 1903; p. 81). In 1912, concern in determining the placement of roasters was expressed because of “complaints and lawsuits for damages” (Hofman, 1922, p. 60). The major types of equipment used for controlling emissions at zinc facilities include baghouses, electrostatic precipitator, flues and settling chambers, and scrubbers.

The sophistication of emission control equipment has evolved and their effectiveness have dramatically improved since the mid-1850s when little, if any efforts were made to control atmospheric emissions. The reduction in emissions is not only dependent on the design of the equipment, but rely on factors such as their adequacy to treat the types and amount of material generated, adequacy of maintenance, enforcement of regulations, and the costs to install and operate.

The following is a brief and generalized discussion in alphabetical order of the major types of equipment that have been, or currently are being used to limit the amount of material that potentially could enter the atmosphere as dust, fumes, and gas. Actual technologies used to reduce emissions at facilities reported in this study are described in the individual plant profiles in Appendix 2.

Baghouses

Baghouses contain cylindrical bag filters that separate particulates from cooled flue gases by filtration as they pass through the material. Baghouse technology may have originated in the zinc industry as a method employed to recover zinc oxide derived from the fuming of ores. In the 1850s, baghouse filter bags were composed of cotton and wool, depending on the acidity of roaster gases. The use of wool was favored when the gases were sulfurous because the natural oils contained in the material offered some protection against the formation of corrosive sulfuric acid. Early baghouses were prone to clogging, holes, and tears (Martin, 1913). In later years, some bags were composed of asbestos and later gave way to the use of fiberglass. Cloth and fiberglass prevail as the most common material used for filter bags. The material captured in the baghouses at zinc smelters is sold generally or reprocessed to recover materials of value such as arsenic, cadmium, gold, lead, and zinc. An additional benefit of baghouses has been the neutralization of sulfur dioxide by zinc oxide and carbonates contained in the emission flow.

Cyclonic Dust Collectors

Cyclonic dust collectors, or cyclones, have been in use as a means for the removal of particles contained in gas and fluid streams for more than 100 years. Although not usually the sole method of removing particulates from a medium prior to release to the atmosphere, they serve an important component in a system for reducing plant emissions.

As the name of the device implies, the conical or cylindrical shape of the cyclone establishes a high-speed rotation of the medium flowing through it, similar to a whirlpool, which causes larger and denser particles in the rotating stream to strike the outside wall and causes them to fall to the bottom of the cyclone or into a bag where they can be removed and either treated to recover materials of value or disposed as waste. The process continues as the rotating flow moves towards the narrow end of the cyclone and the rotational radius of the stream is reduced, separating smaller and smaller particles. While the separation of particles is occurring, the cleaned medium travels upward through the spiraling medium and exits to cyclone. The efficiency of the device to remove particulates depends on the force exerted on the particles, particle size and mass, and the amount of time the material resides in the cyclone (BPA, Air Quality Solutions, p. 63, 2008b).

Electrostatic Precipitators

For more than 100 years electrostatic precipitators (EPS), often referred to as “Cottrells”, have been widely employed for controlling plant emissions to the atmosphere and for ensuring that the sulfur dioxide generated from roasting ore and concentrate is cleaned sufficiently for the production of

sulfuric acid. EPSs have wide application in business, industry, and in homes. In industrial applications, the material captured by a precipitator often is treated to recover marketable products.

The Cottrell precipitator was patented in 1907 by Frederick Cottrell. Its first commercial applications included the collection of materials contained in emissions generated by smelting activities and manufacturing of cement in California that were causing environmental damage and to generate revenue from the recovery of material that was lost during smelting. At about the same time, Cottrell precipitators were installed at a copper smelter in Tennessee to treat a portion of the plant's emissions in reaction to the resentment of the local population to sulfurous emissions, judgments, and pending lawsuits resulting from the environmental damage attributed to the plant emissions and the ready market for sulfuric acid. Clean sulfur dioxide gases are required for the manufacture of sulfuric acid.

Cottrell's work on the principle of exposing material entrained in gas to a high-voltage electrical field ranging from about 40 kilovolts to about 100 kilovolts, while at the same time only minimally impeding the flow of the gas. After the particles are charged, they are directed through a series of alternately charged collector plates or wires where particles with the same polarity as the plates or wires are repelled, while particles with the opposite polarity are attracted to the plates or wires—similar to how a magnet works (BPA, 2008a). Material is recovered at the bottom of the precipitator after falling from the collectors under its own weight or by physically “rapping” or shaking them.

At some plants Cottrell precipitators replaced baghouses or were added to improve the control of emissions and or longevity of equipment. For example, in the treatment of acidic sinter plant gases, EPSs were placed before baghouses in order to prevent the corrosive gases from destroying the bag filters (Welch, 1936).

Vaporized elements such as arsenic, cadmium, mercury, and zinc commonly are captured by the EPSs.

Depending on the size of a plant and the number of circuits, a facility can be fitted with numerous EPSs. If properly maintained they are capable of recovering from 90 to 98 percent of particles contained in the treated off gas (Avallone and others, 2007).

Flues and Settling Chambers

Settling chambers and flues were among the first types of technologies used to capture solid materials entrained in roaster-generated combustion gases. Both methods are relatively simple in design and are based on the principle that cooling and lowering the velocity of gases results in the condensation of vapors and reduced the carrying capacity of particulates causing them to fall from suspension.

In the early part of the 20th century flues, usually composed of iron, lead from roasters and furnaces to chimney stacks that could measure several hundred feet or more in

length. Their effectiveness at removing material varied. Eventually, flues were constructed using metals and alloys such as aluminum and stainless steel that were better suited to resist the corrosive nature of the gases. Flues may contain numerous draw points from which accumulations metal-rich fumes and residues were emptied, removed, and treated to recover material of value. Flues continue to be part of the gas-cleaning process at zinc plants where they work in conjunction with ancillary equipment, which results in improved overall recovery of emissions.

The use of settling chambers became increasingly important in the late 1800s as a method to clean sulfurous gases generated from roasting sphalerite ore in order to manufacture sulfuric acid. Settling chambers used in the production of sulfuric acid were usually lead-lined in order to avoid the corrosive nature of gas and condensate.

Scrubbers

Scrubbers of various types and sizes have been employed for the removal of materials contained in industrial gas streams for more than 150 years (Hills, 1856). Historically, their use in zinc production has been twofold; first as a means to remove potentially harmful dust from gases produced at the plant and secondly as a method to clean sulfurous off gas produced in roasters for the production of sulfuric acid. Scrubbers generally compliment or supplement other gas control technology. Among the various types of scrubbers, wet scrubbers are the most common type, although dry scrubbers, which inject slurry of acid neutralizing reagent into a stream of off gas is used also. The process of wet scrubbing entails the use of water, sometimes containing chemicals, which is sprayed under pressure through nozzles into the gas flow. Materials contained in the gas stream are removed by absorption or chemical reaction with the solution. Some of the water evaporates as it cools the gases, especially if the process-gas is hot, and is lost with the exhaust, but may be controlled if the mist is considered potentially harmful. Water droplets are separated from the exhaust and recirculated back to the water reservoir where it is recirculated and makeup solutions added if necessary. Evaporated water is replaced by fresh water and chemicals. Depending on the type of wet scrubber, sludge, containing dust and other material recovered by the process are removed periodically through a drain at the bottom of the scrubber. The residue is either processed for its valued components such as cadmium, mercury, and zinc or in other cases disposed, sometimes as a hazardous waste.

Stacks

Before and into the early 20th century, tall chimneys usually were the primary and sometimes sole method of atmospheric emission control. They were constructed based on the assumption that noxious gases (a term generally applied to sulfurous gases) and entrained materials if discharged at

a sufficient height would be diffused more thoroughly and become so diluted as to be relatively harmless. For some areas this may have been a correct assumption. However, it was later recognized that the use of high stacks actually increased the area subjected to damage while the use of small stacks increased the intensity of damage to a limited area. As a partial solution to the problem, dilution of gases using induced air and multiple chimneys was implemented at some sites (Fulton, 1915). In stacks, material accumulated at the bottom of stacks, and as accretions at the mouth of the stack and on the stack walls. Accretions were removed to avoid choking the system and to recover the value of its metal content.

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Appendix 2. Profile Reports of Zinc Smelters

The following zinc smelter profiles describe specific details pertaining to the individual smelters evaluated in this study. They are listed alphabetically by state and city.

Bergen Point Zinc Works, Bayonne, Hudson County, New Jersey

Introduction

The Bergen Point Zinc Plant in New Jersey (Miller, 1941, p. 330), produced zinc oxide (referred to as zinc white in historical literature) and zinc metal (referred to as spelter in historical literature) from approximately 1875 until its permanent closure in 1886. It was abandoned in 1888 (Stone, 1916). The plant was occasionally referred to by its location (for example, Bergen Point). It was unclear in some cases, if information provided in the literature was referring to the Bergen Point Zinc Plant owned by the Bergen Port Zinc Company or the white lead (lead oxide) - zinc white (zinc oxide) facility owned by the Bartlett Zinc Company (BZC), [formed in 1868 (New Jersey State Legislature, 1869)] later known as the Bartlett Zinc White and Zinc Company, also located in Bergen Point. Little technical and no capacity or production data information pertaining to the facility was discovered in the literature, and was therefore not included in this study. The Bergen Point Zinc Company, however, was a producer of zinc metal and zinc oxide and the Bartlett Zinc Company production was limited to a zinc oxide-lead oxide mix as a pigment.

The plant owned by the Bergen Port Zinc Company was located in close proximity to established sources of primary feedstock in New Jersey and Pennsylvania. Good infrastructure also favored the location. Sulfide ore from Pennsylvania was roasted at the remote Bergen Point site because roasting of sulfide ore, with its attending sulfurous emissions at the smelter facility in Jersey City, New Jersey, was not tolerated by residents in the densely populated area (Dunn, 1995b; p. 780). Hofman (1922, p. 61) noted that roasting was problematic since the sulfur dioxide fumes were likely to cause complaints and result in lawsuits for damages. The production of sulfuric acid was attempted for a few years in the 1880s, but was short lived because of the high carbonate content in the sulfide ore and poor economics. Roasting was either discontinued or greatly reduced a few years before the plant permanently closed as a result of a feedstock change from the sulfide ores supplied from Pennsylvania to oxide ores from New Jersey.

Total production of zinc and zinc oxide by the Bergen Point Zinc Company, expressed in zinc metal equivalents and rounded to two significant figures, was estimated at 27,000 short tons. Based on limited data and considering the time

period, roasting method, and technologies used to recover zinc and zinc oxide from ores, approximately 1,200 short tons of zinc and 18,000 short tons of sulfur from ores, contained in various forms, may have been emitted from fugitive and stack sources to the atmosphere.

Map Number (fig. 1)

1

Plant Names

Bergen Point Zinc Works
Bergen Point
Port Bergen
Bergenpoint
Bergenport
Bergen Port
Constable Hook (Stone, 1916)

Location

The plant was located in Bayonne, New Jersey. Located at approximately latitude N40°38'51" (40.6475) and longitude W074°08'30" (-74.141667).

Owners/Operators

1875(est.) - 86—Bergen Point Zinc Company (Simon Rau and Company, Pennsylvania, 1881, p. 79; Ingalls, 1902; 1908 ; U.S. Geological Survey, 1887).

Years of Operation

The plant was constructed and began producing in 1875 (Dunn, 1995b, p. 780; Miller, 1924, p. 59). The plant shut down was reported as producing in the 1884 USGS Mineral Resources of the United States (U.S. Geological Survey, 1885, p. 476). Miller provided information on the smelter for the period 1881- 85 (Miller, 1941, p. 330). The plant reportedly closed permanently during 1886 (U.S. Geological Survey, 1887).

Production History

The Bergen Point Zinc Works produced zinc metal and zinc oxide. It was estimated, using some broad assumptions that the facility's total production over its 12-year life was about 27,000 short tons of zinc as zinc metal (60 percent) and

zinc contained in zinc oxide (40 percent). A minor amount of sulfuric acid was produced in a plant using roaster gases.

Zinc Metal

In 1875, the facility at Bergen Point produced 895 short tons of zinc metal, of which 500 short tons of zinc metal were derived from sphalerite ores supplied by the Correl mine in the Friedensville District, Pennsylvania (Miller, 1924, p. 59; Miller, 1974, p. 332; Ripley and Dana, 1883). No information was available regarding the quantities of ore supplied from other mines. For the year 1884, the plant was reported to have an annual capacity of 2,000 short tons of zinc metal (Miller, 1941, p. 330; U.S. Geological Survey, 1885, p. 476).

It was estimated, based on limited data, that the facility's annual zinc metal production was 1,500 short tons for the years 1876-85, and 895 and 500 short tons of zinc in 1875 and 1886 respectively; partial production years. The production estimate was based on using 75 percent of the published capacity for 1884 as the average annual production. Seventy five percent was chosen because smelters employing horizontal retorts during this time period rarely achieved full capacity for a number of reasons, including breakage of retorts, furnace failure, inconsistent ore grades and other factors. Using these assumptions, total zinc metal production over the life of the facility is estimated at 16,000 short tons using about 65,000 short tons of ore.

Zinc Oxide

The plant initially opened in 1875, as a producer of impure zinc oxide. In 1875, the first year production statistics were available the Bergen Point plant produced 1,000 short tons of impure zinc oxide (Miller, 1924, p. 59; Miller, 1941, p. 332; Ripley and Dana, 1883). It was estimated that the operation averaged 1,250 short tons of zinc oxide for the years 1876-85. No production data prior to 1875 or post-1875 are available in USGS Minerals Yearbooks or in other literature investigated, although zinc oxide was mentioned as a plant product for 1884. It was estimated that 350 short tons of zinc oxide were produced in 1886, a year of partial plant operation. Rounded to two significant figures, total impure zinc oxide (75 percent zinc oxide) production was estimated at 14,000 short tons or about 10,000 short tons of contained zinc equivalents from about 40,000 short tons of ore.

Sulfuric Acid

Sulfuric acid was produced from sulfurous gases produced by roaster for a short period of time towards the end of the smelter's life, but was discontinued because of unfavorable economics and technical problems caused by the increasing amount of limestone in the ore, which buffered the acid-making process (Miller, 1924, p. 75, 349).

Feedstock Sources and Ore Types

After 1875, sulfide ore originating from the Friedensville Mining District was no longer shipped to Jersey City because of issues related to heavy sulfur fumes generated from roasting ore in the heavily populated city. Instead, at least some of the ore production was shipped to and roasted at the newly constructed Bergen Point smelter, (Dunn, 1995b, p. 780). Some of the feedstock may not have required roasting or was roasted elsewhere. In 1875, approximately 500 short tons of zinc metal were recovered from sphalerite ores delivered from the Ueberroth and Hartman mines at Friedensville, Pennsylvania. Sphalerite from the Correll Mine, (also known as the Saucon mine), also in the Friedensville District, was treated at the smelter from 1875-81 (Miller, 1941, p. 329) and from 1881-85 ore was received from the Ueberroth, Hartman and New Hartman mines (Miller, 1941, p. 330), also mostly sphalerite, because most of the oxide ores had been mined out by 1875. In 1880, the Company purchased all of the Lehigh Zinc Company properties in the Friedensville District including the Correll Mine [also known as Saucon mine (Ingalls, 1908)], its most important feed source for the Bergen facility at the time (Miller, 1941, p. 333). From 1879 until about 1884, the Correll Mine supplied sphalerite ore and concentrate to the Bergen Point smelter. These hand-sorted sphalerite ores were described as being extremely low in arsenic, antimony, and lead. The feedstock averaged between 30 and 40 percent zinc with high amounts of associated pyrite (Government Printing Office, 1884; p. 364). Figure 20 is a photograph taken circa 1915 of an underground mining operation in the Friedensville District.

By the end of 1884, feed to the Bergen Point Zinc Works consisted almost entirely of a mixture of franklinite and willemite from mining operations in the Franklin-Sterling Mining District of New Jersey (Miller, 1941, p.330). These ores averaged approximately 24 percent zinc (Schnabel, 1907).

Following the closure of the Bergen Point plant in 1886, all of the sulfide ores mine in the Friedensville District were roasted and smelted locally (Miller, 1924, p. 57; Miller, 1941, p. 330).

The Bergen Point Works purchased impure zinc oxide recovered from wastes generated at local galvanizing plants for several years (Martin, 1909), and may have also reprocessed impure zinc oxide produced onsite, but statistical data is not available.

Technology

In the first few years of the operation only impure zinc oxide using a stationary grate furnace and baghouse were used. Later, zinc metal was produced using Belgian furnaces containing ceramic horizontal retorts. The plant had an onsite roaster that was used to calcine the sphalerite ore shipped from Pennsylvania. The facility experimented with the production of sulfuric acid for a time by capturing the sulfurous fumes generated by the roaster (Miller, 1924). No descriptive data on



Figure 20. Photograph of an underground mining operation, circa 1915, in the Friedensville Mining District in the Saucon Valley of Pennsylvania. The surface and underground mines of the District provided feedstock to plants in New Jersey and Pennsylvania on an intermittent basis for many years. Underground mining was complicated by the presence of large amounts of water, which required large-scale and costly pumping. Photograph courtesy of Library of Congress (2010).

the technology employed were available, but were probably similar to that employed by other plants of its day.

Roasting of feedstock prior to furnacing to produce zinc oxide was likely greatly reduced or ended by 1884 as the ore used at the plant originated from nonsulfidic sources in New Jersey.

Zinc Metal

In the late 1870s, the zinc metal plant was described as using Belgian furnaces containing horizontal retorts. Each furnace contained 70 retorts that could process 3,175 pounds of calcined (roasted) sphalerite ore mixed with 1,900 pounds of anthracite as a reductant over a 24-hour period. Approximately 75 percent of the zinc contained in the calcine was recovered. Each furnace burned 5.5 short tons of coal to provide the heat energy to recover 1 short ton of zinc. Five retorts (7 percent of the furnaces' total retort capacity) were destroyed by the combination of high heat and iron in the calcine reacting with the retorts in a furnace every 24 hours. The retort failures significantly contributed to the relatively high loss of zinc. Furnaces needed to be rebuilt after one year of service. To recover one short ton of zinc, about 1.9 short tons of coal was needed as a reductant and 5.5 tons for heat (Schnabel, 1907).

Most of the roasted sphalerite ores contained about 42 percent zinc [roughly 55 percent zinc oxide, plus 26 percent iron oxide], suggesting that each furnace, under optimum conditions, was capable of producing nearly 1,000 pounds of zinc over a 24-hour period (Schnabel, 1898; p. 167; Ingalls 1902, p. 232) and required replacement to maintain plant capacity. The actual number of furnaces installed at the site during this time period was not available.

In 1884, the plant was described as possessing 8 Belgian furnaces containing a total of 888 retorts (111 retorts per furnace) with a capacity to produce approximately 2.25 short tons of zinc/year/retort or about 2,000 short tons of zinc per year using mostly willemite and franklinite feed from New Jersey (Miller, 1941, p. 330; U.S. Geological Survey, 1885, p. 476).

Zinc Oxide

In 1875, a stationary grate zinc oxide plant and baghouse was constructed on the site to treat calcined sulfide ore and in later years, ores from the Franklin-Sterling District (Dunn, 1995; Miller, 1924; Schnabel, 1907).

Zinc oxide was produced using stationary grate zinc oxide furnaces. The calcine derived from sphalerite or direct shipping franklinite-willemite ore were mixed with anthracite

and heated in the furnace to the point that the zinc was reduced, volatilized, oxidized by air, and directed through conduits. The zinc oxide flakes were captured in bags in the baghouse. Because the furnaces predated the use of the traveling grate, grates needed to be manually loaded and raked by hand tools during firing and cleaned out and the reloaded before the cycle could be repeated.

Emission Estimates

Zinc

The estimates of fugitive and stack emissions of zinc and other materials should be considered as general estimates because of the limited amount of available data pertaining to the site. Using these data and assumptions related to historical production, ore grades, metal recovery, roasting, and the experimental and newly developed technologies employed, it was estimated that approximately 1,200 short tons of zinc in various forms was emitted to the atmosphere from fugitive and stack sources. The sources of zinc emissions from producing zinc metal included, to varying degrees, roasting ore, preparation of charges for the retorts, broken and cracked retorts that occurred during distillation, loading and unloading retorts, and losses from retorts during condensation. Losses from zinc oxide production include roasting, preparation of charges for reduction in the stationary-grate zinc oxide furnaces, initial heating of charges in the furnaces, stirring charges during furnacing and emptying depleted charges from the furnaces; leakage of fumes from the furnaces' retorts, conduits, and in the baghouse; and packing product for shipment.

Sulfur

Sulfur dioxide emissions were produced from roasting sulfide ores containing sphalerite and pyrite at the Bergen Point site. It was estimated that approximately 18,000 short tons of sulfur was emitted from the plant mostly as sulfur dioxide, but it also was a constituent in dust, fumes, and gas of different compositions. The estimate was based on the following assumptions: (1) approximately 1/3 of amount of the total ore received at the smelter originated from New Jersey and did not require roasting and all ores received from Pennsylvania were roasted at the smelter site; (2) the ore consisted of sphalerite, with associated pyrite; (3) the feedstock to the roaster averaged 32 percent sulfur; and (4) 95 percent of the sulfur was burned off and released from the plant as dust, fumes, and gas. Also, the capture of sulfur by the acid plant was not considered because it appears to have operated for only a short period of time and may have used only a small portion of the sulfur dioxide produced by the roaster. Sulfur emitted from coal used as fuel and as a reductant was not included in the estimate.

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Passaic Zinc Works, Jersey City, Hudson County, New Jersey

Introduction

The Passaic smelter was constructed by the Passaic Zinc and Construction Company in 1854 and initiated zinc oxide production in the same year. The plant was located in the small town of Communipaw, N.J., also referred to as La Fayette, (Foster, 1892; p. 185), now a suburb in southeastern Jersey City, N.J. The original facility was constructed to supply zinc oxide pigment for the paint industry (Dunn, 1995a; p. 171). The site was located close to primary sources of ore, at first from the Lehigh Valley and Saucon Valley, both in Pennsylvania, and later, exclusively, from the mines developed in the Franklin-Sterling District, in New Jersey. The availability of several forms of transportation and easy access to domestic and foreign markets favored the location of the plant. As the plant became established and expanded, it produced, in addition to zinc oxide (1854–1901), zinc metal (1875–1901), and spiegeleisen (1884–1901) (Dunn, 1995a; p. 171; Dunn, 1996; p. 858). Zinc production was affected negatively by technical problems associated with furnace failures, and by low metal prices at a national level during the “Panic of 1893” and the several years thereafter, but statistical data for all; but a few of the years the plant operated are not available.

For the years the plant operated it was calculated that the zinc plant may have produced a total of 45,000 short tons of high purity zinc metal and 211,000 short tons of zinc oxide, containing about 171,000 short tons of zinc for a total of 216,000 short tons of zinc. In the course of producing zinc, zinc oxide, and spiegeleisen it was estimated a total of nearly 12,500 short tons of zinc was emitted to the atmosphere as fugitive and stack emissions.

Portions of the original zinc plant still stand (see figure 21), but have been modified over the years in order to serve different purposes. In 2010 it was the site of a housing project.

Map Number (fig. 1)

2

Location

The plant was located in Communipaw, a southeastern suburb of Jersey City, Hudson County, N.J. at approximately, N40°42'46" (40.712778); W074°03'44" (-74.062220).

Alternative Names

- 1) Passaic Zinc Works
- 2) Passaic Smelter

- 3) Jersey City Smelter

Years of Operation

1854–1901 (Dunn, 1996; p. 858, Hofman, 1922).

Ownership

- 1) Passaic Mining and Manufacturing Company, 1853–71 (Dunn, 1995b; p. 771)
- 2) Passaic Zinc (Works) Company, 1871–97 (Dunn, 1995b; p. 780) (Lead and Zinc in the United States, Ingalls, 1908, p. 314).
- 3) New Jersey Zinc Company, 1897–1901 (Dunn, 1995a; p. 210; 1995b, p. 785)

Primary Products

- 1) Zinc oxide—1854–192)
- 2) Zinc metal—1875–1901.
- 3) Spiegeleisen—1882–1901.

Feedstock Sources and Ore Types

The chemistry of feed treated at smelters is the most important factor in determining the composition of plant emissions. The types of feed treated at the Passaic smelter consisted primarily of zinc oxide and zinc silicate minerals that also contained large amounts of iron and manganese. Calcite was a significant gangue mineral. Rarely were there any sulfide minerals or other minerals containing appreciable amounts of metals common to other ores such as cadmium, copper, lead.

In the earliest years of the Passaic plant’s operation, some sauconite (a secondary zinc-rich clay mineral) and smithsonite were shipped to the Passaic smelter from the Company’s mines in the Saucon Valley of Pennsylvania (Dunn, 1996; p. 858), but the amount available was limited. Beginning in 1875 any sulfide ores produced by the company in the district were shipped to the Bergen Point smelter in New Jersey. Beginning in the mid- to late-1850s the Passaic Zinc Company brought zinc deposits into production in the Franklin-Sterling Hill area (New Jersey Geological Survey, 1855) which became the primary source of feedstock over the 47 year operating life of the Passaic Smelter. The miners initially extracted zincite which assayed about 65 percent zinc and hemimorphite, which assayed about 55 percent zinc. Zincite was known locally as “red ore” or “red oxide ore,” and “calamine” was a local term to describe hemimorphite. The use of these colloquial terms led to confusion among those not familiar with the local zinc industry. Some of the hemimorphite ore from the company’s New Jersey mines was shipped to the Bethlehem, Pennsylvania facility owned by the Lehigh Zinc Company (Dunn, 1995a; p.109). The hemimorphite ores, however, did not occur in great abundance; although it was a component



Figure 21. The older buildings in the foreground of this photograph were part of the original Passaic Zinc Works. The plant was constructed in the mid-1850s and shut down in 1901. The later buildings were constructed following the closure of the smelter when the Whitlock Cordage Company moved to Jersey City in 1905. Most of the structures at the site remain since the photograph was taken in 2000, but have undergone significant conversion as housing. Photograph provided courtesy of Leon Yost, 2009.

of the feedstock through the 1880s, it was not a major ore mineral. Hemimorphite and some smithsonite from the Sterling Hill Mine and the Passaic Mine in New Jersey also were constituents of feed to the plant for zinc metal and zinc oxide production. They continued to supply ore through the 1870s (Palache, 1935) and into the 1880s. As these types of ore became exhausted, a shift occurred to proportionately larger amounts of franklinite for the manufacture of zinc oxide.

Feedstock was dominated by zincite, franklinite, and willemite. Zincite continued to be a major component of the plant feed from the time the Passaic smelter first opened through the 1880s (Dunn, 1995a; p. 287).

In 1871, mines in the Franklin-Sterling Hill District continued to supply the Passaic facility with zincite ore. During this period, the ore was separated by hand at the mine mouth. The large pieces of pure zincite were sent directly to the smelter where they were crushed and ground before mixing with anthracite for the production of zinc oxide. The lower grade ores were first crushed and ground and then treated by gravity separation in a series of jigs and tables at a nearby mill to separate the zincite from the waste rock (Dunn, 1995b; p. 787). The resulting zincite concentrate was also sent to the smelter for the production of zinc oxide. Zinc oxide was the sole use of this ore until the furnaces containing horizontal retorts were installed for producing zinc metal in 1874. Feed that was high in zinc silicate and zinc-iron-manganese ores, such as franklinite, could not be used for producing zinc metal because manganese iron-silicate formed while furnacing. The molten silicate caused erosive damage to the retorts. For this reason, the ores were better suited for zinc oxide production.

In 1882, franklinite was reported to be the chief mineral for zinc oxide production (Dunn, 1996; p. 868). The iron-manganese

rich furnace residues remaining from the use of this ore served as feed for the Spiegel furnaces installed in 1884 (Dunn, 1996; p. 868; Dewey, 1885) from which spiegeleisen was produced.

In 1883, willemite and hemimorphite continued to be an important part of the plant's feed for the production of zinc metal. The hemimorphite originated from the Sterling Hill Mine (Dunn, 1995b; p. 806), Passaic Mine, and the Buckwheat Field Mine (Dewey, 1885).

In 1884, a portion of the ores for producing zinc oxide originated from the Buckwheat Field Mine in the Franklin-Sterling Hill District. The mix of franklinite, willemite, and zincite averaged 29 percent zinc, while samples from the Sterling Hill Mine containing the same ore minerals assayed 19.8 percent zinc (Dewey, 1885; Foster, 1892, p. 185). The ores from the Buckwheat Mine contained several times the amount of calcium, primarily from the presence of calcite, than the ores from Sterling Hill. These ores also contained about 18 percent iron, 11 percent manganese, and 10 percent silica (Dewey, 1885; p. 273-274; Dunn, 1996, p. 871).

In 1893, the zinc metal plant reportedly treated willemite and hemimorphite from New Jersey and calamine from Virginia (Ingalls, 1903, p. 656) as part of its feed. In this case, calamine actually was smithsonite, a zinc carbonate mineral.

From about 1898 until the plant's closure in March 1901, the smelter benefitted from the advent of Wetherhill magnetic separators used by the New Jersey Zinc Company. The concentrates (assaying nearly 50 percent zinc) produced by this method resulted in a clean willemite-concentrate suitable for zinc metal production. Franklinite concentrate assaying about 23 percent zinc was used for zinc oxide production (Ingalls, 1902, p. 278).

Spiegeleisen

Feed for the production of spiegeleisen (an iron, manganese, and carbon alloy) used in steelmaking originated from the furnace residues, also referred to as "clinker," remaining from zinc oxide production using franklinite as the dominant feedstock. In the 1850s clinker or residuum from the zinc oxide furnaces using New Jersey ores contained from 3-7 percent zinc and averaged about 6 percent zinc oxide (Dunn, 1996; p. 870). In 1885, the average composition of 5 samples of residuum taken from the furnaces using franklinite as a primary source of feedstock ranged from 4.06 to 10.74 percent zinc oxide with a weighted average of 6.92 percent zinc oxide (5.56 percent zinc). Other elements and their average content in the suite of samples included 24 percent iron, 14 percent manganese, and 10 percent silica (Banner, 1891).

In 1886, a sample of residuum from the Passaic zinc oxide furnaces and used as feedstock for producing spiegeleisen contained 4.7 percent zinc oxide (3.8 percent zinc).

Production and Technology

Zinc Oxide

The Passaic plant initiated production in 1854 to supply zinc oxide as a pigment for use in the paint industry. Zinc oxide production was based on the direct (American) process using almost exclusively ores from New Jersey. The major features of the facility included crushers and grinders to reduce the size of the ore to a fine powder; charge preparation, stationary grate zinc oxide furnaces, and a baghouse for the capture of zinc oxide (Dewey, 1891, 1892, p. 185).

In the late-1850s or early 1860s, the Passaic plant had 24 zinc oxide furnaces measuring 4 feet in width, 3.5 feet high, and six feet in length. In order to make zinc oxide, the plant workers produced a charge for each stationary grate furnace consisting of 250 lbs of pea coal and 600 lbs of zinc ore averaging nearly 30 percent zinc. The furnace required 300 lbs of coal powder as an energy source to fumes the zinc. The stationary grate furnaces were vented to the atmosphere until the charge began releasing zinc fumes to an extent that they were redirected to a baghouse for recovery as zinc oxide. The charge was burned for 6 hours and then manually raked out and reloaded. Zinc oxide fumes from the furnace were directed by fan-driven drafts through conduits that were cooled externally by air and water causing the zinc fumes to form zinc oxide flakes. The zinc oxide flakes were collected by filtering the draft through flannel bags. The product from the bags was further ground, compressed, and packaged. Sweepings collected in the plant were reprocessed in the zinc retorts (after 1875) or in the zinc oxide furnaces (Dunn, 1996, p. 868; Foster, 1892, p.185; Ripley and Dana, 1863).

Production and capacity statistics were published infrequently. In 1856, the plant produced 1,163 short tons of zinc oxide, and in 1860 zinc oxide production was reported at 2,400 short tons per year (Dunn, 1996; p. 865) from 16 furnaces. By 1867, the facility had 24 furnaces, thereby boosting production to a reported 280-300 st/mo or about 3,500 short tons per year (Dunn, 1996, p. 865).

It was reported in 1885, that the operation had expanded to 48 furnaces for the manufacture of zinc oxide (Annual Report of Regents of the Smithsonian Institution, 1885), but the year of the expansion and capacity and production statistics were not published. The total maximum annual plant capacity was estimated to be roughly 6,500 short tons of zinc oxide; equivalent to about 5,200 short tons of zinc. The estimate was based on the following: (1) 48 furnaces; (2) a single furnace had the capacity to treat 600 pounds of ore per charge that was burned for approximately 6 hours each; (3) 4 charges per 24 hours; (4) feed grade averaged 30 percent zinc; (5) the recovery of zinc from ore to zinc oxide was 83 percent; and

(6) 99 percent zinc oxide in product. Figure 22 is a photograph of a zinc oxide furnace taken at the Passaic plant in 1884. The zinc oxide furnace in the photograph was typical of those used in the region to treat ores from New Jersey and Pennsylvania.

By 1900, as a result of significant technical developments that included magnetic separation of ore in the early 1890s and improvements in temperature control, zinc recovery in the zinc oxide plant was approximately 83 percent (Ingalls, 1903; p. 675), while average zinc recoveries over the life of the plant probably ranged 75-80 percent.

Based on the limited production data it was estimated that for the years 1855-1901 the plant may have produced approximately 211,000 short tons of zinc oxide, containing about 171,000 short tons of zinc.

Zinc Metal

Zinc metal, often referred in the literature as spelter, was produced at the Passaic plant beginning in 1875 using horizontal retorts that were externally heated by coal-fueled furnaces. Zinc metal continued to be produced at the plant until the facility permanently shut down in 1901. The ores supplied to the plant rarely contained materials that negatively affected the value of the zinc metal.

In 1875, Miller (p. 329) reported that the spelter plant was constructed to treat New Jersey ores as the primary source of feed to Belgian furnaces containing horizontal retorts (Dunn, 1995a,b, p. 215, 777). The plant originally had two blocks of four furnaces with each furnace containing 56 retorts to a furnace (Dunn, 1995b, p. 780, 777) for a total of 448 retorts. The plant reportedly produced 784 short tons of zinc in 1875, the year the plant opened (Ripley and others, 1883).

In the late-1870s each furnace was reported to have the design capacity to accommodate approximately 2,700 pounds of ore in 70 retorts and could yield 1,000 pounds of zinc metal over a 24-hour period. The three lower rows of retorts were charged twice during this period because they were exposed to higher heat; the other retorts were not recharged during the 24-hour period. To produce one ton of zinc from all of the retorts in the furnace, 4.5 short tons of coal were required as fuel to heat the furnace and 1.3 tons were required as a reductant. In a 24-hour period, 6.4 percent of the retorts were destroyed in the furnace during the process of reduction, leading to significant losses of zinc fumes. A furnace would provide service for two years before it needed to be rebuilt. The number of furnaces was not provided (Schnabel, 1907; p. 167).

In 1880, additional Belgian furnaces and a crusher were added (Dunn, 1995b, p. 774, 780; Miller, 1941, p. 329) (Dunn, 1995ab, p. 212, p. 780; Annual Report of Regents of the Smithsonian Institution, 1885), which expanded plant capacity, but the number of furnaces and retorts was not provided. Charges to each retort consisted of 32-39 pounds of ore and 21 pounds of anthracite coal dust as a reductant (Foster, 1892, p. 185).

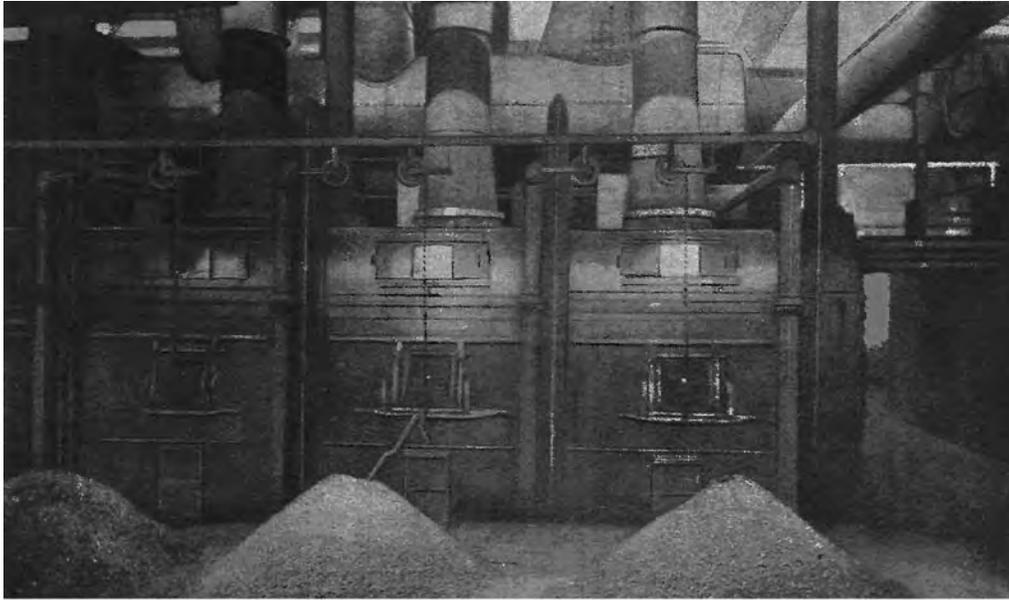


Figure 22. Photograph taken in 1884 of zinc oxide furnaces at the Passaic Zinc Works, Jersey City, New Jersey. The ducting at the top of the furnaces lead to the baghouse. Note piles of charges consisting of ore and coal in preparation for loading into the furnaces. The charges were loaded, raked, and unloaded manually. Ore was supplied by the mines in the Sterling Hill Mining District in New Jersey. Residuum from the furnaces was used to produce high-manganese iron called spiegeleisen, also popularly known as pig iron (Dewey, 1891).

In 1885, it was reported that the smelter had 12 spelter furnaces arranged in blocks of 4 each (Dewey, 1885). Assuming that the additional retorts became operative in 1880, and of the similar design of 56–70 retorts to a furnace, there would have been a total of 672 retorts. Figure 23 is a photograph of the horizontal retorts and furnace taken at the Passaic plant in 1884. The retort-furnace arrangement shown in the photograph was typical of those used to produce zinc metal.

In the late 1880s, the furnaces were described as having Belgian furnaces, some containing 216 retorts and others 252 retorts, but again, the total number of furnaces of each size at the facility was not published. At optimum furnace performance, 83–85 percent of the zinc contained in an ore charge containing 45 percent zinc was recovered. The ore component of the charge consisted of a mix of willemite from New Jersey combined with lesser amounts of smithsonite from Virginia (Ingalls, 1903). During this period a retort would last about one month because of improvements in the composition and design of horizontal retorts. The zinc produced from the Passaic plant was known for its high purity.

Based on an average annual production of 2.7 short tons of spelter per installed retort for the years 1875–1901, it was calculated that the zinc plant may have produced a total of roughly 46,000 short tons of high purity zinc metal. The estimate does not account for speculative occurrences such as periods of reduced production, closures resulting from local or national occurrences, economic conditions, or interruption because of major technical problems.

The plant was noted for its high-purity zinc because of its source of feedstock. In the 1890s, zinc metal produced from the plant assayed more than 99.5 percent zinc with a trace of lead and iron (Ingalls, 1903).

Spiegeleisen and Byproduct Zinc Oxide

Between 1882 and 1884 a spiegel furnace, essentially of the same design as a blast furnace used for producing iron, was purchased and constructed for the Passaic Company. The plant went into operation in 1884 and was located in marshes several miles west of the main facility. No rationale for the location of the plant was encountered in the literature. Feed to the plant consisted of high iron-manganese residues that remained from the furnacing of franklinite ore used to produce zinc oxide. This material previously had been considered waste. The material contained about 6 percent zinc oxide (Dunn, 1995a, p. 171, p. 216; Dunn, 1996, p. 873) of which some portion was recovered. A continuous supply of residue from the zinc oxide plant plus a stockpile of residue accumulated from previous years ensured a readily available and large supply of feedstock. The high-manganese iron product, known as pig iron or spiegeleisen, was purchased by the local steel industry.

The blast furnace measured 9.75 feet by 37.5 feet (Dewey, 1885) and had a stack that measured 45 feet high and 10 feet in diameter. The furnace was reported to have a design capacity of 7,300 gross short tons per year of spiegeleisen containing approximately 15–20 percent manganese and more than 80 percent iron (Directory to the Iron and Steel Works of the United States, 1896). Although some zinc remained in the waste produced from the spiegel furnace, nearly all of the contained zinc likely was volatilized given the blast furnace's high temperature. The plant had condensers that were designed to capture impure zinc oxide as it cooled. Additional zinc was collected from accumulations lining stacks, pipes, and other equipment. By one account, the material assayed as high as 85 percent zinc, suggesting that zinc metal, also referred to as "blue powder," had also precipitated in the furnace equipment (Dunn, 1996, p. 870). The recovered material was either

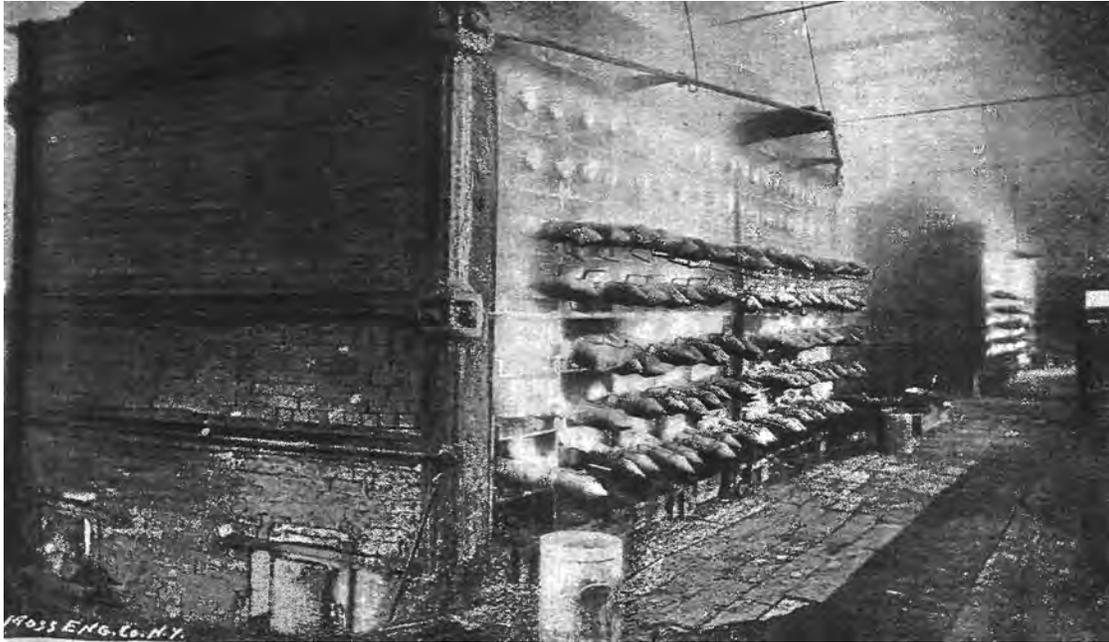


Figure 23. An 1884 photograph of a Belgian furnace containing horizontal retorts at the Passaic Zinc Works, Jersey City, New Jersey. Note prolongs (condensers) attached to the open end of the retort, escaping zinc fumes, and second furnace in the background. Ore was supplied by the mines in the Sterling Hill Mining District in New Jersey. Residuum from the retorts was used to produce a high-manganese iron called spiegeleisen, also known as pig iron (Dewey, 1891).

added to retorts for zinc metal production or to furnaces for the production of zinc oxide. To avoid double-counting, zinc and zinc oxide recovered from the impure compound fed to the furnaces and retorts was not included in the calculations of the Passaic plant's total zinc production.

In 1885, the plant was producing about 11 short tons of spiegeleisen per day using as feed, 2.29 short tons of coal, 2.89 short tons of residuum, 0.63 short tons of limestone, and 25 pounds of scrap (presumably iron-based) (Journal of the Iron and Steel Institute, 1886). In the mid-1880s, it was reported that a single charge to a spiegel furnace consisted of a blend of 1,150 pounds of residuum, containing about 6 percent zinc oxide; 1,000 pounds of anthracitic coal, and 270 pounds of limestone were required, but the proportion of materials varied based on the iron and manganese content of the residuum, and the total tonnage varied depending on the size of the furnace. It was estimated that “blasting” 50-60 charges of these charges would produce 10 tons of spiegeleisen daily. The composition and ratio of approximately 2.2 short tons of residuum to 1 ton of spiegeleisen was nearly the same as New Jersey Zinc's spiegeleisen plant at Palmerton, PA plant in 1892 (Schnabel, 1907). Waste produced from the spiegel furnaces consisted of a slag composed mostly of alumina, iron, calcium carbonate, manganese, and silica. It was observed during the iron-making process that there were losses caused by “escaping gases” (Journal of the Iron and Steel Institute, 1886).

In the late-1890s, the plant was reported to have produced 70 tons of spiegeleisen and recovered 13 tons of

impure zinc oxide per week from the high-manganese-pig iron-making process (Dewey, 1891). Evaluating these data suggests that, although the spiegeleisen statistic is supported by other data, the recovered zinc oxide statistic is likely incorrect. Residuum derived from using franklinite to produce zinc oxide, the feedstock used for producing spiegeleisen, generally contained 6 percent zinc oxide (Schnabel, 1907) which suggests that the zinc oxide contained in the residuum treated in the furnace on a weekly basis was 13 short tons. Examining the zinc oxide production from another spiegeleisen plant, specifically the Palmerton, PA plant, it was likely that approximately 5 short tons of impure zinc oxide, or about 55 percent of the zinc contained in the residuum actually was recovered on a weekly basis with the balance remaining in the slag and emitted to the atmosphere. Plant capacity for 1884 was published as 4,500 short tons of spiegeleisen (Directory to the Iron and Steel Works of the United States, 1884; Schnabel, 1907).

In 1889 and 1890, the plant produced approximately 12.4 short tons of spiegeleisen per day. The product assays averaged about 83.25 percent iron, 11.63 percent manganese, 4.33 percent carbon, 0.69 percent silica, and 0.20 percent phosphorous (Brough, 1893).

In 1892, the plant had the annual capacity to produce 6,000 net short tons of pig iron, or 7,500 gross tons containing 80 percent iron from zinc residuum (Directory of Iron and Steel Works of the United States, 1890).

In 1896, it was reported that the plant's annual capacity was approximately 7,300 gross short tons (5,800 net short

tons) per year of spiegeleisen containing approximately 15–20 percent manganese and over 80 percent iron (Directory to the Iron and Steel Works of the United States, 1896).

Limited published production statistics, anecdotal information relating to interruptions in production and technical problems resulted in an assumption that the plant operated at about 80 percent of its published annual capacity over its operating life, except for 1895 when the plant was closed because of an explosion (Dunn, 1995a, p. 210; Dunn, 1996; p. 873–874).

It was estimated that the plant produced approximately 97,000 short tons of spiegeleisen and recovered about 9,000 short tons of impure zinc oxide (74 percent zinc) containing about 6,500 short tons of zinc, which was used as additional feedstock to retorts and zinc oxide furnaces. To avoid double counting, the zinc oxide produced from the production of spiegeleisen was not included in total production of the facility, however atmospheric emissions of zinc from the spiegel furnaces were included as a component of the plant's total zinc emission estimates.

Total Zinc Production

When the plant was first constructed in 1855 its primary purpose was to produce zinc oxide. Zinc metal was first produced at the facility in 1875 with the installation of Belgian furnaces. Both products continued to be produced until the plant closed in 1901. Total production of zinc and zinc oxide over the life of the plant was estimated at 216,000 short tons of zinc contained in the plant's two primary products, zinc and zinc oxide. The total was made up of 211,000 short tons of zinc oxide (171,000 short tons of zinc) and 45,000 short tons of zinc metal.

Emission Estimates

There were numerous sources of fugitive and stack emissions containing zinc to the atmosphere at the Passaic plant. Sources of fugitive emissions that the production of zinc and zinc oxide shared in common included the unloading of feedstock; crushing, grinding, and drying of ore; and preparing the charge mixtures for zinc oxide furnaces and retorts. Losses from the zinc oxide process included preheating charges, loading, stirring charges during furnacing, and unloading charges; "leakages" in conduits leading to the baghouse, losses in the baghouse, and losses during packaging of zinc oxide.

During the process of producing zinc metal, zinc losses to the atmosphere occurred during breakage and diffusion of zinc through retorts, fumes escaping without condensing and tapping of retorts during reduction; and emptying and cleaning hot retorts at the end of a reduction cycle and loading new charges into retorts.

Losses of zinc to the atmosphere also occurred during the efforts to recover zinc during the production of spiegeleisen through leaks in conduits, escape of zinc from stacks and condensers, and during zinc oxide collection for the purpose of reprocessing in the retorts or oxide furnaces.

Zinc

Based on a limited amount of process data reported by Ingalls in 1903, it was estimated that losses of zinc during preparation of the charge (ore unloading, crushing, grinding, and mixing with coal) and by volatilization during the production of zinc metal from preparing the charge, retorting, tapping and pouring zinc handling ranged from 5 percent to greater than 12 percent (Ingalls, 1903; p. 533). Most of these losses were emitted to the atmosphere through stacks and as fugitive emissions. Additional losses, not related to volatilization, include zinc remaining in retort residues, especially in the presence of sulfur (Ingalls, 1903).

Information pertaining to fugitive and stack emissions related to the production of zinc oxide was limited and relied in part on discussions with chemical and process engineers (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; Robert Kuba, Manager of Technology, Horsehead Corporation, oral communication, 2008) and historical data that suggest losses during this period were approximately 5 percent of production.

Because most of the Passaic plant's production was during a period that the recovery of zinc and zinc oxide used emerging technologies it was assumed that losses were relatively significant. That, and the limited amount of available technical data, it was estimated that approximately 12,500 short tons of zinc equivalents, made up 7 percent (3,000 short tons) of zinc recovered from zinc metal production, 5 percent of the zinc (9,000 short tons) in zinc oxide production, and 3 percent (500 short tons) of the zinc contained in residuum for the production of spiegeleisen was released to the atmosphere as fugitive dust, fumes, and gas over the life of the operation.

Lead

Although lead was present in hardystonite and galena in a relatively large percentage of the ores treated at the smelters, the amount of the minerals was low, which resulted in high-purity zinc products. The average lead content of Franklin Mine ore for the years 1926–29, 25 years after the closure of the Passaic Smelter was reported as 0.049 percent. Galena was present in calcite at the Sterling Mine and was considered a contaminant (Dunn, 1995a; p. 213). A large percentage of any lead contained in minerals accompanying the zinc ores treated at Passaic likely was volatilized and emitted to the atmosphere, a component in zinc oxide and furnace residues. The value of the zinc oxide did not appear to be negatively affected by the presence of lead.

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Newark Zinc Works, Essex County, New Jersey

Introduction

The Newark Zinc Works, located in Newark, N.J. was one of the first commercial zinc oxide plants in the United States. Its location on the Morris Canal allowed for the delivery of coal, ore, and other materials (Dunn, 1996, p. 868) and the shipping of products. It initiated production in 1852 and was owned and operated by the New Jersey Zinc Company (NJZ). The zinc ores mined in the Sterling, New Jersey area were the chief source of feed to the operation. By the time the plant permanently shut down and dismantled in 1910 it had produced spiegeleisen (high-manganese pig iron), zinc metal (spelter), and zinc oxide (Miller, 1941, p. 328–329). The property was sold in 1919 (New Jersey Zinc Company, written commun., 2009).

Over the life of the plant, approximately 310,000 short tons of zinc oxide (containing about 250,000 short tons of zinc) and 22,000 short tons of zinc metal were produced. Nearly 250,000 short tons of spiegeleisen were produced also. Zinc oxide recovered at the spiegel plant served as a portion of the feed to the zinc metal and zinc oxide plants.

It was estimated that a total of approximately 15,100 short tons of zinc equivalents may have been emitted to the atmosphere over the life of the operation.

Map Number (fig. 1)

3

Location

The facility was located on the Passaic River and the Morris Canal in Newark, New Jersey. The approximate coordinates of the plant were N40°43'59" (40.733012); W074°08'27" (-74.140829).

Alternate Names

Newark Zinc Works
Newark Plant

Owner/Operator

New Jersey Zinc Company—1852–80;
New Jersey Zinc and Iron Company—1880–97;
New Jersey Zinc Company—1897–1910 (Dunn, 1995a, p. 210, New Jersey Zinc, 1948).

Years of Operation

The plant's initial production of zinc oxide in 1848 was small and inefficient. It was not considered a commercial success (Dunn, 1995, p. 214) and operated mostly on an experimental basis. The plant initiated commercial-scale operation in 1852 and became established as a significant domestic zinc oxide and spiegeleisen producer by 1855. The Newark plant was never recognized as a large producer of zinc metal at any time in its history; the plant relied on the production and sale of zinc oxide and spiegeleisen for most of its revenues.

The plant continued to operate, essentially uninterrupted, until its closure in 1910 (Dunn, 1995a, p. 214; Jolly, 1994). Production at the plant was phased out as the NJZ smelter at Palmerton, Pa, expanded (Dunn, 1995a, p. 211). The Newark facility was no longer listed in the tables of zinc metal producers published in the USGS Mineral Resources of the United States after 1910.

Primary Products

Zinc oxide (commercial production)—1852–1910
Zinc metal—1860–1910
Spiegeleisen—1855–1910

Capacity and Production

Zinc Oxide

From about 1848–51 the facility operated on an intermittent basis primarily as an experimental plant for treating franklinite to produce zinc oxide. In 1852, the plant entered the commercial stage and produced 1,083 short tons of zinc oxide, followed by 1,805 short tons of zinc oxide in 1853 (Miller, 1941, p. 328). The 1853 annual report by the company's president stated (Dunn, 1996, p. 856) that the plant produced 1,213 short tons of zinc oxide in 1853 and about 2,022 short tons of zinc oxide in 1854. It was reported also in 1854 that the plant's capacity for producing zinc oxide was 50 short tons per week, equivalent to 2,600 short tons per year (Wilson, 1854). The difference in statistics could be explained if Miller's estimates originally were metric, but published subsequently as English units. For the period 1852 through 1860, more than 19,500 short tons of zinc oxide were reportedly produced (Dunn, 1996, p. 857). In 1883, it was reported that the Newark plant had produced 61,480 short tons of zinc oxide from January 1852 to the end of 1875 (Ripley and Dana, 1883).

In 1884, approximately 8,500 short tons of zinc oxide were produced from the furnaces at the Newark plant (Dunn, 1996, p. 870). Based on furnace capacity data, the operation had the capability to produce 9,300 short tons in 1885 (Dunn,

1996, p. 870), suggesting that the plant was operating at near design capacity in 1884. In 1886, 60,000 wooden barrels of zinc oxide were produced (Dunn, 1995a, p. 210). Although not stated in this particular reference, barrels used for most grades of zinc oxide contained approximately 300 pounds of zinc oxide, equivalent to a total of about 9,000 short tons; although barrels sometimes were used that could contain 150–200 pounds of zinc oxide, which would result in a significantly lower total annual production of 4,500–6,000 short tons (United States Bureau of Standards, 1917).

An estimate of zinc oxide produced over the operation's life is based on a number of major assumptions since actual production data for many of the years the plant operated were not available in the literature. Using the limited amount of published data on capacity and production over the zinc oxide plant's period of operation from 1852–1910, it was assumed that the plant's expansions were proportional to expansions of the spiegeleisen facility occurring in about 1870 and again in 1886. Using this assumption, and published data for certain years or range of years, the zinc oxide plant's total production was 19,600 short tons for the years 1852 through 1860, estimated 4,000 short tons capacity per year of zinc oxide 1861 through 1869; for the years 1870–84 capacity was estimated to be 8,000 short tons of zinc oxide per year; and from 1885 through 1910 capacity was estimated at 9,000 short tons of zinc oxide per annum based on published data (Dunn, 1995a, p. 210). Using these estimates and actual production statistics, and assuming a plant utilization rate over the life of the zinc oxide plant of 80 percent of plant capacity, it was estimated that total zinc oxide production was roughly 310,000 short tons of zinc oxide containing approximately 250,000 short tons of zinc. Specific occurrences and factors that can negatively effect production such as technical problems (especially in the first years of the plant's long history), labor issues, and economic downturns were not available. The estimates include zinc oxide recovered in the spiegeleisen plant and reprocessed in the zinc oxide or zinc metal plant.

Zinc Metal

Except in a few cases, production-related statistics and data related to zinc metal production data were not reported in the researched literature. The lack of information may be a result of company policy, inactivity, incomplete reporting, or small production. The zinc metal plant operated as a small experimental facility using impure zinc oxide as feed that was recovered from manufacturing spiegeleisen, but by 1864 the plant was operating on a larger-commercial basis (Dunn, 1996, p. 215; Miller, 1941, p. 329).

It was reported that the Newark plant had produced 5,980 short tons of spelter during a period from mid-May 1864 to the end of 1875 (Ripley, 1883), an annual average of about 500 short tons of zinc.

In the mid-1880s, the plant was reported to possess an estimated annual capacity of 1,137 short tons of zinc (U.S. Geological Survey, 1885, p. 476), or 2.7 short tons of zinc per

retort annually. It appears from this statistic that the plant did not realize more than 50 percent of its stated capacity.

In 1886, 450 short tons of spelter was reportedly produced, with the operation described as small and relatively inefficient (Dunn, 1995a, p. 210). Using these data, and the experimental nature of the plant in most of its first decade of operation, it was estimated that the plant produced an average of 375 short tons of zinc metal per year 1860–75 (lesser amounts in the earlier years) and 450 short tons annually 1876–1910. It was assumed that there was an expansion to coincide with that in other parts of the plant. Based on these data and estimates, total zinc metal production over the operation's life was calculated to have been roughly 22,000 short tons. The estimate includes zinc oxide recovered in the spiegeleisen plant and reprocessed in the zinc oxide or zinc metal plant.

Spiegeleisen

Spiegeleisen, a high-manganese iron alloy and known more commonly today as pig iron, was produced in 1855 from zinc-depleted franklinite ore residues removed from the zinc oxide furnaces. In 1856, during a 21-week period, the furnace used 1,631 short tons of residuum and produced 552.5 short tons of spiegeleisen and 77,255 pounds of zinc oxide (Dunn, 1995a), suggesting a 35 percent zinc recovery based on 6 percent zinc oxide in residuum. The balance was contained in slag and lost as atmospheric emissions.

In 1870, approximately 4,000 short tons of spiegeleisen were produced annually (Dunn, 1995a, p. 216) at the Newark plant. It was assumed that this estimate pertains only to this facility, because spiegeleisen was not produced at the company's Palmerton plant until 1881 (Hall, 1915). A field report written in 1880 stated that the Newark plant was shut down in 1879, but the length of the closure was not stated (Strecker, 1880). It was assumed for this analysis that the closure was brief, as no mention of the closure was found in other literature. In 1885, the addition of a second furnace at the site was planned by New Jersey Zinc (Dunn, 1996; p. 870) and was probably built because production in subsequent years increased.

In 1886, the operation reported that it had produced 6,500 short tons of spiegeleisen from zinc oxide furnace clinker containing 3–11 percent zinc oxide, and averaged 6 percent zinc oxide (Dunn, 1995a, p. 210; Dunn, 1996, p. 873). In 1887, the plant had a reported capacity of 7,500 short tons of spiegeleisen (AISA, 1888).

Calculating the total amount of spiegeleisen produced over the life of the property with little capacity and production statistics was problematic. It was assumed that production of spiegeleisen from 1856 through 1869 was relatively low; perhaps on the order 1,400 short tons per year (spiegeleisen production in 1855 was estimated to be 700 short tons). Based on Dunn, 1995 (Dunn, 1995a; p. 216), it was assumed that beginning in 1870, 4,000 short tons were produced annually through 1885, and that 6,500 short tons per year was produced

from 1886 through 1910. Using these estimates, approximately 247,000 short tons of spiegeleisen was produced over the life of the operation. Approximately 16,000 short tons of zinc contained in about 20,000 short tons of impure zinc oxide was recovered in the condensers and flues based on an average of 45 percent recovery of the 6 percent zinc oxide in clinker, a ratio of 2.94:1 clinker to spiegeleisen, and total spiegeleisen production (247,000 short tons). The zinc oxide was returned as supplemental feed for the zinc metal and zinc oxide plant.

Primary Feed Source and Ore Types

For the period 1852 through at least 1896, virtually all of the primary feed to the operation was derived from the NJZ company-owned mines in the Sterling area of New Jersey (Dunn, 1995a, p. 109). For example, in 1896, an average of 2,500 tons per month of ore, averaging 32 percent zinc, were reportedly produced from the Buckwheat (Taylor) mine of which 1,900 short tons was sent to the Newark plant. The balance was sold on the market (Dunn, 1995b, p. 829-830).

Feed and Technology

The feed and technology discussion have been combined in this summary because during the period that the plant operated, technological innovations developed that permitted changes in feed types and processing. No roasting was necessary for any of the feed since the ore minerals supplied from the company's mining operations in New Jersey were non-sulfidic consisting of zinc oxide (franklinite and zincite) and zinc silicate (hemimorphite) minerals. Up until the last decade of the 19th century, feed was primarily franklinite, with subordinate willemite and zincite. In the year 1896, the plant processed about 1,900 short tons of ore per month grading 32 percent zinc (Dunn, 1995b, p. 830).

With the advent of magnetic separation (Wetherill process) in the late-1890s, three mineral concentrates were produced from ores extracted from the mines in the Franklin and Sterling District, New Jersey. The concentrates and their primary use were, franklinite used for zinc oxide and spiegeleisen; willemite used for spelter; and a mixed concentrate, which was further worked for its valued constituents (franklinite and zincite) using gravity methods, such as jigs and tables and fed to the appropriate process (Dunn, 1995a, p. 198).

The iron-manganese rich residuum, also termed clinker, remaining from smelting franklinite for the production of zinc oxide served as the feed to the spiegel furnaces for producing spiegeleisen or pig iron.

Zinc Metal

In 1860, the first year of experimental spelter production, no ore was used as feed. Rather impure zinc oxide recovered from the zinc oxide furnace chimneys, flues, and iron cooling chambers were used. The zinc oxide collected from the condensers and flues in the spiegel plant may also have served

as feedstock. The mixture charged to the horizontal retorts in the furnaces was based on a ratio of 30 pounds of impure zinc oxide to 12 pounds of coal (Dunn, 1995a, p. 215). The impure zinc oxide material probably contained about 75 percent zinc or higher. Miller reported that the plant produced the first domestic commercial zinc spelter beginning in 1865 by using zinc oxide recovered from the spiegeleisen plant (Miller, 1941, p. 329) which is corroborated by an internal NJZ report. In 1866, spelter was produced experimentally from willemite ore (Miller, 1941, p. 329) and proving commercially viable continued to be used to produce spelter in the ensuing years (Dunn, 1995a; p. 215). In 1884, there were reportedly 7 Belgian retort furnaces, containing a total of 416 horizontal retorts (U.S. Geological Survey, 1885, p. 476), which at 2.7 short tons of zinc produced per retort per annum, had an annual zinc capacity of about 1,100 short tons. Dunn quoted a report written in the year 1885 stating that the spelter furnace only used zinc residues collected from the spiegeleisen plant to produce zinc metal (Dunn, 1996, p. 871, Second Supplement), which assayed about 85 percent zinc (zinc dust and zinc oxide), but this was not consistent with other data sources and could not be resolved. It may not have been referring to the use of all of the furnaces in this manner. The USGS reported that the zinc plant closed in 1905 (U.S. Geological Survey, 1906), but was not clear if it was intended to mean temporary or permanent closure. Corroborating data was not discovered and it was assumed that the plant continued to operate until the plant permanently closed in 1910.

Zinc Oxide

Zinc oxide was produced using the Wetherill process which, in broad terms, relied on a furnace to vaporize the zinc contained in the ore and a baghouse to capture condensed zinc oxide as flakes using filtration of furnace gases through large cotton or wool bags. The plant likely employed the use of a stationary-grate furnace, which produced more fugitive and stack emissions than the traveling grate because the furnace charge was allowed to fumes up a stack to the atmosphere as it climbed to optimum temperature before directing zinc-laden gases to the baghouse and because the stationary furnace needed to be manually loaded, charge stirred, and unloaded after completion of the furnace cycle, which allowed dust, fumes, and gas to escape. The traveling grate used as a way to continuously feed and empty the zinc oxide furnace increased the efficiency of zinc oxide production, partly by decreasing zinc emissions, but did not come into popular use until the 1920s. A mixture of franklinite, willemite, and zincite ores were used to produce zinc oxide beginning in the mid-1860s (Ingalls, 1903, p. 303). The primary constituent of the feedstock transitioned to franklinite by the mid-late 1890s with the advent of magnetic separation at the beginning of the 20th century. Some hemimorphite from the Franklin-Sterling District of New Jersey may also have been used in the earliest years of the operation to produce zinc oxide and it is possible

some small amounts of ores were shipped to the plant from Pennsylvania.

“Dirty” pea coal was used in the mixture as a fuel source to generate heat. Pea coal was a term to describe a low-value coal product produced from the screening of anthracite coal that produced a relatively large amount of ash, but was low in sulfur content. A layer of 1.5 inches of pea coal was loaded onto the grate at the bottom of the furnace upon which a charge consisting of 400 pounds of ore mixed with 200 pounds of coal was placed. The coal was ignited and when the optimum temperature was reached as evidenced by the formation of zinc fumes in the furnace, a flue was opened. The opening permitted a draft, generated by fans, to direct the zinc fumes and other gases through condensing chambers where flakes of zinc oxide formed by cooling and oxidation. The draft carried the flakes to a bag room in which the flakes were captured in cotton or wool bags as the plant’s zinc furnace emissions passed through the pores of the material making up the bags. In the mid-1880’s, zinc oxide was produced from 128 furnaces, each yielding 100 pounds of zinc oxide from each charge. Four charges could be run over a 24 hour period per furnace. Dunn described the production of zinc oxide at the Newark facility in detail as it existed in 1885 (Dunn, 1995a).

Spiegeleisen

A small blast furnace with one stack was built in 1855 to produce spiegeleisen by smelting the zinc-depleted iron-rich furnace clinker remaining from the production of zinc oxide (Dunn, 1995a, p. 216). This occurrence marked the first spiegeleisen production in the domestic zinc industry. Spiegeleisen, an alloy of iron, containing approximately 15 percent manganese (but could range from 10-20 percent) (Penrose, 1891) and small quantities of carbon (burned and unburned coal) and silicon, was a commodity desired by iron and steel manufacturers for strengthening their products. The zinc oxide content of the furnace clinker used in the production of spiegeleisen generally averaged 6 percent (Dunn, 1996, p. 870), but ranged from 3 to 11 percent (Dunn, 1996). About half of the zinc contained in the clinker was fumed in the spiegel-blast furnaces and the balance remained in the slag. The clinker assayed approximately 25 percent iron.

Oyster shells from local restaurants were used as flux in the process (Strecker, 1880; p. 416 and 417). Dunn reported that in 1856, significant amounts of zinc were lost during the production of spiegeleisen (Dunn, 1996). In 1856, during a 21-week period, the furnace used 1,631 short tons of residuum and produced 552.5 short tons of spiegeleisen and 77,255 pounds of zinc oxide or about 2.95 tons of residuum to produce one ton of high-manganese pig iron and recovered about 110 pounds of zinc in impure zinc oxide (Dunn, 1996, p. 856), which contained approximately 74 percent zinc. Using these data and estimates, approximately 44 percent of the zinc contained in the residuum was recovered and the balance was contained in the slag or lost through emissions. For the purposes of estimating overall zinc recovery and losses,

this factor was used in calculations through the year 1869. By 1870, the approximate time that the plant underwent modification, zinc oxide recovery was assumed to have improved to 55 percent. Although the zinc oxide was valued for its metal value and recycled in retorts and furnaces, accumulations in the earlier equipment caused the spiegeleisen furnace to be shut down once a week to clean out the thick accumulations of impure zinc oxide that formed in the system. If not removed the material would impede exhaust flow in the chimney and flues. During this period the spiegel furnaces were small and operated irregularly needing to be cleaned out frequently (Journal of the Iron and Steel Institute, 1886). The frequency was not reported.

In 1882, zinc oxide content in zinc oxide furnace clinker was reported as 3-4 percent zinc oxide (Dunn, 1996, page 868), and in 1885, zinc oxide content in clinker was estimated at 6 percent zinc oxide (Dunn, 1996; p. 868; 870). In the same year the plant was described as emitting vaporized zinc from the top of the furnace’s chimney as a “dense white cloud” (Dunn, 1996, p. 870). Relatively large amounts of zinc oxide and zinc powder were recovered, as crusts formed in flues and pipes and in condensers (Dunn, 1996; p. 870).

In 1883, a stack (30 feet tall and 8 feet in diameter) was constructed to replace one built in 1871, and in 1885 a new stack was built (31 feet tall and 8 feet in diameter) to replace stacks built in 1855 and 1863 (American Iron and Steel Association, 1888).

Based on a description provided by Dunn (Dunn, 1996; p. 871), the estimated material requirements in 1885 to produce one ton of spiegeleisen at the facility included 1.3 short tons of anthracite coal, 1.6 short tons of clinker or residuum from the zinc oxide furnace, and 500 lbs of limestone. A charge to the spiegel furnace at the Newark plant contained 1,000 pounds of anthracite, 165 pounds of limestone, and 1,200 pounds of clinker. Production during this period was stated as 10 short tons of 25 percent manganese in spiegeleisen per furnace per day (Dunn, 1996). Clinker from the zinc oxide furnaces generally contained approximately 6 percent zinc oxide (Dunn, 1996). The addition of a new furnace in the 1880s of a more advanced design may have improved zinc oxide recovery to about 50 percent. Spiegeleisen furnaces built around this period were equipped with redundant systems allowing the furnace to operate while one set of flues, pipes, and other equipment could be cleaned.

It was reported also that by the mid-1880s there were two recently-built spiegel furnaces operating that were capable of producing 9 and 10.75 short tons of spiegeleisen, respectively. The smaller furnace could accommodate a charge of 900 pounds of coal; 1,200 pounds of residuum from the zinc oxide furnaces, and 275 pounds of limestone. The larger and newer furnace was more efficient. It was charged with 900 pounds of coal, 1,275 pounds of residuum from the zinc oxide furnaces, and 300 pounds of limestone (Journal of the Iron and Steel Institute, 1886).

A report written in 1892 described the nearby Passaic smelter that used a similar furnace design. The Passaic plant

produced 70 short tons of spiegeleisen and recovered 13 short tons of zinc oxide per week from the iron-making process, based on 50-60 charges of 1,500 pound loads of residuum processed per day (Bulletin of the United States National Museum, 1892). The ratios of spiegeleisen production per unit of feed were essentially the same (Dunn, 1996; p. 870), since both used franklinite as their primary feed for the production of zinc oxide.

Emission Estimates

The sources of atmospheric fugitive and stack zinc emissions at the plant included manual, mechanical, and pyrometallurgical processes used to produce spiegeleisen, zinc metal, and zinc oxide; however no quantitative data related to losses of zinc at the Newark plant were encountered in the literature.

Sulfur emissions were likely low because of the low sulfur content of anthracite used as a reductant and the relatively rare incidence of sulfide minerals accompanying the ore.

In addition to zinc, other metals that could have been potentially injurious to human health and the environment such as arsenic, cadmium, copper, lead, and tungsten, were only present in Franklin-Sterling ores in small amounts when taken as a whole, but there were zones within the ore bodies from which extracted ores contained anomalously high levels of these metals. The company's reputation of producing high purity zinc products are evidence of the overall "clean" nature of the feedstock.

Zinc Emissions

The Newark plant operated during the initial development of the domestic zinc industry. Using new and adapted technologies to treat the unconventional ores extracted from the Franklin-Sterling District in N.J., atmospheric losses of zinc generated by fugitive and stack emissions were relatively high per unit of product. Losses likely ranged from 5 to 8 percent of zinc production (Ingalls, 1903). Sources of atmospheric emissions generated prior to retorting or treatment in the zinc oxide furnace emissions to the atmosphere included dust generated by unloading, crushing, grinding, and drying and blending feedstock with anthracite and other materials. Greater zinc losses were experienced in the process steps for recovering zinc by reduction and distillation in retorts and zinc oxide using furnaces and baghouses, including packaging of zinc oxide.

It was estimated that a total of approximately 15,500 short tons of zinc contained in dust, fumes, and gas was released to the atmosphere during the production of spiegeleisen, zinc metal, and zinc oxide.

Zinc Metal

In 1917, approximately 4.1 percent of the zinc contained in feed to the retorts was estimated to have been lost as volatilized zinc emitted through broken and cracked retorts,

chimneys, and other avenues of escape to the atmosphere during the distillation process in the retorts (Hofman, 1922, p. 208). This estimate did not include roasting, sintering, and other steps prior to reduction.

In the 1940s, approximately 2.5 percent of the zinc placed in the retorts was lost to the atmosphere. This estimate accounted for losses by diffusion through retorts, volatilization of zinc from broken and cracked retorts, through chimneys during initial heating, and during tapping of molten zinc (Liddell, 1945, p. 458). Additional losses were experienced during charge preparation and handling of material, and if roasting and sintering were required.

Considering that these estimates are more recent and the state of the technology in the late-1800s was one in which retorts frequently broke, furnaces failed, and the entire process was less efficient and more labor intensive, zinc losses through atmospheric emissions at the Newark plant likely reached 6 percent of the amount of zinc produced or approximately. Based on the types of feed and equipment used, the range of years the plant operated, the products produced, and using the limited amount of available data, it was estimated that an amount equal to about 6 percent of recovered zinc or about 1,500 short tons of zinc was released to the atmosphere as fugitive dust, fumes, and gas over the life of the operation.

Zinc Oxide

As discussed earlier, most of the fugitive zinc emissions related to zinc oxide production originated prior to furnacing and were generated from unloading, crushing, grinding, drying, blending feedstock with anthracite and other materials, and from grinding and packaging the zinc oxide product into barrels. Stack and fugitive zinc emissions released to the atmosphere from the furnace during actual zinc oxide production originated from escaping fumes during initial heating of the zinc feedstock in the furnace prior to directing the fumes to the baghouse, leaks in conduits and bags, during the loading, stirring charges during furnacing, and raking the charge onto the furnace grate and emptying the furnace.

During the late-1960s more efficient technologies using a traveling grate and treating similar ores lost approximately 3.5 percent of the zinc through fugitive and stack emissions (see the discussion of the Palmerton plant). Considering the experimental nature early in the operating life of the Newark plant and lower efficiencies as technologies for recovering zinc oxide were developing, it was estimated that approximately 5 percent of the zinc or 12,500 short tons was emitted to the atmosphere as dust, fumes, and gas during the 59-year period that the facility produced zinc oxide.

Spiegeleisen

The production of spiegeleisen, a high-manganese pig iron, also contributed to emissions. Although not quantified in the literature, the operation was described anecdotally as emanating white clouds of zinc fumes from the stacks of the spiegel furnace during the iron-making process (Journal of

the Iron and Steel Institute, 1886). In 1855, the Newark plant was described as losing a large amount of zinc through the chimney of the spiegel furnace (Dunn, 1996; p. 856). It was conservatively estimated that approximately 1,500 short tons of zinc contained in dust, fumes, and gas was emitted to the atmosphere during the production of spiegeleisen and handling the recovered impure zinc oxide for recycling in the retorts or zinc oxide furnaces. The estimate was based on limited information pertaining to: (1) spiegel production; (2) the amount of clinker required per unit of spiegeleisen recovered and the zinc content of clinker from the zinc oxide furnaces; (3) and the amount and grade of slag remaining from spiegeleisen production; and (4) the amount of zinc oxide recovered from the spiegel furnaces.

Lead

Although lead was present in hardystonite and galena in the Franklin ores treated, there is little information pertaining to the amounts on the tonnage and grade. The average lead content of the Franklin Mine ore for the years 1926–29, 25 years after the closure of the smelter was reported as 0.049 percent. Galena was present in association with calcite at the Sterling Mine and was at times considered a contaminant that affected the purity and therefore the value of the company's zinc product (Dunn, 1995a, p. 213). The total amount of lead released to the environment was relatively low.

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Bamford Spelter Plant, Lancaster County, Pennsylvania

Introduction

The original plant at Bamford, Pennsylvania was built in the 1850s and produced zinc oxide for about two years. A zinc metal (referred to as spelter in the operation's contemporary reference sources) plant was constructed at the same location in the 1870s and produced for approximately 5 years. Both operations, located near Lancaster, PA (Miller, 1924 p. 14), relied on locally mined silicate (hemimorphite), carbonate (smithsonite), and sulfide (sphalerite) ores as feedstock for the plants (Miller, 1924 p. 49-50). Neither operation appeared to be economically successful, and from available statistical data, never achieved plant-design capacities.

Nearly 40 short tons of zinc were released to the atmosphere as fumes, gas, and vapor through fugitive and stack emissions as a result of producing approximately 500 tons of zinc in metal and zinc oxide. Considering historical ore assays, it is likely that cadmium, lead, and sulfur were also emitted to the atmosphere, especially during roasting. Mercury also was a likely component of the atmospheric emissions. Samples of the ore were determined to contain 15 parts per million mercury (Jolly and Heyl, 1968). Sulfur emissions probably were quite considerable for the short period the site treated sphalerite as the chief ore mineral.

Map Number (fig. 1)

4

Location

The plant was located in close proximity or within the city of Bamford, Pennsylvania at N40°05'05" (40.084726); W076°23'23"(-76.389882).

Alternate Names

1855—Lancaster Zinc Company (Miller, 1924, p. 49).
1872—Bamford (Bamfordville) Zinc Mine and Spelter Plant (Miller, 1924, p. 49).

Years of Operation

Zinc oxide production—1855–56 (Miller, 1924, p. 49)
Zinc metal production—1873–77 (Miller, 1924, p. 53)

Owners/Operators

1855–1872—Lancaster Zinc Company;

1872–1883—Charles Bamford;

1883 – Leased from Charles Bamford by the Lehigh Zinc and Iron Company (LZIC). The LZIC relinquished the property back to Charles Bamford after ten months (Miller, 1924, p. 49).

Primary Products

Zinc oxide—1855–56.

Zinc metal—1873–76. The zinc, considered relatively pure for the time period, averaged 99.687 percent zinc, 0.034 percent cadmium, 0.262 percent lead, 0.017 percent iron, and a trace of copper. (Miller, 1924; p. 53).

Feed

The ore feed was derived locally from small surface and underground mines (Robert Smith II, geologist, Oral communication Pennsylvania Geological Survey- August. 9, 2004). Smithsonite ore, referred to in the literature as calamine, was the original zinc ore mineral of economic interest at the site. At first it was mined from the surface and at the uppermost part of the underground portion of the mines. As mining progressed underground, however, the ore body became less oxidized and transitioned into ore minerals consisting predominantly of sphalerite with subordinate smithsonite. An assay of sphalerite at one of the company's mines yielded 65.87 percent zinc, 32.28 percent sulfur, 0.81 percent iron, 0.34 percent lead, and 0.07 percent cadmium (Miller, 1924, p.51). Assays of ore, representing about a year's production, however, averaged much lower at 11-12 percent zinc (Smith II, 1977, p. 25) mostly because of the high dilution from limestone that accompanied the sphalerite. Other minerals found in association with the zinc ore included galena, tennantite, and dolomite (Miller, 1924, p. 51). The zinc plant at Bamford also received some minor amounts of smithsonite from the Sinking Valley area in 1876 (Miller, 1924, p. 14).

Capacity and Production History

A report evaluating the inactive mines in the Bamford area estimated that mining activity at Bamford removed a total of 25,000 short tons of ore and waste, while another appraisal of the area estimated that 67,000 short tons of ore was extracted (Smith II, 1977, p. 25). The Pennsylvania Geological Survey estimated the total amount of the zinc contained in the ore mined at Bamford by assuming that 10,000 tons of ore was extracted which contained an average of 12 percent zinc, equivalent to 1,200 short tons of zinc (Smith, 1977, p. 25). If the average zinc recovery in the course of zinc metal and zinc oxide production was 75 percent, approximately 900 short tons of zinc contained in oxide and sulfide ore was potentially produced and sold from ores extracted from the Bamford area.

However, the actual percentage of the total amount processed at the Bamford plant is not known.

Zinc oxide production at Bamford was initiated in 1855, when 10 furnaces with a combined design capacity of one short ton/day of zinc oxide were constructed (Miller, p. 49, 1924). From the literature researched, however, the capacity appears to have never been achieved. Although actual zinc oxide production data was not available, sales of zinc oxide from the plant was nearly \$2,000 for the 6 months the plant operated in the year 1855 (Miller, 1924; p. 49). With a market value of approximately 7 cents per pound for high-quality zinc oxide in the mid-1850s (Dunn, 1995; Jolly, 1994, p. 126) it was estimated that a total of approximately 14 short tons of zinc oxide was produced and a total of 42 short tons was produced during the 1.5 years the plant operated. Although no production data was stated, a report written in 1892 stated that Bamford produced zinc oxide during a period between 1850 and 1860 (J.P., Lesley, 1892).

The site remained idle until 1872, when a roasting plant and a Belgian furnace containing horizontal retorts were built for the production of zinc metal. A report on site visit in 1876 stated that the retorts daily yield was 1,500 pounds per day of zinc (Miller, 1924, p. 50). At some point in the plant's production history 244 retorts operated for a few years (Smith, 1977). With this number of retorts, 500 short tons of zinc metal may have been produced annually. Limited annual production data suggests that productivity at Bamford was actually quite lower. A report written in 1876, suggests that the operation operated intermittently because of interruptions in the supply of feedstock (Miller, 1924).

Zinc metal production in 1873 was reported as 20 short tons; in 1874, 86 short tons; in 1875, 164 short tons; and in 1876, 87 short tons (Miller, 1924, p. 53). In the year 1883, it was reported that Bamford's spelter production in 1875 was approximately 60 short tons (Ripley, G., and Dana, C. eds., 1883). No zinc production data was available for the years 1872 and 1877.

The mine and facilities closed in 1877 because of poor economics caused by low ore grades and high water pumping costs (Miller, 1924, p. 50). The mine was rehabilitated in 1883 under lease by the Lehigh Zinc and Iron Company, but closed the same year without any reported production (Miller 1924, p. 49).

Published production statistics from the zinc and zinc oxide plants totaled nearly 400 short tons of contained zinc. It was assumed that production over the life of the property totaled approximately 500 short tons by including the two years, 1872 and 1877, that data was not available, in which a total of an additional 100 short tons was possibly produced.

Technology

In 1855, the facility reportedly constructed 10 furnaces for the production of zinc oxide, with a total capacity of 1 short ton per day of zinc oxide and based on available literature, operated for only two years (Miller, 1924, p.49). The

plant's design capacity appears to have never been achieved. Smithsonite was the primary feed for the plant, but feed derived from the roasting of sulfide ore may have occurred for a brief period following depletion of the carbonate ore.

The site remained idle until 1872, when a mill and smelter to produce zinc metal was constructed under Bamford's direction. The plant was similar in design to that used by contemporary operations at South Bethlehem, Pa. Sphalerite ore was initially hand picked from the local mine, also owned by Bamford, but as the ore grade decreased with depth it required upgrading by jigging, a gravity separation method. There were two-double hearth furnaces and two single-hearth furnaces for roasting. Gases, dust, and fumes generated from the roasting process were emitted directly to the atmosphere, as there were no settling chambers or acid plant.

The zinc metal plant used a roaster and Belgian furnaces consisting of four furnaces in 1 block, each with 56 retorts, for a total of 244 retorts. Based on other operations recovering spelter during this period, approximately 500 tons of zinc per year could be expected at 80 percent capacity utilization, suggesting that the site suffered from lack of feed and or economic and technical problems or both. The plant's retorts measured 4.75 feet long and 8.25 inches in diameter and were charged with a mixture of ground and roasted sphalerite and coal dust. Production suffered at times from lack of feed (Miller, 1924, p. 50). The zinc metal produced at the plant was considered very marketable because of its high purity. An analysis of the zinc assayed 99.68 percent zinc, 0.034 percent cadmium, and 0.262 percent lead (Miller, 1924, p. 53).

Supplying ore to the smelter became increasingly difficult as ore reserves became increasingly depleted and water problems were encountered with increasing depth at the mines. As a result, the smelting facilities closed after only a few years of production (Smith II, 1977, p. 31). It is unlikely from empirical and statistical data that the plant was ever fully utilized or very efficient. A photograph of the remnants of the Bamford Zinc Works taken around 1900 (Smith II, p. 19) shows a furnace stack about 70 feet in height.

Zinc Emission Estimates

There were several sources of fugitive and stack zinc emissions released to the atmosphere. The major sources included the processing of ore prior to roasting, roasting, charge preparation for zinc oxide furnaces and retorts, and furnacing for zinc metal and zinc oxide. Although the plant operated for only a short period of time and production was quite small there appears to have been lasting environmental affects caused by the plant's operation more than 100 years ago. Stunted and chlorotic plant growth west of the Bamford plant site has been attributed to contamination caused by the Bamford operation's roaster, zinc metal, and zinc oxide facilities (Smith II, 1977, p.31–32; Rosen and others, 1978, p. 151). Chlorosis develops when a plant cannot produce chlorophyll. The disease can develop from a wide range of conditions such as lack of essential minerals, attack by infection or infestation,

and air pollution. In the case of the Bamford site, the disease was (and perhaps still is) apparently caused by zinc replacing magnesium during uptake by root systems (Smith II, 1977). Rosen and others (Rosen and others, 1978) detected zinc soil levels as high as 50,000 parts per million (5 percent).

The estimates of zinc recovery and losses of zinc resulting from the manufacture of zinc and zinc oxide were based on general historical data and discussions with industry experts. Losses of zinc to the atmosphere resulted from fugitive and stack emissions. These included unloading feedstock, crushing, grinding, roasting, preparing the charge, furnacing (including loading, stirring charges during furnacing, and unloading stationary-grate furnaces), losses from fractured and broken retorts, losses in conduits and the baghouse, and product handling for the production of zinc metal and zinc oxide. Based on analogous operations and discussions with zinc industry experts, the total losses during processing of the ore likely ranged from 5 to as much as 12 percent (Ingalls, 1903, p. 533; Robert Kuba, Manager of Technology, Horsehead Corporation, oral communication, 2008; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008) of the contained zinc. Most fugitive and stack emissions during the production of zinc oxide occurred during the unloading of ore, crushing, grinding, and mixing with anthracite or coal; and loading, stirring charges during furnacing, and unloading the stationary-grate furnaces, leaks through conduits leading to the baghouse and in the bag room. Losses also occurred during the preparation and packaging of zinc oxide product.

During zinc metal production, zinc and other materials were emitted to the atmosphere as fugitive and stack emissions through broken and fractured retorts, passage of zinc through porous retorts, losses during retort poor fitting condensers and fumes control, and during removal and cleaning of retorts. Considering these factors common to Belgian furnaces and the apparent inefficiencies of the Bamford operation approximately 8 percent of the zinc produced or nearly 40 short tons was lost to the atmosphere as fumes, gas, and vapor through fugitive and stack emissions.

Considering historical ore assays, it is likely that arsenic, cadmium, lead, and sulfur were emitted also to the atmosphere, especially during roasting. Sulfur emissions were probably quite considerable for the short period the site treated sphalerite as the chief ore mineral.

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South Bethlehem Zinc Smelter, Northampton County, Pennsylvania

Introduction

The South Bethlehem plant, also often referred to in literature as the Lehigh Zinc and Iron Company or Lehigh Zinc Works, was located in the city of Bethlehem, Pennsylvania, referred to in some of the early literature as Augusta, Pennsylvania. The plant was built on the west side of the Bethlehem Iron Company's iron works along the south bank of the Lehigh River. It was the second commercial zinc oxide production facility in the United States, following the New Jersey Zinc Company's Newark plant that opened two years earlier (Octagon, 2005) and was the first in the United States to commercially produce spelter (slab zinc) on a large scale and the first to produce sheet zinc (Hall, 1915).

The plant first went into production in 1853 as a zinc oxide plant. However, the plant evolved rapidly from a relatively small single-product operation into a large multi-product facility. The facility initially relied primarily on local ores from the nearby Friedensville District, Pennsylvania for its feedstock and later from the Sterling, New Jersey District. By the 1870s, the Lehigh Valley was considered the center of the American zinc industry (Wildlands Conservancy, 2007). Smithsonite, hemimorphite, and roasted sphalerite comprised the initial plant feed. Most of the roasted zinc sulfide ore was processed into zinc metal, referred to as spelter in historical literature, while the zinc carbonate and silicate ores generally were processed into zinc oxide (Miller 1941, p. 333), often referred to as zinc white in the literature of the day. By the late-1870s the company was confronted with rapidly increasing mining costs, depletion of carbonate and silicate ores, and increasing dependence on the remaining sulfide ores, with the technical and social problems inherent in treating them. In order to remain competitive the company was forced to switch to processing ores from New Jersey, chiefly franklinite for zinc oxide and willemite for slab zinc.

The plant was managed in the early years by Samuel Wetherill, who was succeeded by Joseph Wharton, two of the leading developers of the early U.S. zinc industry. The plant permanently shut down in 1911. It was estimated, based on limited data, that the South Bethlehem plant produced approximately 146,000 short tons of zinc as metal and zinc contained in zinc oxide and emitted approximately 6,700 short tons of zinc to the atmosphere in dust, fumes, and gas. Figure 24 shows photographs of the plant in South Bethlehem, PA taken circa 1905.

Map Number (fig. 1)

5

Location

The plant was located in South Bethlehem (a section of present-day Bethlehem, PA), Pennsylvania at approximately N40°36'39" (40.610833), W075°22'00" (-75.366667).

Alternate Names

Lehigh Zinc and Iron Company (Henry, 1860)
Lehigh Zinc Works (Ingalls, 1903)
South Bethlehem Zinc Smelter (Jolly, 1994)

Years of Operation

1853 (Dunn, 1995a, p. 172); MR, 1912).

Plant Ownership During Production Years

1853–55—Zinc Works (Hall, 1915)
1855–60—Pennsylvania and Lehigh Zinc Company (Hall, 1915).
1860–81—Lehigh Zinc Company (Hall, 1915)
1881–97—Lehigh Zinc and Iron Company (Hall, 1915; Dunn, 1995a)
1897–1911—New Jersey Zinc Company (Internal NJZ report)

Primary Products

Zinc
Zinc oxide
Spiegeleisen
Specialty zinc-based products

Feed Sources and Ore Types

The sources of feed to the South Bethlehem plant were dominated by two districts; the Friedensville District, Pennsylvania which supplied feedstock from 1853 to about 1876 and the Sterling District in New Jersey from about 1876 until the plant's closure in 1910.

The South Bethlehem plant was constructed originally to treat the hemimorphite and smithsonite ores discovered in the Lehigh Valley of Pennsylvania in the 1850s (Henry, 1860; p. 236). These ores were eventually developed into surface and underground mines comprising the Friedensville District. As exploitation of the ore bodies continued, the relatively easily-mined open pit and shallow underground mines were developed into deeper higher-cost underground mines (figure 20). With the deepening of the mines the ore became less altered and sphalerite mineralization began to dominate production. From the years 1859 through 1876 the smelter received Friedensville ores, consisting primarily of zinc



Figure 24. Photographs of the zinc smelter located in South Bethlehem, Pa., circa 1905. Note the plant emissions originating from the buildings that contained the horizontal retort furnaces and other facilities, probably the crusher, dryer, and roaster plants. Steam plumes generally dissipate quickly as opposed to other atmospheric emissions which diffused in the valley. Stockpiles of ore are visible in the lower photograph. The label on the lower photograph “Zinc and Iron Works” refers to the zinc products and the spiegeleisen (pig iron), a high-manganese iron, that was also produced at the plant. Photographs provided courtesy of The Bill Weiner Collection, Bethlehem, Pa.

silicates and carbonates grading approximately 47 percent zinc with subordinate sphalerite, grading approximately 47 percent zinc (Miller, 1941). The hand-picked highest-grade and purest material was sent for spelter production and the lower grade less-pure material was washed, hand-cleaned and then sent to the zinc oxide furnaces (Miller, 1941, p. 349). From 1861 through 1863, 6,000 to 8,000 short tons of Friedensville ore, consisting of mostly smithsonite was treated annually (Wharton, 1871). In the mid-1870s an effort was made to produce concentrates from ores containing disseminated sphalerite through grinding and jigging, but it was largely unsuccessful (Miller, 1941, p. 350). The individual mines in the Friedensville District that supplied the plant included the Hartman, Old Hartman, Three Corner, and the Ueberroth (Miller, 1941; p. 330).

In the early- to mid 1870s, as oxide and carbonate ores became depleted and sphalerite was encountered, the high grade sphalerite (42-44 percent zinc) was sent to reverberatory furnaces located at the South Bethlehem plant for roasting. By the 1930s these types of furnaces were used only in sparsely populated areas because of the sulfurous gas emissions (Fairlie, 1936).

The roasted product was used for zinc metal production. Previously mined low- grade material residing in waste piles which contained fine grained smithsonite and hemimorphite was jigged to produce a concentrate containing 20 percent zinc that was sent to the oxide furnaces. Lower grade sphalerite containing 15-25 percent zinc, was first heap-roasted at the mine site and then either sent to the reverberatory furnaces at South Bethlehem for re-roasting and used for spelter production, or, if sufficiently roasted, sent to South Bethlehem for zinc oxide production (Miller, 1941; p. 350). Miller reported that it was likely that some minor amounts of greenockite, a cadmium sulfide mineral, accompanied the sphalerite, but assays and amounts are not available. Overall, Friedensville ore was reportedly very pure from a metallurgical perspective, with virtually no arsenic, cadmium, or other deleterious elements (Miller, 1924, p. 63) that would negatively affect the value of zinc products.

In 1864, roasted sulfide ore from the Ore Hill Vein Mine and roaster near Warren, in Grafton County, New Hampshire was shipped to the Bethlehem plant; however, the initial mining operation proved uneconomic, and the mine was reported to have temporarily shut down after a brief period of production. The mine reopened and closed several times during the next 40 years until about 1905 and may have supplied feedstock to the Bethlehem plant up to 1905 (U.S. Forest Service, 2008, p. 170).

In 1874, the South Bethlehem plant purchased 4,000 short tons of hemimorphite (described as calamine in the literature) from the Joplin, MO area. The ore grades would not have exceeded 52 to 54 percent contained zinc (U.S. Geological Survey, 1911, p. 373; Ingalls, 1908; p. 294). These ores probably were purchased to offset the decreasing availability of local zinc silicate ores used for producing slab zinc from the retorts.

For a few years, beginning in 1876, hemimorphite ores (calamine) were shipped from the Passaic Zinc Company's Passaic Pit, located near Sterling Hill, New Jersey, to the South Bethlehem plant in Pennsylvania for the purpose of producing zinc metal. Shipped franklinite ore was used for zinc oxide production (Dunn, 1995a, p. 109, 203).

By 1876, all of Lehigh Zinc and Iron Company's Friedensville mines were closed as they became uncompetitive with producers in New Jersey. Furthermore, zinc metal producers in the central states, which included Arkansas, Kansas, Missouri, and Oklahoma, also became more competitive. The depletion of zinc carbonate and zinc oxide ores at the Company's mines contributed to the loss of market position (Miller, 1924, p. 341).

Beginning in 1876, Lehigh arranged a 5-year contract with NJZ to obtain 1,000 short tons of ore per month from NJZ's mines in New Jersey consisting of a mix of zincite (a zinc oxide mineral), franklinite (an iron, zinc, and manganese oxide mineral), willemite (a zinc silicate mineral), and hemimorphite (a zinc silicate mineral, that made up most of the plant's feedstock) (Miller, 1941, p. 352). The ore-purchase arrangement likely continued until NJZ purchased the Lehigh operation in 1897.

Feed from other local mines owned by other companies in the Friedensville District decreased through the late-1870s until approximately 1881, when nearly all of the ore treated at South Bethlehem originated from the New Jersey operations in the Franklin-Sterling District. In 1881, the local mines the Ueberroth, Old Hartman, and New Hartman that supplied most of Bethlehem's feed, were purchased from the Lehigh Zinc Company by the Lehigh Zinc and Iron Company (Hall, 1915). In 1881, a smelter for producing slab zinc was built at the Ueberroth mine and a zinc oxide plant was constructed at the Old Hartman mine site, but neither plant was used until 1886. During the interim, the ores from the mines were shipped to the Bergen Point smelter in New Jersey where the smelting of sulfide ores was more acceptable because of its less-populated location. The Correll and New Hartman were the last mines in the District to close in 1893 (Miller, 1941; p. 330).

It was estimated that prior to 1894, zinc recovered from ores mined in the Friedensville District totaled 50,000 short tons of zinc and 90,000 short tons of zinc oxide, or approximately 122,000 short tons of zinc in product (Miller, 1924). Another account suggested that by the year 1894 the District produced roughly 200,000 short tons of zinc as metal and in zinc oxide (Smith II, 1977).

The purchase of Franklin ores reduced or eliminated the need to roast local sulfide ores, and thereby reduced costs. Contributing to the decision to limit processing of sulfide ore were social pressures, in the form of lawsuits, resulting from the public's resentment of sulfurous emissions released into the atmosphere by roasting (Miller, 1941; p. 349).

Beginning in about 1892, some willemite and zincite concentrates from Franklin, New Jersey were treated also. The addition of ore from New Jersey containing the zinc minerals franklinite $[(Zn, Fe^{2+}, Mn^{2+})(Fe^{3+}, Mn^{3+})_2O_4]$, hemimorphite

(($Zn_4Si_2O_7(OH)_2 \cdot H_2O$), willemite (Zn_2SiO_4), and zincite ($Zn(Mn,Fe)O$), with minor amounts of other minerals that contained cadmium, calcium, fluorine, and other elements, in the year 1886, would have changed the chemistry of products, air emissions, and slag.

Hofman (p. 288) stated that a concentrate containing predominantly franklinite averaged 22 percent zinc, but ranged 18.41–28.78 percent zinc (Hofman, 1922, p. 289). As a component of franklinite, zinc content ranges from 14–18 percent zinc (Palache, 1935). No arsenic, lead, or sulfur were reported by Hofman in assays of several franklinite concentrates processed at Bethlehem during the period 1915 to 1920 (Hofman, 1922). In 1883, a sampling of franklinite feed yielded average assays of 22 percent zinc (Hofman, 1922, p. 289).

Estimated Annual Capacity and Production

Zinc Oxide

The South Bethlehem plant produced zinc oxide from the year 1853 until 1899. In the year 1900, the zinc oxide plant was dismantled, although zinc metal production continued (Hofman, 1922, p. 286, 290). One published report stated that the plant produced zinc oxide in 1910, but this was not supported by other data (U.S. Geological Survey, 1910, p. 285). Historical statistics pertaining to the production of zinc oxide at South Bethlehem were not widely published. The plant was designed originally with an annual capacity to produce 2,000 short tons of zinc oxide, but production ceased when the plant was destroyed by a fire in 1853 (Hall, 1915). The plant was rebuilt and re-started production in 1856 (New York Times, 1873).

For the period 1853 through 1857, a total of 4,725 short tons of zinc oxide were reportedly produced at the South Bethlehem plant from ores mined in the Friedensville District (Miller, 1941, p. 59, 330), although the operation did not produce for part of this period. From September 1857 through February 1860, 4,728 short tons of zinc oxide were produced at the plant (Reichel, W.C., 1872) for an annualized average of about 2,000 short tons of zinc oxide from ores of hemimorphite and smithsonite. In the mid- to late-1850s, the plant was capable of producing 2,500 short tons of zinc oxide annually (Henry, 1860; p. 234). In 1865, the zinc oxide production from Lehigh County amounted to about 3,000 short tons (Miller, 1941, p. 330). This estimate might include a small amount of zinc oxide produced from other facilities in the valley. In 1867, the plant produced 320,000 pounds of zinc oxide per month (Dunn, 1996, p. 858) or about 2,000 short tons annually. The 1883 edition of American Cyclopaedia described the plant as having produced 47,191,829 pounds (23,600 short tons) of zinc oxide from 1868 through about 1875 for an annualized average of about 1,800 short tons (Ripley and Dana, 1883).

Zinc oxide production over the life of the operation was estimated using reported zinc oxide production statistics and

statistical data relating to spiegeleisen production at Bethlehem. Using these estimates approximately 65,000 short tons of zinc oxide (53,000 short ton zinc equivalents) was produced over the life of the operation.

Zinc Metal (spelter)

Zinc metal, or spelter as it was referred to in early literature, was initially produced at the South Bethlehem plant in 1859 (Hofman, 1922, p. 9; Octagon, 2005), and its production continued until the plant shut down in 1911. Although the plant had a nameplate capacity of approximately 3,600 short tons per year of zinc metal derived from 1,200 retorts (Miller, 1941) from about 1860–1906, annual zinc production during that period appears to have rarely exceeded 1,500 short tons. In the winter of 1860–61, the annual capacity was stated as 2,000 short tons per year, but annual production was closer to 1,200–1,500 short tons (First Century of National Existence, 1874; Wharton, 1871). During this period a single retort at the South Bethlehem furnaces produced approximately 2 short tons per year (Wharton, 1871). From 1860–75 zinc metal production averaged approximately 1,350 short tons per year. In 1862, the charges to the retorts consisted of 12.5 million pounds of ore and 5.3 million pounds of coal for a ratio of about 2.4:1, and nearly 26.5 million pounds of coal was used to fuel the furnaces (Wharton, 1871). Although zinc metal production statistics pertaining to the South Bethlehem plant for the years 1876–1911 were not available, the number of installed retorts at the plant was published for some of those years. The furnaces at Bethlehem could accommodate 1,200 retorts until 1907, when an expansion at the plant increased the number of installed retorts to 1,620. Following the expansion, an annual capacity to produce 3 short tons of spelter per retort was not unusual. In 1875, the plant produced 1,505 short tons of zinc metal from ores delivered from the Ueberroth and Hartman mines (Miller, 1941, p. 330). Tonnages of feedstock from other mines were not available.

Considering the plant's ore supply problems and technical problems (discussed later) in the zinc plant resulting in low capacity utilization, zinc production was estimated at 2,000 short tons per year for the period beginning in the mid-1870s until the plant's closure in 1911.

Using these data and assumptions, the South Bethlehem plant produced approximately 94,000 short tons of zinc metal over its operating life.

Spiegeleisen

Blast furnaces for the production of spiegeleisen were constructed to make use of the zinc oxide residues, a product of the manufacture of zinc oxide from franklinite. Production of spiegeleisen, a high-manganese iron, was initiated in 1881 and was assumed to have ended in 1899 when the zinc oxide plant closed in 1899.

In the publication titled *Directory to the Iron and Steel Works for the United States* (DISW) for the years 1883, 1884, 1890, 1892, 1894, and 1896, annual spiegeleisen production

at South Bethlehem was reported to have ranged from 2,700 to 3,000 short tons per year and averaged slightly more than 2,800 short tons. In 1896, annual capacity was stated as 5,000 short tons of spiegeleisen (American Iron and Steel Works, 1883, 1884, 1890, 1892, 1894, and 1896). Using these data and other assumptions, such as reduced production in beginning and ending years, total spiegeleisen production was estimated at 51,000 short tons for the period.

The estimate of impure zinc oxide recovered from the spiegeleisen production for the years 1881–99 was based on metallurgical studies performed during the plant's operation (Schnabel, 1898; Hofman, 1922) and the total amount of clinker (the residuum remaining from zinc oxide production) treated in the spiegel furnaces. Using these data, it was estimated that roughly 3,000 to 4,000 short tons of zinc contained in impure zinc oxide and zinc and zinc-based accumulations were recovered over the life of the spiegeleisen plant and was used as supplemental feedstock for the retorts.

Technology

The South Bethlehem plant was the site of several major technological advances in the early development of the zinc industry in the United States. It was the site where the first zinc oxide was produced directly from ore. It was also the second commercial producer of zinc oxide, the first commercial zinc metal producer, the first commercial sheet zinc producer, and where the development of using magnetic separation of zinc ore minerals mined from the Franklin, New Jersey zinc deposit took place.

Roasting

In the 1860's most of the ore treated in the roaster consisted of mostly smithsonite with lesser amount of hemimorphite and averaged about 26 percent zinc. By the early to mid-1870s, an increasing amount of the ore used at the Bethlehem plant was sphalerite ore that was crushed at the mine site and passed over and through sieves. Lower-grade sphalerite and high-grade sphalerite were separated by hand. Before a zinc product could be recovered from the low grade ore it was first heap-roasted. In 1872, the heap was described as sphalerite ore piled on iron grates supported by walls on two sides with a central supporting wall. The low-grade ore was placed into stalls on top of the grates forming mounds measuring 27 feet long, 15 feet wide, and 8 feet high (Schnabel, 1898; p. 39). Below the grate a wood-fueled fire was started to initiate the burning of the ore. The pile of ore was disturbed to ensure burning and the removal of as much sulfur as possible. Applying the dimensions of the mound and incorporating several assumptions, such as void space, sulfur content, percent ore versus gangue, and specific gravity it was estimated that perhaps 30 short tons of sulfur would be eliminated and emitted to the atmosphere during heap roasting, which could last

from as little as 10 days to as long as 70 days (Austin, 1909, p. 84-85).

When a sufficient amount of sulfur was removed, the ore was shipped to the South Bethlehem plant where it was crushed and was either re-roasted or was fed directly as part of a charge to a zinc oxide furnace or to retorts for zinc metal production (Miller, 1941, p. 336).

High-grade sphalerite was shipped directly to the South Bethlehem plant where it was roasted for about 24 hours. A mixture of 40 percent by weight of coal and 60 percent by weight ore was prepared for roasting. Roasting left from one to two percent of sulfur in the reduced ore, which was then mixed with coal and charged to retorts in the zinc metal works (Miller, 1941, p. 350). Roasting activities were halted essentially by the late-1870s as the plant became reliant on supplies of nonsulfidic ore from New Jersey as a result of increasing costs at local mines and possible lawsuits from sulfurous fumes emanating from roasting of ore at mine sites and the South Bethlehem plant.

Experience had shown that heap roasting was a nuisance and caused damage to livestock, vegetation, and crops (Austin, 1909, p. 84). The South Bethlehem plant did not have an acid plant because there were no economic or technological advantages to remove particulates from the emissions generated during the roasting process. It would have been difficult to produce sulfuric acid profitably because of the presence of limestone with the ore (Miller, 1941, p. 349).

Magnetic Separation

The use of the franklinite-rich ores (which contained, in addition to franklinite, willemite, zincite, and gangue minerals) for the manufacture of zinc oxide and spiegeleisen had been accomplished in 1860s, but the mixed ores were not suitable as a primary source of zinc metal feedstock because of their low zinc content and the reaction between the iron oxide in the franklinite with the silicates composing the retorts. The reaction resulted in retort failures (Miller, 1941, p.329).

The South Bethlehem plant developed a mineral separation method that used the variation in magnetic affinity of ore minerals mined in the Sterling, New Jersey area, in the 1890s, to produce multiple concentrates. This was a major technological advance that improved the recovery of zinc and permitted, for the first time, production of slab zinc derived from a high-tonnage mix of selected zinc minerals mined in the Franklin District.

In 1892, successful bench scale experiments using magnetic separation led to the installation of a pilot plant at Lehigh's South Bethlehem plant that treated bulk ore received from New Jersey's Sterling District. The zinc ore consisted of 51.92 percent franklinite, 31.58 percent willemite, 12.67 percent calcite, 0.52 percent zincite, 3.31 percent tephroite (a manganese silicate), and other gangue minerals. The ore was crushed, mixed with anthracite coal (20 percent of the ore weight), and passed through a brick-lined revolving cylinder furnace heated by gas in order to make the franklinite

sufficiently magnetic for separation. The hot ore was then placed into a revolving cooler and sprayed with cold water. After cooling, it was sifted to remove unburned coal (which was used subsequently on the grates of the zinc oxide furnaces, whereby the small quantity of zinc retained in the coal and fines were recovered). The ore was collected in bins and fed to three magnetic separators, arranged in series. These machines produced a clean nonmagnetic product of willemite, zincite, calcite, and silicates; and a magnetic product consisting chiefly of franklinite. The franklinite was sent directly to the zinc oxide furnaces and the non-magnetic willemite-rich portion to jigs and tables where calcite and silicates were removed. The resulting non-magnetic fraction was then used as feed to the retorts to produce zinc metal. The magnetic concentrate, consisting of chiefly franklinite with some willemite, assayed about 29.66 percent ZnO, 37.20 percent iron, and 9.34 percent manganese. The nonmagnetic portion was chiefly willemite, assaying from 46.38-48 percent zinc, 3.76 percent iron, and 6.68 percent manganese, 2 percent iron, and 7 percent manganese. The non-magnetic light minerals recovered from the jigs and tables consisted chiefly of calcite and silicates (Proceedings of the Engineer's Society of Western Pennsylvania, 1916; p. 60; Ingalls, 1908; 368) that were discarded.

Although the pilot process gave satisfactory results, the cost of heating the ore and the uncertainty of producing a uniformly magnetic product led to further experiments and successful development of an improved process. In 1896, the first commercially successful circuits were installed at the South Bethlehem plant, in Pennsylvania and at the Hill Mine in the Sterling District (School of Mines Quarterly, 1900, p.240), which used a more advanced magnetic separation technique that did not require heating ore (Dunn, 1995, p. 188, 198) and thus began supplying separate franklinite and willemite concentrates to several smelters, including Lehigh's Bethlehem plant. Franklinite was the feedstock for the production of zinc oxide with byproduct spiegeleisen produced from the zinc oxide furnace clinker; willemite, with minor amounts of zincite, for the production of zinc metal. In February 1897, the Bethlehem plant treated 4,812 short tons of mixed franklinite-willemite ore using the magnetic separators (School of Mines Quarterly, 1900; p. 242). The franklinite-rich component averaged about 23 percent zinc (Hofman, 1922; p. 289).

Zinc Oxide

The South Bethlehem plant, which began operating in 1853 through at least 1892, had six blocks of furnaces, each containing approximately 34 furnaces for the production of zinc oxide (Schnabel, 1898; p. 228; Hofman, 1922, p. 352; Whitney, 1854). Furnaces measured approximately 3 feet high, 3 feet wide, and 5.5 feet long (Schnabel, 1898; p. 229). The plant was originally designed to produce about 10 short tons of zinc oxide per day from hemimorphite and was reported to recover from 40 to 60 percent of the zinc contained in the ore. Recoveries likely improved as technologies improved (Whitney, 1854). From the plant's opening through the early

1870s, locally acquired hemimorphite was the chief zinc ore mineral used to produce zinc oxide. Prior to being loaded into the zinc oxide furnace, the ore was first crushed, ground, and mixed with coal. The zinc contained in the ores was volatilized in the furnace from which zinc fumes were directed by fans and captured as zinc oxide flakes in bags in the baghouse. The product recovered in the baghouse assayed more than 99 percent zinc oxide and was packed into barrels (Henry, 1860; p. 237; Hofman, 1922, p. 290).

As the more desirable oxide ores became depleted the company was forced to transition to low-grade sphalerite ores, which were heap roasted prior to shipping to the Bethlehem plant. By the late-1870s, the company, faced with rising costs associated with underground mining complicated by water incursion and additional labor and materials to process the ores, coupled with major concerns of litigation from the local population resulting from "obnoxious" fumes generated by heap roasting and re-roasting at Bethlehem (Miller, 1941, p. 350). These issues caused the company to sign a contract to purchase franklinite ore from the Sterling District in New Jersey. Processing the franklinite was advantageous for its lower cost, the ability to furnace the ores in essentially the same manner, and permitted the establishment of a new and useful byproduct, spiegeleisen from process residues.

Before a charge containing franklinite concentrate was fed to the zinc oxide furnace a layer of anthracite weighing 150–200 lbs was heated.

A charge to a double furnace consisted of a moistened layer of 740 lbs of 50:50 ratio concentrate and anthracite which was laid on a grate over the preheated layer and furnaceed for approximately 4-6 hours (Hofman, 1922, p. 289). Single furnaces held charges of about 425 pounds and were also placed on top of a grate in the same manner. Zinc fumes emitted from the furnaces were directed through a vertical flue, which connected to a common flue through which gases and dust were collected and moved by drafts induced by fans through two cooling chambers, the largest of which measured approximately 100 feet long, 20 feet wide, and 40 feet high. Zinc oxide flakes formed when the zinc fumes cooled were collected from doors at the bottom of the chamber. Any remaining, and usually more pure, zinc oxide flakes were directed to a baghouse which contained 708 cotton bags measuring 30-40 feet long and 2 feet in diameter. Fumes were captured by the bags and gases allowed to pass through the cotton weave and emitted to the atmosphere (Schnabel, 1898, p. 228). Approximately 83 percent of the zinc contained in the ore was recovered as zinc oxide. Most of the balance remained in the residue or escaped during unloading and preparing the furnace charge, from the stationary-grate furnace during charging, stirring charges during furnacing, and emptying, leaked from conduits and the baghouse, and was lost during packaging of the product. Some zinc oxide was deposited, and eventually recovered, in flues and other equipment. Although the plant underwent some changes over the period it operated, the overall technology applied for the recovery of zinc oxide from ore remained essentially the same. The zinc oxide plant

was dismantled following the construction of the Palmerton plant in 1900 (Hofman, 1922, p. 290).

Zinc Metal

The South Bethlehem plant was the first commercially successful plant to produce zinc metal in the United States from ore. In 1855, an experimental plant was built on the site to produce zinc using vertically-oriented retorts, but closed shortly after opening because of high costs (Hall, 1915). The first pilot furnace was constructed in 1859 and contained 45 retorts. After continuing research by the Company's principals, a slab zinc plant was constructed on the site in 1860 with 16 Belgian furnaces, each with between 54 and 75 horizontal retorts (Miller, 1941, p. 330, Wharton, 1871). Retort breakage was considerably high; life expectancy was about 17 days and condensers about 6.5 days (Wharton, 1871). It was reported, that in 1862, 13,614 retorts and 47,870 condensers were "consumed," suggesting that zinc losses during retorting was substantial. The plant originally treated locally mined hemimorphite ores until the early 1870s when roasted sphalerite was treated because of exhaustion of the preferred ores. In the 1870s, the retorts were charged about every 12 hours. About 82 percent of the contained zinc was recovered (Schnabel, 1898; p. 168). However, Miller reported that zinc carbonate and silicate ores contained 47 percent zinc, from which 75 percent was recovered, and that roasted sphalerite ore, which also assayed 47 percent zinc, yielded about 72 percent of the contained zinc. The difference was attributed to residual zinc sulfide remaining in the retort residuum (Miller, 1941; p. 336).

As a result of increasing costs for mining and treating ores from mines in the valley, and the local populace's resentment of sulfurous fumes generated by roasting, the plant switched to cheaper willemite-rich ores originating from the Sterling, New Jersey area in the late-1870s or early 1880s.

In the 1880s, furnaces were fired for a period of 15 months before being repaired or replaced (Schnabel, 1898; p. 168). In the 1890s, there basically were two different furnace configurations: two-sided furnaces with 7 rows of 20 retorts in each row for a total of 280 retorts and one-sided furnaces with 4 rows of 20 retorts on a side for a total of 160 retorts. Furnace life was about 2-5 years and retort life was usually 35 days or less. Retorts measured 7 inches in diameter and 51 inches long. A charge to all, but the uppermost row of retorts, consisted of a mix of 60 percent ore that assayed approximately 50 percent zinc, and 40 percent anthracite. The mixture was burned for about 12 hours. As in the 1870s, the uppermost retorts, which received less heat, were sometimes used to distill scavenged dusts, spillage, and sweepings which assayed about 65 percent zinc (Miller, 1941, p. 336). These were furnaced for 24 hours (U.S. Geological Survey, 1911; p. 377). Approximately 82 percent of the zinc was recovered and the remaining retort residues assayed 6-7 percent zinc. The balance was lost through breakage, referred to as "butchering" of retorts in the furnace, diffusion through retorts, losses from vapors escaping the mouths of retorts, and accumulations in

equipment. Nearly 4 percent of the retorts were destroyed in the furnace on a daily basis (Schnabel, 1907). For each short ton of willemite ore contained in the charges, 2.25 short tons of anthracite coal were necessary for heating the furnace to a temperature sufficient to achieve distillation (Ingalls, 1903; p. 286).

The plant was expanded in 1907 with the addition of 420 retorts for a total of 1,620 in 18 furnaces (U.S. Geological Survey, 1910, p. 259; U.S. Geological Survey, 1913, p. 283). At that time it was reported that 2.75 short tons to 3.30 short tons of anthracite per ton of ore in furnace was required while the more modern Palmerton plant required only 2 short tons (Ingalls, 1908; p. 333). The South Bethlehem plant permanently closed in 1910, as expansions at the more modern and more efficient plant at Palmerton, Pennsylvania offset the loss in South Bethlehem's capacity.

Spiegeleisen

Spiegel-blast furnaces were installed to produce spiegeleisen in 1881 (Hall, 1915). The high-iron manganese residuum (clinker) remaining from furnacing the franklinite-based charge to manufacture zinc oxide was used as feed to the spiegel furnace. The residuum, weighing about 66 percent of the weight of the original franklinite-anthracite charge, assayed about 6 percent zinc oxide, 40 percent iron, 11 percent manganese, 20 percent silicon dioxide, and 0.026 percent phosphorous. Clinker could range from 5-10 percent zinc oxide (Hofman, 1922; Schnabel, 1907). The spiegel furnace gases were routed through a series of pipes and condensers in which zinc and zinc oxide would be deposited, collected, and fed to the slab zinc or zinc oxide plant during the iron-making process. Approximately 55 percent of the zinc contained in the clinker was recovered during the iron-making process.

The spiegel plants at South Bethlehem were of a more modern design than the Newark plant in that there was redundancy built into the plant's design which allowed the removal of accumulations of dust and impure zinc oxide in flues and pipes without interrupting the production of spiegeleisen. It is not known if the plant had condensers installed on spiegel furnaces prior to the early 1890s.

Additional zinc oxide was collected from accumulations lining stacks, pipes, and other equipment which generally assayed about 74 percent zinc. By one account, some samples of the material assayed as high as 85 percent zinc, suggesting that zinc metal had precipitated also in the oxygen-depleted atmosphere of the furnace equipment (Dunn, 1996, p. 870).

The amount of zinc oxide furnace clinker or residuum required to produce one ton of spiegeleisen ranged from about 2:1 to 3:1 (Schnabel, 1907; Dunn, 1995a). The ratio depended on the manganese and iron content of the ore treated in the zinc oxide furnaces. Based on a ratio of 2:1, about 100 short tons of residuum averaging 6 percent zinc oxide, 100 tons of coal, and 50 pounds of limestone comprised a charge to yield approximately 50 short tons of spiegeleisen and recover about 3.5-4 short tons of impure zinc oxide containing about 74

percent zinc (Schnabel, 1907). Using these data, zinc recovery in the spiegeleisen plant was estimated at nearly 55 percent, with the balance remaining in slag, or lost as dust, fumes, and gas during the iron-making process. It was estimated that approximately 3 percent of the zinc contained in the zinc oxide furnace clinker was lost as dust, fumes, and gas.

Atmospheric Emissions

Fugitive and stack emissions to the atmosphere of sulfur, zinc, and other materials were generated at the South Bethlehem plant site, as well as at heap roasting operations offsite from sulfide ores. Metals such as cadmium, lead, and mercury were either very low or not encountered in assays of nonsulfidic local ores and those shipped for treatment from New Jersey, but if present, would have been released as a component of atmospheric emissions, along with zinc. Manganese, a metal present in franklinite, would have also been released in relatively small amounts.

It was estimated that a total of about 6,700 short tons of zinc were emitted to the atmosphere as fugitive and stack emissions in the course of producing zinc metal, zinc oxide, and spiegeleisen. Data were insufficient to develop an estimate of other materials emitted to the atmosphere.

Zinc, Zinc Oxide, and Spiegeleisen

Emission data for the South Bethlehem plant have been not published and little information relating to emissions at other zinc smelter complexes operating during the time period is available. However, based on the experimental nature of the operation early in the plant's life and limited statistical and technical data (Proceedings of the Engineer's Society of Western Pennsylvania, 1916), emissions in varying amounts and species were produced during the steps required to produce spiegeleisen, zinc metal, and zinc oxide.

Ore Preparation

Atmospheric emissions from fugitive and stack sources were generated prior to placing zinc-laden charges into retorts or zinc oxide furnaces. Ores from New Jersey did not require calcining or roasting. The sources included: (1) unloading, drying, crushing and grinding ore; (2) roasting of sulfide and calcining carbonate ores by physical movement of material and volatilization; and (3) blending ores and combining with anthracite or coal to form charges (broken retorts, crusts, and scrapings also were blended). Losses of zinc, mostly from fugitive sources, during this period could reach as much as 1.5 percent of the total recovered zinc as metal and in zinc oxide or nearly 1,500 short tons.

Zinc Metal

Sources of fugitive and stack losses generated during the production of zinc metal using horizontal retorts was relatively

high compared to plants constructed in the 20th century because of the use of early technology and their inherent problems. Sources of emissions included (1) loading of charges into the retorts; (2) diffusion through retort walls owing to the permeability of retort material; (3) escape through fractures in retorts; (4) breakage of retorts; (5) losses from the mouths of retorts and during collection of zinc from condensers; and (6) removal and cleaning of retorts. Losses from these steps from 1859 through 1911 may have amounted to 3-4 percent of total zinc metal production, and perhaps up to 5 or 6 percent owing to the high destruction rate of retorts in the earlier years. Zinc contained in emissions to the atmosphere over the period zinc metal was produced was conservatively estimated at about 3,300 short tons.

Zinc Oxide

Sources of fugitive and stack losses generated during the production of zinc oxide using stationary-grate furnaces (the standard equipment that was used prior to the introduction of travelling grates in the 1920s) included (1) dispersion during loading, stirring charges during furnacing, and emptying furnace charges; (2) losses through fractures in furnace walls; (3) leakages from conduits leading to the baghouse; (4) escape of dust, fumes, and gas from the baghouse; and (5) handling losses during collection, preparation, and packaging in barrels for shipment. The total losses through these sources from 1853 through 1899 were up to about 3 percent of total zinc oxide production or approximately 1,600 short tons of zinc.

Spiegeleisen

The clinker collected from the zinc oxide furnaces served as feedstock for producing spiegeleisen. The zinc content of the clinker varied somewhat, but averaged 6 percent zinc oxide (about 4.5 percent zinc) during the period that the plant operated. During the process of producing spiegeleisen approximately 55 percent of the zinc was recovered in flues and condensers, with most of the balance contained in the slag. It was estimated that roughly 3 percent of the zinc contained in the clinker, or 300 short tons of zinc, was released to the atmosphere from 1881 through 1899 as a component in dust, gas, and fumes during the production of spiegeleisen and the collection and movement of condensed material containing zinc.

Sulfur

Sulfur emissions were produced from the open-air heap roasting of sphalerite at some of the mine sites and from the roasting operation at the South Bethlehem plant, mostly during the 1870s. The mineral sphalerite contains up to 33 percent sulfur. Sulfur emissions were not calculated because the amount of sulfide ore that was roasted is not known. The proportion of ores initially roasted offsite and unburned sulfide ores shipped to South Bethlehem for roasting also is not known. Perhaps 90 percent or more of the sulfur contained

in the sphalerite heap roasted offsite was eliminated with the balance almost entirely removed by the roasters at South Bethlehem. In the absence of an acid plant, which removes suspended particulates and uses the sulfur dioxide generated from roasting to manufacture sulfuric acid, and depending on the efficiency of the roasting process, up to 98 percent of the sulfur remaining in the sulfide ores could have been released to the atmosphere.

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Keystone Zinc Works, Birmingham, Huntington County, Pennsylvania

Introduction

The inactive Keystone Zinc Works, located near Birmingham, Pennsylvania is approximately 90 miles east northeast of Pittsburgh, Pa. The zinc oxide plant was constructed in 1864 and relatively small and short lived. The ore body that supplied feedstock to the facility was originally mined for lead in the 18th century. However, with technological advances in the mid-19th century, the Keystone Mine was reopened and a few surrounding zinc deposits were developed to supply feedstock for the manufacture of a high-lead zinc oxide product. Although most of the ore feed originated in close proximity to the plant, some production may have originated from across the county line in Blair County, Pa (Smith II, 1977, p. 96). The zinc ores were composed of primarily sphalerite with subordinate smithsonite.

An estimate of historical production was made difficult because of inconsistent and sparsely reported regional production data and plant-specific operating data in the literature. It was estimated that roughly 400 short tons of zinc equivalents and 130 short tons of lead equivalents were recovered in a high-lead zinc oxide product over the life of the operation. In the course of producing the oxide, approximately 30 short tons of zinc and 13 short tons of lead were released to the atmosphere as components in dust, fumes, and gas.

Map Number (fig. 1)

6

Location

The furnace operation was located in close proximity to the town of Birmingham (about 5 miles southwest of Tyrone), Pennsylvania [N40°38'52" (40.647778); W078°11'44" (-78.195556)] or near the Keystone mine located at N40°38'56" (40.648889); W078°12'46" (-78.212778) (Smith II, 1977, p. 91).

Alternate Names

Birmingham;
Keystone Mine;
Keystone Works;
Keystone Zinc Company;
North Sinking Valley; and
Sinking Valley (Miller, 1924, p. 13-15; Smith II, 1977; p. 89, 95).

Years of Operation

Archeological evidence supports that indigenous people manufactured lead for ammunition around 1750. In 1776, a crude lead smelting furnace was constructed and operated for a short period to supply General Washington's troops with lead for ammunition. Sphalerite was considered worthless and a hindrance at the time because the technology to recover zinc from sulfide ores had not yet been developed (Lininger, 2008).

In 1864, the mine reopened with the addition of an onsite roaster and zinc oxide furnaces. The mine and its support facilities closed after operating for about 6 years and the mine site has remained inactive since 1870 (Lesley, J.P., 1892; p. 445; Miller, 1924; p. 14).

Owners/Operators

Keystone Zinc Company

Feed Sources, Grades, and Ore Types

The greatest percentage of ore feed to the roasters and oxide furnace originated from two local mines; the Birmingham and the Keystone, but tonnage and grade statistics were unavailable. Feed was provided by other mines in the valley and from sources more distant, but little information on the amounts, grades, and origin of the feed from these operations was found in the literature. Although some data related to the metal content of sphalerite, concentrates, and stockpiles were available and provide information on the nature of the chemistry of the ore bodies, they should not be considered representative of feedstock over the life of the operation.

Zinc oxide and zinc carbonate ores associated with lead minerals may have been recovered in the earliest part of mining activities, but once the altered ores were exhausted, sphalerite with subordinate galena predominated for most of the underground mines' production life.

Reported grades of ore that fed the Keystone Company's roaster and furnace vary widely. Analyses of four ore samples reportedly raised from the Birmingham shafts are presented in table 6; however, no production tonnage data was reported. Table 7 lists the results of samples taken from various sources of ore in the valley that fed Keystone's roaster.

Several sphalerite samples reportedly taken from the Keystone mine assayed 51.63 percent zinc and 15.91 percent lead, while other sphalerite samples taken from shafts and outcrops in the area ranged from 18.22-42.87 percent zinc and 0.34-25.80 percent lead (McGreath, 1879). Several assays determined that the ores contained about 5 ounces of silver per short ton of ore (Crookes, 1871).

In 1877, it was published that ore treated at the Keystone Works was "galeniferrous" and contained 6-8 percent lead (Williams 1877).

Table 6. Analyses of ores (in percent) raised from the Birmingham shafts. Values, except for zinc conversion from zinc oxide to zinc equivalents, are presented as in the referenced source (Miller, 1924, p. 15). The low sulfur content and high carbonic acid content suggests that the four samples likely were smithsonite taken from the altered parts of the ore body, and not representative of the overall plant feed.

Sample number, element or compound, and content as weight percent	I	II	III	IV
Silica	4.53	9.67	9.67	6.90
Carbonic acid	27.80	20.80	19.03	28.69
Oxide of calcium	1.84	--	--	--
Zinc oxide	46.95	34.50	31.10	47.50
Zinc	38.03	27.95	25.20	38.48
Lime	2.48	11.08	1.17	2.17
Sulfur	0.74	0.12	0.25	0.18
Lead	5.44	0.82	1.09	1.20
Iron, magnesia, and water	10.22	14.01	37.69	13.36

Table 7. Analyses of individual ore samples (weight percent). Shaft numbers refer to the Keystone site. Values, except for zinc conversion from zinc oxide to zinc equivalents, are presented as in the referenced source (Smith II, 1977a). Grade data may not be representative of actual feedstock.

	Ore roaster stockpile	Average of ore from No. 2 shaft	No. 3 shaft ore	No. 4 shaft ore	No. 5 shaft ore	Kinch farm high-graded ore
Zinc (percent)	15.9	37.7	27.7	24.9	38.7	45.2
Lead (percent)	51.6	5.4	0.8	1.1	1.2	6.2

Some gravity concentrate, consisting of sphalerite and galena, recovered in buddles (troughs that collect the “heavies” from jigs) from the Silver Hill Mine in Davidson, South Carolina; served as feed for the production of Bartlett white lead, a high-lead zinc oxide, at the Keystone site (Williams, 1877). Tonnages and grades were not reported.

Production History

Mining and zinc oxide production commenced in 1864, and several thousand tons of ore were mined until the plant closed in 1870 (Miller, 1924). It was also reported that more than 2,000 short tons of ore were mined by the Keystone Company (Miller, 1924), and at least 50,000 kg (55 short tons) of zinc were produced at the Keystone Mine from sphalerite, the chief ore mineral (Smith II, 1977). Applying these two numbers against each other and a 75 percent overall plant recovery would suggest an average zinc content in ore of about 4 percent zinc, significantly lower than any published numbers, lower than would be expected if the ore mineral processed was sphalerite, and a grade significantly lower than what was considered economic, unless there were significant revenues generated by other commodities recovered from the ore.

Significant contributions of ore to the smelter also originated from neighboring mines and prospects. A published estimate stated that approximately 3,500 short tons of ore assaying a combined value of 12 percent zinc, plus lead was mined in the area by 1881 (Smith II, 1977). This estimate probably included the Keystone Mine and production from other mines

and prospects in the immediate Birmingham, Pa area. Smith II, 1977 reported that 1,300 short tons of primary ore containing 30 percent zinc and 2,000 short tons of secondary ore containing 8 percent zinc were extracted from the Keystone Mine (Smith II, 1977, p. 96). Assuming a 75 percent zinc recovery, approximately 413 short tons of zinc in zinc oxide potentially was recovered from the smelted ores. However, based on several analyses of samples taken in drives, shafts, and waste dumps at the Keystone mine site it appears that the actual ore grades for secondary ores may have been considerably higher than 8 percent (Smith II, 1977).

For this evaluation, it was estimated, based on limited data, that total ore production from the mines in Sinking Valley, Pennsylvania was 3,500 short tons containing an average of 15 percent zinc and an average of 5 percent lead. With an overall zinc and lead plant recovery of 75 percent, approximately 400 short tons of zinc equivalents and 130 short tons of lead equivalents were possibly recovered over the life of the operation. Additional ores may have been treated at the roaster and zinc oxide plant, but data are not available. The recovered zinc was contained in a high-lead zinc oxide product.

Products

The furnaces produced two products: 1) a high-lead zinc oxide product used as a paint pigment, containing 73.246 percent zinc oxide (59 percent zinc equivalent), 25.084 percent lead sulfate (19 percent lead equivalent), 0.574 percent zinc sulfate, 0.186 percent cadmium sulfate, and other impurities

(Miller, 1924); and 2) a product termed “Bartlett white lead,” a high-lead zinc product used in paint that assayed 72.083 percent zinc oxide, 23.968 lead sulfate, 0.256 cadmium chloride, and other forms of zinc and lead (Williams, 1877). The Bartlett white lead probably was produced in only relatively small amounts relative to total production and was produced from the roasted concentrate shipped from South Carolina. The material from South Carolina likely was fed separately when the material became available in sufficient quantities, since it resulted in a different product. It is not likely that there were multiple systems enabling concurrent production of different zinc oxide products.

Technology

The commercial application of the Wetherill process for producing zinc oxide from sulfide ores in the 1860s provided the incentive to develop the sphaleritic deposits in the area. The zinc ores, containing significant amounts of lead, were first roasted in a reverberatory furnace. It is unlikely that there were any emission controls or acid plant. As a result most fugitive and stack emissions were released directly into the atmosphere as dust, fumes, and gas. The reduced ore, and South Carolina concentrate when available, were placed in a furnace with a reductant, such as coal, resulting in the volatilization of the contained zinc and lead on a stationary-grate furnace (Williams, 1877). The fumes were directed and cooled as they passed through flues leading to a baghouse (using burlap, cotton, or wool bags) where zinc and lead oxide flakes were captured by filtration. Approximately 75 percent of the contained lead and zinc in roasted feedstock were recovered by the process.

Zinc and Lead Emission Estimates

Technical details pertaining to the roaster, oxide furnaces, and baghouse were not available and tonnage and grade data were inconsistent and incomplete. Considering the time period and the technology used, it is reasonable to assume that 7 percent of the total amount of zinc recovered from the ore or about 30 short tons of zinc was released to the atmosphere as dust, fumes, and gas. Emissions were produced during the preparation of ore for treatment, loading, stirring charges during furnacing, and unloading stationary grate furnaces, leakages in conduits leading to and in the baghouse; and during the packing of products for shipment. Approximately 13 short tons of lead may have been emitted to the atmosphere assuming the lead content in the ore averaged 5 percent and 10 percent was lost as atmospheric emissions. A higher emission percentage than zinc was assumed because of lead’s lower boiling point than zinc.

Sulfur Emission Estimate

Based on similar mineral composition, zinc ore grades, and sulfur content in producing mines (Sampson and others, 2007; Ceylan and others, 2002), it was estimated that as much as 90 percent of the contained sulfur or approximately 400 short tons of sulfur (800 short tons of sulfur dioxide) were emitted to the atmosphere. The calculation was based on the assumptions that 3,500 short tons of ore, averaging 15 percent zinc in sphalerite contained 13 percent sulfur with subordinate galena and pyrite. Ten percent of the sulfur also was assumed to have been retained in the furnace residue and in the oxide product.

This rough estimate should be considered with some caution considering the lack of data pertaining to actual feed grades and mineralogy. The ore could have contained greater amounts of sulfur in pyrite, and other sulfide minerals or could have been lower if the ore contained nonmineralized gangue and oxidized ores depleted in sulfur.

The amounts of emissions generated by the treatment of concentrates from South Carolina were not estimated because they reportedly were roasted prior to shipment, and data on grades and tonnages were not available. The amount delivered was probably quite low.

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Donora Zinc Works, United States Steel Corporation, Washington County, Pennsylvania

Introduction

Except for a few interruptions because of environmental, labor, and technical issues, the American Steel and Wire Company's Donora zinc plant operated continuously from 1915–57. It was the largest zinc smelter in the world when it initiated production. As with most industrial facilities, production varied over the operation's lifetime owing to changes in economic conditions, political situations, such as World War I and II, labor and technical problems, and other factors.

The site occupied by the Donora zinc facility encompassed about 40 acres and shared services and some materials with the Donora steel plant located adjacent to the zinc smelter (Mining Digest, 1916, p. 114).

The plant relied on ore and concentrates brought in by barge, rail, and ship from multiple mines representing a wide area of the United States and from overseas. The plant roasted ores and concentrates onsite and produced zinc metal and byproduct sulfuric acid to generate most of its revenue. During some periods in its history, it produced hydrochloric acid, and byproduct metals such as cadmium (U.S. Bureau of Mines, 1941, p. 27) germanium, indium, lead, and zinc sulfate. The zinc and acid produced at the smelter were used in manufacturing of steel-based products at the adjacent facility (figure 24).

The activities practiced for zinc production at the Donora zinc smelter have been associated with environmental issues related to the plant's atmospheric emissions generated primarily from the roasting and sintering of zinc sulfide ore and concentrate. The plant was considered to be responsible for contributing to air pollution during an atmospheric inversion in 1948 that resulted in loss of life and illness (Lipfert, 1994, Hess, 1995). Figure 25 is a photograph of downtown Donora, reportedly taken at approximately noon during the October 29, 1948 inversion.

It was estimated that the Donora plant produced roughly 1.5 million short tons of zinc and released 73,000 short tons of zinc to the atmosphere as a component in dust, fumes, and gas over the 43-year life of the operation. Other materials contained in emissions included arsenic, cadmium, fluorine, lead, mercury, and sulfur.

Numerous photographs of the zinc plant and its operating details were available through literature and other sources because of the plant's significance of being one the largest zinc plants in the world and its association with a historical occurrence.

Map Number (fig. 1)

7

Location

The Donora zinc smelting facility was located in the town of Donora, Pa. along the bank of the Monongahela River and east of the Donora Steel Works at approximately N40°10'24" (40.173333), W079°51'28" (-79.85778). The town of Donora is about 30 miles southeast of Pittsburgh, Pa. figure 26 is an aerial photograph of the plant in operation dated 1941.

Years of Operation

1915-57 (Minerals Yearbook, 1958, p. 1,291)

Ownership

American Steel and Wire Company, a subsidiary of the U.S. Steel Corporation.

Major Products

Zinc metal
Sulfuric acid

Feed Sources and Types

Historical data on the amounts, chemistry, and source of plant feed were scarce and incomplete for the period that the plant operated. Donora started operating during a period when zinc concentrates produced through flotation started to become widely available. Most smelter feed in the plant's early years was in the form of rich ores that were hand sorted and concentrates produced by gravity methods. Throughout its operating life the plant received and smelted sulfide ore and zinc sulfide concentrate consisting primarily of sphalerite from diverse sources in the United States and overseas. Although the literature denotes sources of Donora's ore and concentrate feed for particular years, it cannot be assumed that these sources of supply were limited to that particular time period or only those sources. The fragmented data in the literature gives this impression. Unless ores and or concentrates were purchased on the spot market, contracts were usually set in place for at least several years. In the case of mines owned by a vertically integrated company, supplies of feed are generally less vulnerable to factors that cause interruptions in supply.

When the plant opened, Donora was reported to have processed ores from domestic and foreign sources with a



Figure 25. Photograph of smog conditions resulting from plant emissions trapped in the valley as a result of an atmospheric inversion at Donora, Pa. The image was reportedly taken at noon on October 29, 1948 (National Oceanic and Atmospheric Administration, 2008).



Figure 26. Aerial photograph taken in 1941 of the Donora Steel Works and Wire Works (white arrow) and the Donora Zinc Works (black arrow) located along the west bank of the Monongahela River. Permission for the publication of this photograph was granted by the Donora Historical Society and the California University of Pennsylvania, Library of Congress, Teaching with Primary Sources Program, 2009.

“large supply” of ore from Broken Hill, Australia (Ingalls, 1916). In 1916, zinc concentrate from Broken Hill assayed 47.5 percent zinc, 13.6 ounces/short ton silver, and 6.3 percent lead. Ore grades at Broken Hill during this period were stated as 16.3 percent zinc, 13.6 percent lead, and 8.2 ounces/ton silver. Fluorspar was associated with the zinc ores and concentrates from Broken Hill, Australia. Efforts were made at the beneficiation plant to reduce the amount of contained fluorspar and other fluorine minerals through acid washing and gravity methods (Worden, 1921; Rickard, 1921). Broken Hill was one of the pioneers in using flotation to separate and concentrate mixed ores (Weed, 1918, p. 1772). Flotation served to increase the grade of the mine’s product and reduce the amount of deleterious materials, including fluorine minerals. Removal of fluorspar and other fluorine-containing minerals from zinc concentrates was advantageous because when the material was roasted the fluorine inflicted damage to the furnace linings. Analyses of zinc concentrates produced at Broken Hill using flotation in the late-1960s did not contain fluorine, although assays of residues discarded from the flotation process taken over a period of 18 months contained from 0.42 percent to 1.14 percent fluorine (Gauci, 1970).

Fluorine bearing minerals were still contained in zinc concentrates produced at the deposit at least as recently as 2001 (Tosi, 2001).

Starting in 1919, all zinc dross produced by United States Steel Corporation was shipped for processing at Donora (American Society of Mechanical Engineers (ASME), 1928). Zinc content in dross often exceeds 85 percent. In the late-1920s, concentrates and slimes from the Joplin District, in Missouri assaying 60 percent zinc and 30 percent sulfur were treated at the plant (Pittsburgh: The City and The District, 1928, p. 181; Hofman, p. 205). Specific analyses of the materials treated by Donora from the Joplin District are not available, but a sampling of 30 sphalerite shipments sent for smelting to an unspecified smelter, in the early 1900s contained an average of 1.37 percent lead, 0.36 percent cadmium, 0.0159 percent arsenic, and other metals (Rothwell, 1906; p. 590). Results from over 4,000 other sphalerite assays published by Rothwell also contained lead and cadmium, and chemical assays of 3,800 zinc concentrate samples from the Joplin region, published by Lindgren in 1918 and presented in table 8, were determined to contain 0.304 percent cadmium and 0.7 percent lead (Lindgren, 1919).

The flotation plant at the Burra-Burra mine site, in the Ducktown Mining District in Tennessee, produced concentrates that were treated at the Donora smelter from at least the

early 1930s until 1951 or later. They assayed approximately 49 percent zinc (U.S. Bureau of Mines, 1935-51, variously paginated). The flotation plant in Ducktown also received ores from the Fontana mine in North Carolina, and other mines in Tennessee throughout the 1930s (U.S. Bureau of Mines, 1938, p. 352). The mine operated from 1899 until 1959 and was primarily worked for copper.

Other mining operations in the Copperhill, Ducktown, and Mascot-Jefferson City Districts in Tennessee, such as the Bible, Boyd, Davis, Eureka and Isabella group of mines also sent concentrates to the Donora plant (U.S. Bureau of Mines, 1937, p. 352). In 1947, the Davis Group produced zinc concentrates assaying 64.44 percent zinc (U.S. Bureau of Mines, 1949, p. 1390). The Davis-Bible mines owned by the Universal Exploration Company, a subsidiary of U.S. Steel, supplied concentrates to Donora from the 1920s through at least the early to mid-1950s (U.S. Bureau of Mines, 1934; 1950; 1953) near Jefferson City, Tennessee. Barite, fluorite, copper, and lead minerals occurred with the zinc mineralization in most of the previously mentioned mines in Tennessee, the amounts of these materials contained in concentrates received by Donora were not available. Based on samples of ore analyzed from the District, the shipped feedstock also likely contained mercury (Jolly and Heyl, 1968).

In the 1930s preroasted zinc concentrate from Joplin, MO was supplied as feedstock. The material was sintered at Donora prior to reduction in the retorts. The unroasted concentrate received from the Joplin District assayed approximately 62 percent zinc, 4 percent sulfur, and contained with less than 1 percent each cadmium and lead (Queneau, 1936).

In the early 1940’s, the Balmat-Edwards area and the Hyatt Zinc Mine in New York were reported as sources of sphalerite concentrate to Donora (U.S. Bureau of Mines, 1943, p.356). The ores mined from the deposits likely contained anomalously high levels of mercury, but the amount contained in concentrates treated by Donora were not available. Balmat ores sampled by Schwartz contained an average of 1200 ppm (0.12 percent) of mercury, considered among the highest of samples analyzed taken from sedimentary exhalative-type zinc deposits in North America (Rytuba, 2000; 2003). See the plant description for the Monaca smelter for additional discussion and assay data on the concentrates produced in the Balmat-Edwards District of New York and their mercury content. The Balmat-Edwards deposits are also relatively high in fluorine-bearing minerals when compared to other zinc deposits, but data on its presence in concentrates were not available (Plimer, 1984).

Table 8. The assays of 3,800 zinc concentrate samples from the Joplin, Mo. (Lindgren, 1919; p. 454).

Element or compound	Zinc	Sulfur	Iron	Silica	Calcium carbonate	Magnesium carbonate	Barium sulfate	Lead	Cadmium	Copper	Man-ganese	Total
Content, percent, and total	58.26	30.72	2.23	3.95	1.88	0.85	0.82	0.70	0.304	0.049	0.01	99.773

Concentrate feed was also received from the Tri—State District and from Wisconsin, and southern Illinois in the early 1940s (U.S. Bureau of Mines, 1941, p. 265), but the amount, duration and mineral composition of the concentrates supplied to Donora is not known. The concentrates produced from the deposits generally assayed about 58 percent zinc (U.S. Geological Survey, 1908, p.528).

Fluorite was reported as a component of some sphalerite concentrates produced from southern Illinois, while it was not found in quantity in sphalerite concentrates from the Joplin, Missouri and Upper Mississippi Valley district.

In 1949, sphalerite concentrate feed to the roasters at Donora included, but was not limited to, the following sources: (1)-East Tennessee (Davis-Bible/Zinc Mine [grading 64 percent zinc in concentrate]; (2)-New York - Balmat (concentrate at 58.6 percent zinc), Edwards (concentrate assaying 58 percent zinc), and Hyatt (concentrate grading 58.6 percent zinc.); and (3) the Tri-State, (containing zinc and some lead) (U.S. Bureau of Mines, 1978) (U.S. Bureau of Mines, 1950, p. VI-24–VI-25). It was reported in 1949 that concentrate graded 60 percent zinc and 30 percent sulfur (Schrenk and others, 1949).

Cotterill (Cotterill, 1950, p. 153) stated that during the 11-year period 1940-50 zinc sulfide concentrates derived from ores mined in Miami and Sahuarita, AZ; Butte, Montana; Magdalena and Hanover, New Mexico; Murray, Utah; Metal-line Falls, Washington; and the Tri-State District, Missouri were treated at the Donora smelter. Sphalerite was the chief zinc mineral contained in concentrates produced from these mines and districts. The Empire Zinc Company's mines, in the Hanover District, the largest zinc producer in New Mexico during this time period, also supplied zinc concentrates to the Palmerton smelter (U.S. Bureau of Mines, 1940).

In the late-1940s it was also reported that the Donora smelter was treating concentrates imported from Belgium, which contained a "high-fluorine content" (Bryson, 2004). Ore and concentrate assay data and specific deposits from which these ores were extracted were not named, although there were numerous mines that were worked during this period that contained sphalerite as the primary ore mineral or in association with subordinate fluor spar in Austria, Belgium, England, and France.

Capacity and Production History

Except for a few references that included actual zinc production statistics for several years, no annual zinc production statistics specifically attributed to Donora were discovered in the literature. A research study examining fluoride pollution in the United States stated that zinc production statistics related to the Donora plant no longer exist (Bryson, 2004). A review of U.S. Steel Company Annual Reports for selected years suggested production data for the Donora zinc smelter, but not specifically by name. In other annual reports, production from two or more Company-owned zinc operations were combined.

Some production estimates for Donora were based on the number of reported installed horizontal retorts.

The first phase of construction of the Donora plant was reported by the U.S. Geological Survey to have been completed in 1915 with 3,648 horizontal retorts (Wright, 1918) and operated at less than full capacity in its first years of operation. In 1916, the second phase of plant development was completed with additional furnaces. The design allowed the operation to contain a total of 9,600 horizontal retorts and to have an effective capacity of 40,000 short tons of zinc metal per year with an equal annual tonnage of sulfuric acid (U.S. Geological Survey, 1914; p. 894; U.S. Geological Survey, 1915, p. 954; U.S. Geological Survey, 1916, p. 819), applying an estimated annual capacity of 4 short tons of zinc/year per retort, about average for the time period.

Process data on the plant's operation prior to 1920, which included ore feed grade, feed tonnages, and zinc recoveries, suggest a daily production capacity of 100 short tons of zinc per day (Hofman, 1922; p. 205; Rothwell, 1922). Projecting these data to an annual basis for the ten furnaces, annual effective capacity could have been approximately 37,000 short tons of zinc.

In 1920, annual zinc design capacity was based on the ability to accommodate the roasting of 87,600 short tons of ore and concentrate and using all 9,120 retorts for distillation (Rothwell, 1922). The zinc content in ore probably ranged from 45 to 55 percent during this period since the use of high-grade sphalerite ores and sphaleritic concentrates had become the standard feed types from sulfide ore bodies. Using these data it was calculated that the annual zinc design capacity, incorporating an estimated overall 85 percent zinc recovery, through roasting and distillation was between 34,000 and 41,000 short tons of zinc.

In 1922, Donora was reportedly roasting concentrate with an unusually high average feed grade for that time of approximately 60 percent zinc (Rothwell, 1922), containing approximately 53,000 short tons of zinc contained in ore and concentrate on an annual basis. With the plant's 87,600 ton ore and concentrate roasting design capacity, an overall zinc recovery of 85 percent through the smelter complex, plus an 80 percent availability of furnaces, the annual effective plant capacity to recover zinc from roasted ore and concentrates might have been about 36,000 short tons of zinc.

A report published in 1928 described the horizontal-retort furnaces used at Donora. The plant had one dross furnace that contained 608 retorts from which zinc was distilled. In addition, there were nine furnaces with a total of 7,296 retorts to distill roasted and sintered zinc ore and concentrate, three with 608 retorts each, and six furnaces with 912 retorts each. With all of the furnaces and retorts in operation, 100 percent capacity utilization, the plant could potentially produce 135 short tons of zinc on a daily basis (American Association of Mechanical Engineers, 1928).

As was typical of most zinc smelter plants, it was unlikely that maximum design capacity was achieved for any length of time because of batch change-outs, scheduled

furnace rebuilds, frequent retort failures, and other anticipated and unanticipated technical and nontechnical occurrences. To delay maintenance and repairs would sacrifice zinc recovery. Plants operated at perhaps 80 percent utilization of capacity at full production. Based on an estimated annual production of 4.5 short tons of zinc metal per retort production capacity from the 7,296 retorts distilling roasted ore and concentrate, and an 80 percent utilization rate, annual production was approximately 26,000 short tons. Annual effective zinc production capacity from retorts processing dross and skimmings was estimated at 8 short tons per retort or about 5,000 short tons. Productivity was assumed to be higher owing to dross causing less butchering of retorts and the greater efficiencies associated with processing material with a zinc grade that could exceed 90 percent zinc.

Using the above calculations the total estimated annual production potential was nearly 31,000 short tons of zinc per year.

The U.S. Steel annual reports for 1933 and 1934 reported zinc smelter production as 21,723 short tons in 1932, 27,145 short tons in 1933 and 33,588 short tons in 1934 (U.S. Steel Corporation, 1929, 1933, 934). Although the report did not identify the operation by name, it is likely that it was Donora because U.S. Steel's only other zinc smelter, located in Cherryville, Kansas, permanently closed in 1931 (U.S. Steel, 2007).

Production at Donora was reduced owing to the Nation's economic distress during the late-1920s into the mid-1930s and the greater efficiency and lower cost per unit production of more modern vertical retorts at its competitors' smelters.

Cotterill reported that zinc production in 1945 at Donora amounted to 43,000 short tons of slab zinc and stated the plant's capacity in 1947 at 48,500 short tons (Cotterill, 1950, p 26), considerably larger tonnages than production statistics and estimates in the 1930s. These higher tonnage data could not be collaborated. Assuming the statistics reported by Cotterill are correct, the significant increase suggests it was likely that one or more of the following may have occurred around 1940: an increase in the plant's efficiency; a plant expansion to meet the needs of World War II treatment of higher grade concentrates; or increase in the proportion of zinc dross as a component of the plant's feed (the material that accumulates at the bottom of galvanizing baths and skimmings (the zinc oxide accumulation that forms at the top of a galvanizing bath). Dross assayed as high as 95 percent zinc and skimmings ranged 65-85 percent zinc (Ingalls, 1903).

From 1917 through 1934, the number of retorts installed in the facility's furnaces was published in U.S. Bureau of Mines and U.S. Geological Survey Yearbooks, but they did not report on individual plant production statistics. No specific production data was reported by either agency for the life of the facility. Rough production estimates could be made from these data where other data was not available, by using industry averages for zinc production per retort during the time period and considering other operational factors that could contribute to reducing production. Retort utilization in

some years was likely less than the installed capacity and estimates of production should be considered with some caution. Although production statistics for Donora were unavailable, only one-third of the Nation's horizontal retorts were used in 1932 (U.S. Bureau of Mines, 1934) and in 1934 horizontal retort utilization was less than 50 percent, because of the introduction and startup of more efficient vertical retorts and generally poor nation-wide economic conditions (U.S. Bureau of Mines, 1935; p. 113). Numerous other factors for estimating production could not be incorporated into estimates. These included economic and labor conditions, company decisions, technical factors affecting production including breakage of retorts and changes in feed grades, and furnace repair or rebuilding.

Because of the absence of annual production statistics for most years, estimates for some years were calculated based on the assumptions that the installed retorts could potentially produce 4 short tons of zinc per year per retort for the years 1915-19 and 4.5 tons per retort for the period 1920, when zinc dross was introduced as part of the feed, through 1957, the year the plant closed. It also was assumed that plant utilization averaged 80 percent. Plant utilization rates may have been higher during the war years, although, as is often the case, efficiency may have suffered. Zinc production per retort was relatively high at the Donora plant. The zinc content of feed, which at times included dross and skimmings which can assay more than 85 percent zinc, was higher than materials processed at many other smelters. Furthermore, the retorts were slightly larger than those used at some other plants. In 1957, the last year the plant operated, production was assumed to drop by one half because of the process of decommissioning.

Based on the aforementioned estimates and assumptions, it was calculated that Donora's total zinc production was roughly 1.5 million short tons of zinc.

Sulfuric Acid

In 1916, hydrochloric acid was the operation's first saleable acid product and was produced from weak sulfuric acid. Beginning in 1919, the production of concentrated byproduct 98 percent pure-commercial grade sulfuric acid (66 degrees Baume') was initiated (American Society of Mechanical Engineers, 1928) and was an important revenue-generating byproduct.

In the late-1920s the acid plant was expanded from the original 3 units to a total of 6 and was producing at a rate of one ton of sulfuric acid for each ton of concentrate roasted. The Langeloth zinc smelter, using similar technology, was described as possessing the capacity to produce 70,000 short tons per year of sulfuric acid from an equal amount of zinc concentrate (Pittsburgh: The City and the District, 1928). Applying these data, it was estimated that approximately 2.8 million short tons of sulfuric acid was produced over the life of the plant at Donora.

As a check, an estimate of sulfuric acid production for Donora was accomplished using actual production data that

permitted an estimate of sulfuric acid production at the Palmerton smelter. The Palmerton, which also burned supplemental sulfur to increase the sulfur content of gases for acid-making, had a ratio of approximately 1.2 short tons of concentrate feed to 1 short ton of byproduct sulfuric acid. Using this ratio as a basis for estimation, Donora may have produced about 2.6 million tons of sulfuric acid over its 73-year production life.

Other Products

Although the major part of the revenues generated at the operation were generated by the primary product of the facility, zinc metal, other material, primarily metal-based compounds were produced. The zinc and acids produced at the Donora zinc facility were used in the Company's steel plant adjacent to the zinc smelter.

The amounts of byproducts recovered and time spans were not extensively detailed in the literature. In 1928, it was reported that 3,000 short tons of zinc sulfate were recovered (American Society of Mechanical Engineers, 1928).

Byproduct cadmium and germanium was reportedly recovered in 1937, and germanium and indium were recovered in 1947 (U.S. Bureau of Mines, 1949, p.1,332; 1950, p. 259). Statistics reporting on the amounts of the metals recovered and the number of years the metals were produced were not available.

Lead, silver, and other byproducts also may have been recovered when considering the assays of some of the treated ores and concentrates. These metals were recovered as components of compounds and metals and mostly were recovered from leaching dusts and fumes captured in the sinter plant after 1927.

Technology

Although detailed information pertaining to the technologies and their specification at the Donora plant were published in 1916, in the 1920s, and in the late 1940's little has been published referring to production of zinc and other products (Ingalls, 1916; Hofman, 1922; Schrenk and others, 1949).

Donora was among the last of the zinc smelters to close that employed horizontal retorts exclusively, as the use of more-efficient vertical retorts became the preferred technology in renovated and newly constructed plants. In 1949, the major facilities of the plant included roasters, sinter plant, retort furnaces, Waelz furnaces, an acid plant, cadmium plant and retort-manufacturing plant (Schrenk and others, 1949). A series of photographs taken of the furnaces, retorts, and assorted equipment and facilities used at the zinc plant over a span of years are shown in figures 11-12, 14-17, and 26-32. A flow diagram of the operation circa 1945 is shown in figure 33.

Ore Preparation

Ore and concentrate was unloaded from railroad cars into concrete bins from which the ore was taken by bucket crane to the crusher. Through at least the 1940s, the ore and concentrates were dried to 1 percent moisture in two Ruggles-Coles cylindrical driers. Ores and coarse concentrates were crushed and ground to minus 14 mesh (Schrenk and others, 1949). The emissions from the drying plant were directed through a dust-collecting chamber before being discharged to the atmosphere through a chimney (Ingalls, 1916; Windett, 1920). Ores and concentrates likely were blended following drying and sampling to optimize zinc recovery and balance sulfur content for acid-making. It was not until the late 1910s and early 1920s that zinc concentrate produced by flotation became widely available.

Roasting and Sintering

When the plant first opened, ore received by the smelter ranged in grade from 20-60 percent zinc and was roasted in six-Hegeler muffle roasting furnaces, each containing seven hearths. The furnaces were 80 feet long, 18 feet wide, and 22 feet high. Each roasting furnace was fired by producer gas derived from burning coal. Combustion gases from the gas producers passed through flues and exited a chimney. Each furnace roasted about 40-50 short tons of ore over a 24 hour period using about 11 short tons of coal, producing emissions containing 4.5 percent sulfur dioxide by volume. The ore was roasted at approximately 1,000 degrees Centigrade. Although the sulfur content of the ore was reduced from 30 percent by weight in the roasting process, about 2 percent remained in the roasted ore or concentrate, which was not unusual for roasted, but unsintered ores and concentrates derived from sulfides. Using these factors, approximately 98 percent of the sulfur was burned off. Each roaster furnace had its own 120 foot-high concrete chimney measuring 5 feet in diameter at the top to vent combustion gases used to heat the retorts contained in the furnaces. The sulfur-containing roaster gases generated from the ore and concentrate were routed to the sulfuric acid plant. Each pair of roasting units served one sulfuric-acid unit. Roaster gases passed through a centrifugal dust catcher 30 ft. high and 20 ft. in diameter. In roasting Broken Hill (Australia) sulfides at Donora, the dust collected was about 2 percent by weight, of the ore roasted (Ingalls, 1916, p. 648-654). In 1921, roasting capacity was stated to be 87,600 short tons of ore (Rothwell, 1921). In the late-1920s the roasting facility was reported to have a capacity to process about 94,000 short tons of concentrate per year on a 350-day schedule (American Society of Mechanical Engineers, 1928).

Prior to 1927, roasted ore or concentrate, containing from 1.5-2 percent sulfur, was mixed with anthracite, to provide a carbon source for the reduction of calcine, and this mix comprised the charge for the retorts in the distillery. Roasting

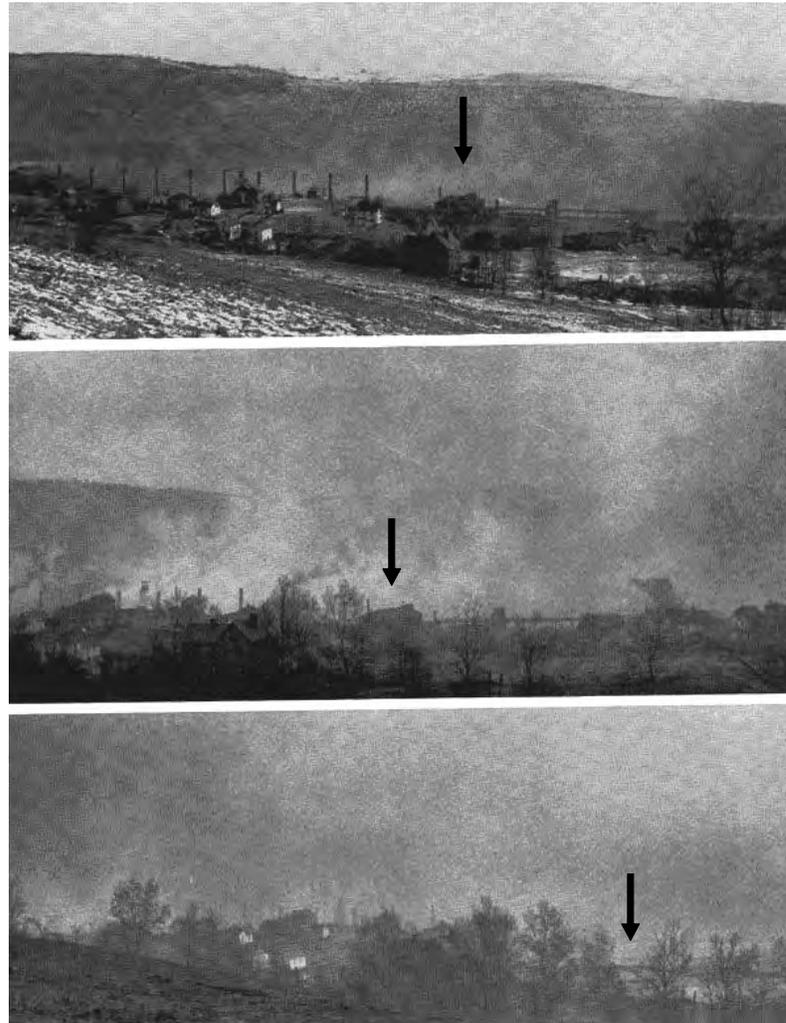


Figure 27. Photographs of atmospheric conditions near the Donora, Pa. zinc plant taken from approximately the same vantage point and time of day on three different days in 1949. The stacks for the furnaces at the zinc plant are visible in the distance in the lower right side of the photographs. Most of the emissions appear to be generated from the buildings that house the horizontal retorts. The superimposed black arrows indicate a building as a reference point for the purpose of comparison between photographs. (U.S. Public Health Service, 1949).



Figure 28. Donora Zinc Works looking northeast, circa 1915. Stacks are dedicated to the plant’s horizontal retort furnaces. Permission for the publication of this photograph was granted by the Donora Historical Society and the California University of Pennsylvania, Library of Congress, Teaching with Primary Sources Program, 2009.

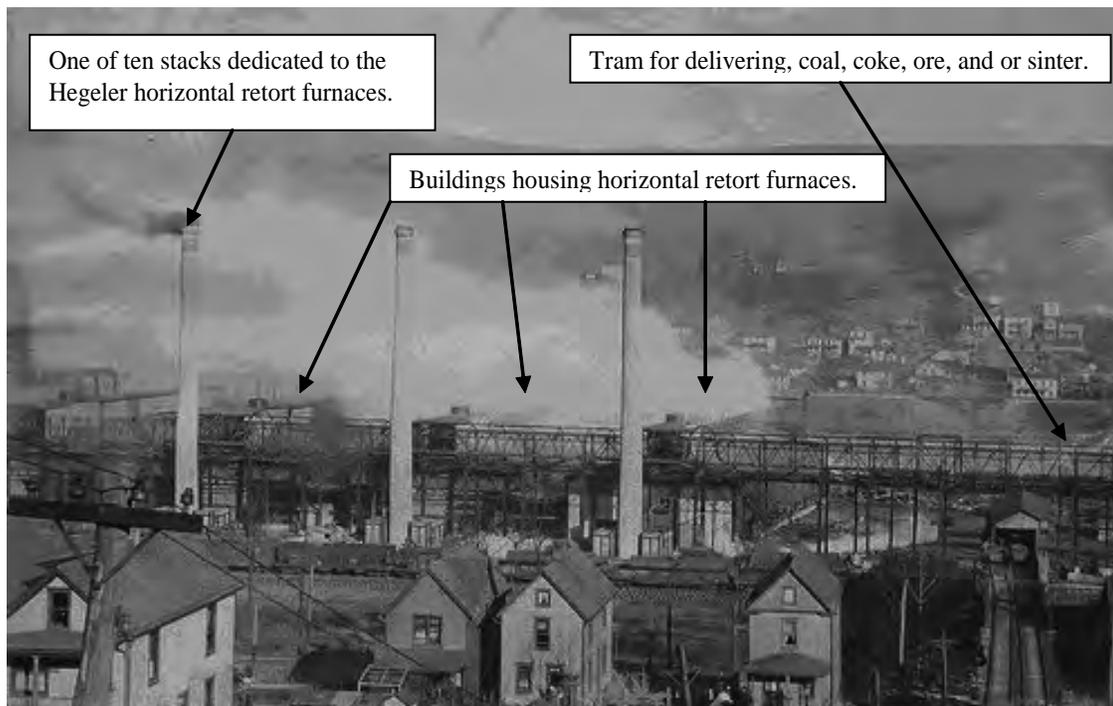


Figure 29a. Photograph of the Donora Zinc Works circa late-1940s. Note plant emissions originating from and “shrouding” the buildings containing the horizontal retort furnaces. Photograph provided courtesy of the Donora Historical Society and Scott Beveridge, 2009.

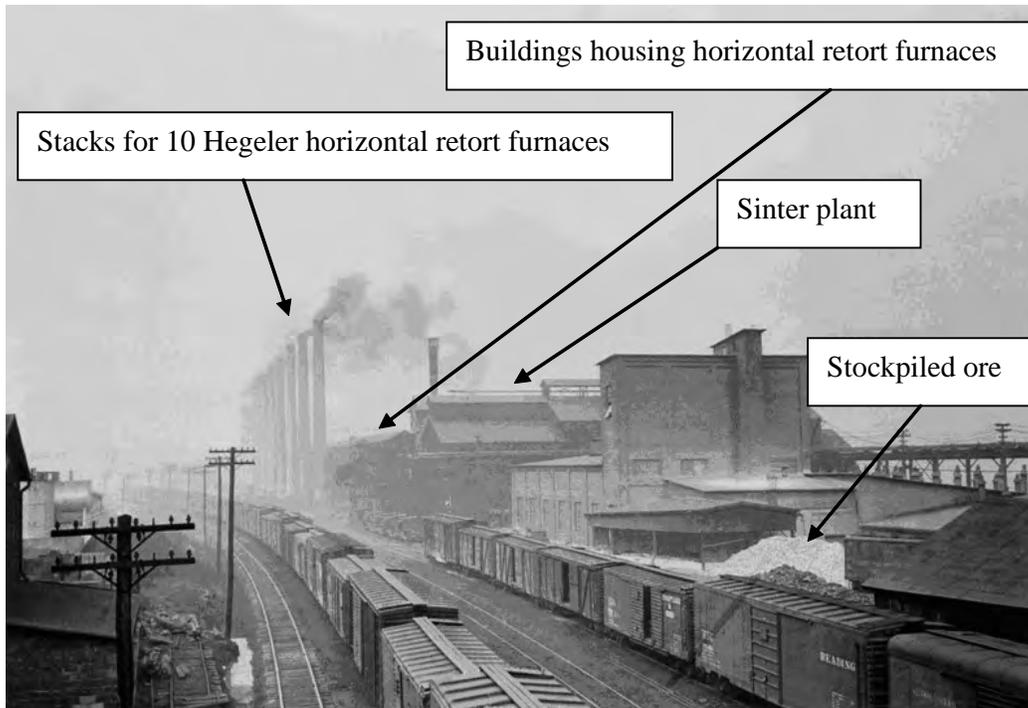


Figure 29b. Photograph of some of the facilities comprising the Donora Zinc Works in Donora Pa., taken a few days after the occurrence associated with the atmospheric inversion on November 3, 1948. The photographer described the site “.....as seen through “fume-laden smoke and fog.” Photograph donated by Corbis-Bettman, 2009.

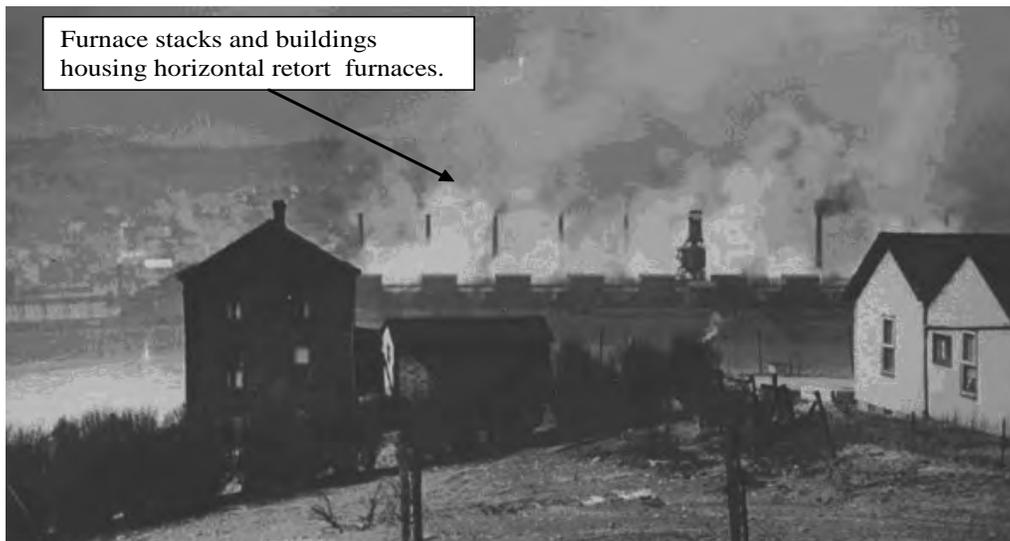


Figure 30. Photograph of the Donora Zinc Works located along the west bank of the Monongahela River (circa 1948) taken from the east bank of the river. Note the emissions originating from the buildings housing the horizontal retort furnaces and the furnace stacks. Permission for the publication of this photograph was granted by the Donora Historical Society and the California University of Pennsylvania, Library of Congress, Teaching with Primary Sources Program, 2009.



Figure 31. Photograph of the Donora Zinc Works possibly taken in 1949 during the data collection phase by the U.S. Public Health Service investigation of the air quality in Donora, Pa. Photograph courtesy of Scott Beveridge and the Donora Historical Society, 2009.



Figure 32. U.S. Public Health Service worker measures air samples from the American Steel and Wire Company's zinc works in Donora during a four day test during April, 1949. An attempt was made to duplicate conditions which caused the deaths of 22 people in October 1948. The Donora Zinc Works are visible in the valley in the background. Most of the white fumes, a characteristic of vaporized zinc, appear to originate from the buildings housing the horizontal zinc retorts. The darker smoke appears to be emitted by the furnace stacks (Image donated by Corbis – Bettmann, 2009).

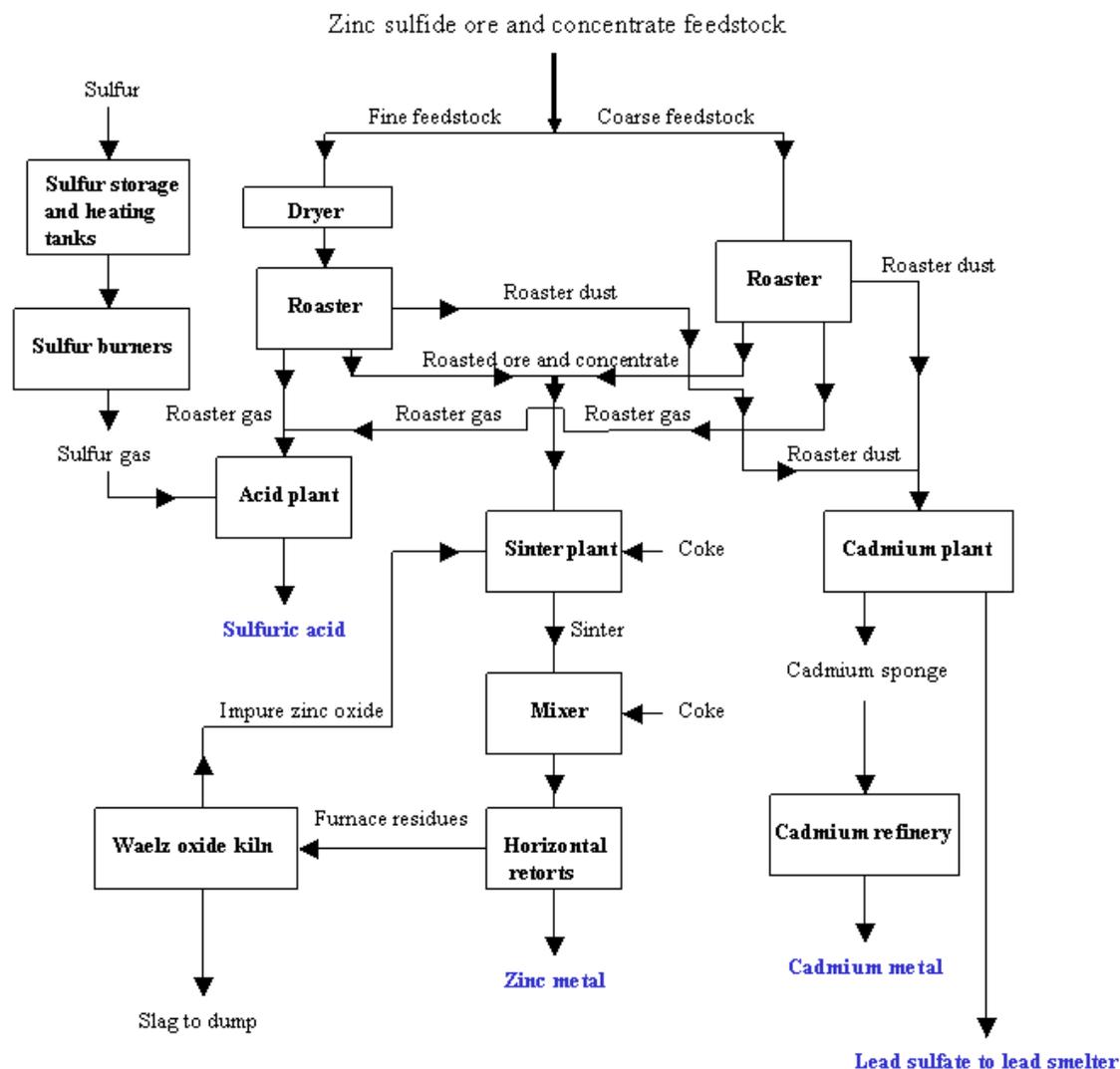


Figure 33. Generalized flow diagram of primary zinc sulfide ore and concentrate at the Donora zinc plant circa 1948. Saleable products in blue. Adapted from a figure provided by and published with the permission of the Donora Historical Society and the California University of Pennsylvania, Library of Congress, Teaching and Primary Sources Program, 2009.

ores and concentrates containing carbonate minerals decreased sulfuric acid production efficiency and harmed the retorts. The presence of fluorite in ore and concentrate was also problematic because the fumes produced during roasting corroded the acid chambers and could damage furnace linings and retorts (Richards, 1909; Worden, 1921).

In the 1940s, it was reported that the fine-grained concentrates (less than 14 mesh) derived from flotation and other fine-grained material were roasted in Herreshoff roasters and coarse ore roasted in a Hegeler furnace. The feedstock was frequently raked in the roasters to ensure complete exposure and maximize the removal of the sulfur contained in the ore. The combustion gases from the two roasters were directed to the sulfuric acid plants (Schrenk and others, 1949).

In 1927, recognizing that the residual sulfur reduced zinc recoveries and affected the quality of the product, a Dwight-Lloyd sintering plant was added to further reduce the amount of sulfur that remained in the roasted ore (calcine) before being sent to the retorts (American Society of Mechanical Engineers, 1928). The sintering plant also served to agglomerate the fine-grained concentrate to permit more efficient movement of zinc fumes and improve the circulation of heat during retorting. The sintering step was also very important to ensure a high quality zinc product by greatly reducing (by volatilization), the amount of cadmium and lead contained in the feedstock. The machine was still in use in the late-1940s and during that time did have Cottrell precipitators to recover dust and fumes. The effluent from the sintering plant was exhausted to the atmosphere through two 110 foot-high stacks (Schrenk and others, 1949)

Retorting

Hofman and Ingalls (Hofman 1922, p205; Ingalls, 1916) described the plant as using 10 Hegeler furnaces, each housing horizontal retorts measuring approximately 52 inches in length and 8 inches in diameter. There were 76 retorts in a row, 6 rows high, for a total of 456 retorts on each of two sides per furnace for a total of 912 retorts. The retorts had a volume of about 1.5 cubic feet and accommodated a charge of ore weighing between 68 and 71 lbs, plus 39 lbs of reductant (anthracite). Zinc was tapped every 8 hours over a 24-hour time period after which it was removed, cleaned, recharged, and replaced in the furnace. Recovery of zinc contained in ore was approximately 80–90 percent and averaged about 85 percent (Hofman, p 205, Schrenk and others, 1949). The furnace's combustion chamber was fired with producer gas at 500 degrees centigrade. Each furnace had two Hughes gas producers. Each furnace required about 3,000 pounds of coal to manufacture producer gas for each ton of ore or concentrate distilled. The waste furnace combustion gases passed through a Rust boiler and then a brick chimney one-hundred and twenty-five feet high and five and a half feet wide (Ingalls, 1916; p 648–654; Hofman, 1922; p. 104, 171, 205, Schrenk and others, 1949). Each furnace had a combustion chamber which measured 315 cubic feet (American Society

of Mechanical Engineers, 1928). Residue from the retorts and broken retorts were placed in a Waelz kiln from which impure zinc oxide was recovered and fed to the sinter plant. The Waelz kiln was a rotating cylindrical-brick-lined furnace that measuring about 120-feet long and 9 feet in diameter. The zinc contained in the feedstock was volatilized as it was heated. The resulting impure zinc oxide was captured in a series of cyclones and Cottrell precipitators and was used as additional feedstock to the sinter plant. The remaining residue, which contained about 1.5 percent zinc, was placed on the slag pile. The Waelz plant was determined to not be a significant source of atmospheric pollution during the investigation performed by the Public Health Service in 1949 (Schrenk and others, 1949).

Although information on the number and type of retorts used to reduce feedstock, through the 1930s was limited, it was reported that the 10 furnaces containing the horizontal retorts were still used for the plant's production of slab zinc in 1949 (Cotterill, 1950; U.S. Department of Commerce, 1933, Schrenk and others, 1949).

Sulfuric Acid-Making

The sulfuric acid production section was built in 1915 as part of the original facility. Two roasters per acid unit were used for acid production (Ingalls, 1916, p. 649).

The acid plants converted sulfurous gases captured from the ore and concentrate roasters into industrial strength sulfuric acid. The roaster gases from the furnaces contained about 4.5 percent sulfur dioxide by volume, which was raised to approximately 8 percent sulfur dioxide by contributions from the burning of sulfur (described in the early literature as brimstone), to meet the sulfur dioxide saturation levels needed for manufacturing sulfuric acid. The sulfur was ignited from the heat of the roaster gases combined with air. About 10,000 to 15,000 pounds of sulfur per furnace was burned daily in this manner. Burning supplemental sulfur for the purpose of acid-making was not unusual during this period of time. Dust settling chambers were employed to remove particulates from the roaster gases prior to reaching the Glover and Gay-Lussac towers to ensure that the final acid products met the desired specifications. Approximately 2 percent of the material roasted was captured as dust in the chambers and recycled as part of retort charges. The cleaned gases were then sent through flues to the acid plant (Ingalls, 1916, p. 649).

In the 1930s, it was reported that the supplemental sulfur for acid making was burned in separate burners, whereas previously sulfur was burned in the dust catchers, and added to the off-gases from the roasters and through a common flue to the acid plant. During this time there were two roasters, each with 16 hearths (Fairlie, 1936; p. 104, 114).

Donora's acid was used by several steel companies in the area for cleaning steel products and converting ammonia to ammonium sulfate at coking plants. It is doubtful that all of the sulfurous emissions from the roasters were recovered in the sulfuric acid plant. Gases, including sulfur dioxide,

generated by sintering ores and concentrates, which often contained about 4.5 percent sulfur, were probably vented to the atmosphere.

It was common practice during this time to discharge excess roaster gases into the atmosphere when not used for the production of acid or when the acid plant was under repair. It also was common practice to release excess sulfur dioxide from the acid plant to the atmosphere.

Hydrochloric Acid

Hydrochloric acid was produced at Donora by heating a combination of the Company's sulfuric acid product and sodium chloride. The resulting hydrogen chloride gas was absorbed in a water mist where hydrochloric acid formed because of the high solubility of the gas with water. The acid was used principally by the steel industry to clean wire before it was zinc-coated. A sodium sulfate byproduct was used by glass manufacturers, paper producers, and other industrial applications.

Other Byproducts

Lead and cadmium were produced, probably as products of leaching residues recovered in the gas-cleaning process ahead of the acid plant and residues or both were captured in the sinter plant. Cadmium metal was recovered in an onsite refinery and lead sulfate was sold to lead smelters.

Plant Emission Estimates and Descriptions

The Donora zinc smelter has been associated with environmental issues related to the plant's atmospheric emissions from the roasting of zinc sulfide ore and concentrate and sintering of calcine.

Air pollution problems caused by the facility were recognized as early as 1918, when the plant's owner settled legal claims for causing pollution, mostly as sulfur dioxide, that affected the health of nearby residents. In the 1920s, residents and farmers in Webster, Pa., less than a mile from the Donora plant, took legal action against the company for damage to and loss of crops and livestock. Although regular sampling of the air was begun in 1926 and stopped in 1935, no records are available.

The Donora zinc plant was at the center of a controversy in 1948 when it was claimed that emissions containing fluorine and sulfur dioxide from the plant, and to a lesser degree other plants in the valley, became trapped in the valley during an atmospheric inversion. The death of 20 people and sickening of a large number of the town's population was attributed to asphyxiation caused by atmospheric pollution (Pennsylvania Department of Environmental Protection, 2008) during the weather phenomenon. Donora closed for part of the year to investigate the "cause and extent of the noxious fumes" (U.S. Bureau of Mines, 1950; p. 1,291; Exner, 1961).

In 1949, the U.S. Public Health Service performed a four-day test in an attempt to duplicate the conditions that produced that allegedly caused the death of 20 people the prior year. Figure 27 is comprised of three photographs illustrating the effects of the zinc plant's emissions on visibility from one viewpoint in an area near the smelter during 1949. Figures 31 and 32 are photographs of the Donora Zinc Works taken in 1949 during the test. Among the findings from the test and other investigations related to the smog occurrence relative to the Donora Zinc Works were that (1) atmospheric emissions from the plant contributed to the death and illness; (2) the zinc plant was a major contributor to atmospheric pollution with "special reference to particulate matter and carbon monoxide;" (3) the highest levels of atmospheric emissions analyzed containing zinc, lead, and cadmium were in the vicinity of the plant; and (4) the sintering operation at the zinc plant was a major contributor to atmospheric pollution, especially for sulfur dioxide (Schrenk and others, 1949).

Other major contributors to emissions in the river valley during this period included coal-powered locomotives, steam-powered engines in riverboats, stationary coal-burning steam generating plants, coke plants, and steel-making plants.

The event contributed to the passage of the first federal air pollution legislation in 1955 (Hess, 1995; Bryson, 1998). Despite its original adoption date of 1955, this Act is popularly known as the Clean Air Act of 1970 (Hess, 1995; Davis and others, 2004).

Zinc Emissions

The most significant sources of zinc emissions to the atmosphere included stack and fugitive emissions, such as dust, that are released to the air from sources other than stacks. These include leaks from equipment, evaporative processes, and mechanical and windblown disturbances.

At Donora, most emissions were generated by handling of ore and concentrate; unloading, crushing and grinding, preparing charges for roasting and retorting, roasting, sintering, leakage during reduction from fractured and failed retorts, diffusion through retorts, escaping zinc fumes from retort mouths, and during the course of removing and replacing retorts. In the late-1940s the roaster and sinter plants were equipped with Cottrell precipitators that would have reduced the emissions produced during drying, crushing, roasting, sintering, and Waelz oxide production. The length of time that the equipment was installed and the amount of reduction in atmospheric emissions by the equipment is not known.

It was estimated that about 5 percent of the zinc produced at the facility, or about 73,000 short tons of zinc equivalents, was released to the atmosphere as a component in dust, fumes, and gas over the 43-year life of the operation. The estimate was based on the following assumptions (1) 90 percent of the feed was from ores and concentrate that required roasting, and the balance in the form of dross, although not roasted, was retorted; (2) the ore and concentrate contained 55 percent zinc; (3) approximately 2.9 million short tons of concentrate was

roasted over the operation's life; and 4) sintering was relatively inefficient at capturing dust and fumes. Table 9 shows that nearly 29,850 pounds of zinc, 400 pounds of lead, and about 332 pounds of cadmium were emitted during a 24-hour period during the test performed by the U.S. Public Health Service in 1949 (Schrenk and others, 1949). Anomalously high levels of arsenic, fluoride, and other materials considered harmful to human health and the environment also were detected in atmospheric emissions during the test. The test was performed when the plant was operating at near capacity levels. The findings reported for zinc in table 9 represents approximately 5 percent of the daily zinc capacity of the plant, lending further support to the estimated zinc losses to the atmosphere calculated for this study.

Other considerations in the estimate included the plant's use of relatively inefficient horizontal retorts and that dust, fumes, and gas, generated from the sinter machine installed in 1927, were not as effectively captured by settling chambers, a baghouse, or other means of capturing material as currently employed devices for most of the facility's operating life.

The zinc emission estimate should be considered with some caution because actual production data were unavailable for many of the years that the plant operated. For some years estimates were made from the number of installed retorts. Therefore, some annual production estimates may not accurately account for factors such as company-specific decisions, local, national and global economic conditions, and interruptions or reductions in production caused by labor and technical problems.

The technologies used, some of which captured material, such as flues and settling chambers used for cleaning sulfur dioxide for acid-making were considered in the estimate.

"On the evening of October 26, 1948, the people of that working class community went to bed not knowing that a suffocating cloud of industrial gases and dust would descend upon them like some biblical plague during the night. Twenty residents died and half the town's population – 7,000 people -- were hospitalized over the next five days with difficulty breathing. The cloud, a poisonous mix of sulfur dioxide, carbon monoxide, and metal dust, came from the smokestacks of the local zinc smelter where most of the town worked." (extracted from U.S. Environmental Protection Agency, 2007, F.Y.I. Report: Donora, Smog Kills, Mid-Atlantic Regional Center for Environmental Information, available at <http://www.epa.gov/Region3/rcei/inthenews/donora.htm>).

Sulfur Dioxide

Not accounting for emissions generated from power, producer gas, and steam generation and other external sources; the primary sources of sulfurous emissions occurred during pyrometallurgical treatment of ore and concentrates, primarily roasting, sintering, and retorting. Releases of sulfur dioxide also probably originated as tail gas from the acid plant. Prior to the installation of the sintering machines in 1927, some sulfur dioxide was emitted from the retorts, as roasted concentrate could have contained up to 4.5 percent sulfur. It is not known if all of the roaster gases were channeled to the acid plant. If there was an oversupply of sulfur dioxide routed to the acid plant it may have been vented directly to the atmosphere. It was a common practice during this time to discharge

Table 9. Estimated pounds per day of zinc, lead, and cadmium discharged into the atmosphere from the Donora zinc plant during air sampling by the U.S. Public Health Service in 1949. (Table adapted from Schrenk and others, 1949).

Facility ¹	Zinc	Lead	Cadmium	Sulfur Dioxide	Total Particulate Matter ²
Cadmium plant	--	--	10	--	13
Sulfuric acid plant	--	--	--	5,000	--
Sinter plant	250	250	100	17,000	2,900
Zinc retort furnaces	24,000	100	220	560	42,500
Waste heat boilers ³	5,200	50	2	34,000	21,600
Total	29,450	400	332	56,560	67,013

¹ Based on emission testing, the Waelz plant and Zinc dross plant were not considered significant contributors to atmospheric pollution.

² Assumed by the author to include particulates from coal-burning to generate producer gas.

³ Emissions from the waste heat boiler plant are the result of use of furnace-combustion gases.

excess roaster gases into the atmosphere when not used for the production of acid or when the acid plant was under repair. Some sulfur fumes and sulfur dioxide may have escaped from burning sulfur, but was not likely significant.

It was estimated based on other operations using similar equipment and feed that about 96 percent of the sulfur was captured in acid, residues, and some products. The balance, approximately 36,000 short tons of sulfur, or 72,000 short tons of sulfur dioxide may have been emitted to the atmosphere based on the following assumptions: (1) 90 percent of the feed was from ores and concentrate that required roasting; (2) the ore and concentrate contained 32 percent sulfur; (3) the dross and other secondary materials that comprised the remaining 10 percent of the feedstock did not contain sulfur; (4) approximately 3 million short tons of concentrate were roasted; and (5) 4 percent of the sulfur contained in zinc feedstock that was roasted may have been released to the atmosphere.

This estimate also should be considered with caution because actual data relating to feedstock and production were unavailable for many of the years that the plant operated.

Sulfuric acid, probably as a vapor, was reported as a plant emission in 1954 (Lipfert, 1994), but no tonnage estimates were provided.

Other Materials Contained in Emissions

The ores and concentrates received as feedstock at the Donora plant originated from ore deposits that represented diverse compositions that contained arsenic, cadmium, fluorine, lead, mercury, and other materials.

A portion of ores and concentrates contained fluorine-bearing minerals, primarily fluorite. When present, most of the fluorine in ore and concentrates would have been vaporized during roasting (Ingalls, 1903; Smith, 1918) and sintering and released as a component of emissions to the atmosphere. The removal of fluorine from the feedstock prior to retorting was desirable from an operational perspective because fluorine was considered deleterious to the value of zinc products. Although fluorite was not used as a flux in the zinc retorts, it was used in nearby steel plants for that purpose.

The amounts of arsenic, cadmium, lead, mercury, and other materials contained in gases, dust, and liberated during the roasting and sintering stages also varied at different times and in varying compositions, depending on the material and mix of materials treated. Anomalously high levels of cadmium and zinc were discovered in air samples near the plant in 1949 (Lipfert, 1994). Table 9 also lists atmospheric emission data collected by the U.S. Public Health Service in 1949 for cadmium, lead, and particulate matter.

On Site Energy Sources and Types

Information relating to energy sources and types during the entire period that the plant operated was not available. However, furnaces were fired by producer gas generated from burning coal (Hofman, 1922, p. 104) at a rate of 2,000 pounds

per hour (Hofman, 1922, p. 171) in the early period of the facility and electricity was supplied by the adjacent steel facility (Ingalls, 1916, p.649).

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Florence Zinc Works, Northampton County, Freemansburg, Pennsylvania

Introduction

Florence Zinc Company's (originally controlled by the Lehigh Zinc and Iron Company) Florence Zinc Works, also known as the Freemansburg plant was located at Florence Siding, near the towns of Freemansburg (alternate spelling Freemensburg) and Bethlehem, Pa. The plant operated from 1891 (Dunn, 1995) and closed in September, 1945 (addendum to New Jersey Zinc unpublished document, 1937). The plant was acquired by the New Jersey Zinc Company (NJZ) in 1897 as part of the "Great Consolidation." Until about 1920, it may have been the only commercial-sized plant in the United States using the indirect process, more widely known as the "French process," to manufacture zinc oxide (Dunn, 1995, page 701). The indirect process used zinc metal, likely supplied by local zinc smelters, such as the South Bethlehem and Palmerton facilities to produce French process zinc oxide (FPO). Zinc oxide appears to have been the only zinc product produced at Freemansburg.

French process zinc oxide had exceptional purity and was more desirable in certain applications than standard zinc oxide produced by the direct method. Uses included pharmaceuticals, pigment for artist paint and other high-quality paints, and as a component in some rubber products.

The plant also may have produced American process (direct process) zinc oxide on an intermittent basis during periods of high demand and insufficient production capacity at NJZ's nearby Palmerton, Pa. plant (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). The process is distinctly different than the French process in that a mixture of ore and a reductant, such as coal, are blended and placed in a stationary-grate furnace and fumes in the presence of forced air. The zinc oxide product's primary use was in paint pigments.

Using very limited data, it was estimated that roughly 2,000 short tons of zinc contained in gas, dust, and fumes were emitted to the atmosphere during the production of roughly 84,000 short tons of zinc oxide in various product forms, containing about 68,000 short tons of zinc.

Map Number (fig. 1)

8

Location

The plant site was located along a rail line in the town of Freemansburg, Pa. at 40°37'35" (40.626389); W075°20'46" (-75.346111).

Alternate Names

Florence Zinc Works
Florence Siding Smelter
Freemansburg Smelter
Freemensburg Smelter

Years of Operation

1891–1945 (Dunn, 1995; p. 701; addendum to 1937 unpublished New Jersey Zinc, post-1945).

Owners/Operators

1891–97—Florence Zinc Company also referred to as the Friedensville Zinc Company (controlled by the Lehigh Zinc and Iron Company).
1897–1945—New Jersey Zinc Company (NJZ)

Primary Products

American Process zinc oxide products
French Process zinc oxide products

Feed Sources and Types

The Horsehead brand of zinc oxide likely was produced at Florence from ores mined in the Franklin-Sterling Mining District in New Jersey (Twitchell, 1914). Franklinite ores predominated in the early years and willemite in the later years. There was no mention of spiegeleisen production from retort residues produced from franklinite in the literature, it might have been treated at Palmerton or disposed as waste.

The French process oxide initially produced at Florence was derived from zinc metal produced from New Jersey ore (Twitchell, 1914) and possibly from mines in the Friedensville, Pa. district. Some zinc-containing scrap probably was also used as feed. Early in the operation's life, when controlled by the Lehigh Zinc and Iron Company, the plant's zinc metal feed probably originated from the South Bethlehem smelter, but after the plant closed zinc metal probably originated from the company-owned Palmerton plant, about 25 miles northwest of Freemansburg.

Production History

Few operational details and production statistics were available for the Florence plant. Sources of information include historical NJZ data relating to the cooperative relationship between NJZ's Palmerton, PA plant and the Florence operation, State bulletins, U. S. Bureau of Mines, U.S. Geological Mineral Yearbooks and other literature; and discussions with industry experts. In 1917, the operation was described as "substantial," (Gardner, 1917) but no quantitative information

for comparison on the application of that term was provided. Using the limited data and some broad assumptions, the relative size and historical production of the zinc oxide operation was estimated.

French Process Zinc Oxide (FPO)

Based on limited information, it was estimated that the plant produced FPO at Florence from 1891 through 1923 and from 1927 through 1945. Based on unpublished information containing partial production data for the periods 1921–24 and 1927–45, it was estimated that the Florence plant's annual FPO production likely did not exceed 1,000 short tons in any of those years and was probably less in years prior to 1923, perhaps 500 short tons. It was estimated that roughly 36,000 short tons of zinc oxide was produced during the operating life of the plant, containing up to 29,000 short tons of zinc.

United States Pharmacopeia (USP)

United States Pharmacopeia (USP), a high-purity medical grade zinc oxide, was produced at Florence from about 1918–45 (NJZ, 2008; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). The production line may have been closed for the period 1925–26. In 1937, 496 short tons of USP were reportedly produced at Florence, during a period of high zinc plant capacity utilization in the United States. Examining historical production statistics, it is unlikely that Florence's share of USP production averaged more than 500 short tons per year or 13,000 short tons in total containing up to 11,000 short tons of zinc (NJZ, 2008).

Kadox

In 1923, plant capacity was increased at Florence with the production of Kadox, a NJZ trade name for a FPO with a standardized composition (NJZ, internal report, post-1945; NJZ; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008) used as a pigment in paints, rubber, and other specialty uses. The addition of furnaces to produce Kadox appears to have coincided with the installation of the first Kadox furnaces at Palmerton in 1922–23 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Although no annual production statistics were encountered in the course of research, annual production was probably not greater than 500 short tons, or 12,000 short tons of total plant production from 1923 through 1945.

Horsehead Zinc Oxide

Although Freemansburg's chief product was zinc oxide produced from fuming zinc metal using the French process (indirect process), some lower purity Horsehead brand zinc oxide using the American process from mixed oxide ores and concentrates mined in the Franklin District of New Jersey or other sources may have also been produced for a period from about 1910 and continued up until about 1918 or into the early 1920s (Dunn, 1995, p. 701; U.S. Geological Survey,

1912, p. 286; Hofman, p. 283, 1922; 2008, Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; Twitchell, 1914). Based on NJZ data, Horsehead production at Florence re-commenced from 1933–43 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008, NJZ, 2008). The annual production of Horsehead zinc oxide production might have varied significantly from year to year, as the Florence plant may have processed surplus New Jersey ores that Palmerton was not able to accommodate during periods of peak production or during periods of maintenance affecting production (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Although production statistics were not available, it was assumed that the average annual production did not exceed 1,000 short tons per year or a total of roughly 25,000 short tons over its production life.

Total Zinc Oxide Production

Overall, the Florence operation was a comparatively small zinc oxide plant, as evidenced in part by the limited amount of published information, but was significant during its earlier years of production in that it was the sole producer of high-purity zinc oxide using the French process in the United States (Dunn, 1995). Total production of the four types of zinc oxide products was estimated at roughly 84,000 short tons over the plant's operating life or about 68,000 short tons of zinc equivalents.

The annual and total production estimates are based on numerous assumptions because of the limited amount of statistical and technical data, and for those reasons should be considered with caution.

Products and Technology

The primary products manufactured at the Florence plant were high-purity zinc oxide, produced using the French process and zinc oxide using the American process. The French process-derived products varied slightly in their chemistry and were called by different trade names, but were all FPO. In the late 1890s to early 1900s, the plant's zinc products traded under the names Florence Red Seal and Florence Green Seal and reflected different levels of zinc oxide purity (Gardner, 1920). Later, after the plant was purchased in 1897 and rebuilt in 1909 by NJZ, the products were traded under NJZ brands and standard industry trade names such as Horsehead, USP, FPO, and Kadox. USP zinc oxide was the purest form of zinc oxide available on the market and found use in medical and other applications. Kadox, a highly pure zinc oxide product used in rubber products, was developed by NJZ and continues to be sold by the Horsehead Corporation.

The lower purity, more widely used Horsehead brand zinc oxide produced using the American process, was a high-demand product which was added as a pigment to paints and other applications.

Technology

Information relating to the technologies employed at the Florence plant to produce zinc oxide was fragmented. As a result, the following description is based, in part, on conjecture. The plant produced several types of FPO, but they all depended on volatilization and oxidation of zinc fumes from molten zinc metal, distinctly different from the indirect or American process that fumes ore to recover zinc oxide.

From 1891 until about 1918 zinc oxide was produced using the indirect process, also referred to as the French process. Specific operating details of the Florence plant were not available. In 1907, the production of zinc oxide in 1907 directly from zinc metal at the facility entailed the boiling and fuming of zinc metal contained in retorts with upward pointing mouths. The resulting zinc fumes emanating from the retorts were directed to an air-enriched chamber where zinc oxide flakes formed upon making contact with the air. Less pure zinc oxide would accumulate at the bottom of the chamber while the lighter high-purity zinc oxide was captured in a baghouse (Holley, 1909; Hofman, 1922). In 1909, NJZ rebuilt and modified the plant with a higher capacity (NJZ internal report), but technical details were not available.

The recovery of zinc using the indirect French process by the methods employed at the plant was high, probably 97 percent and higher. Recovery of zinc in zinc oxide produced using the direct or American process probably ranged from 85 percent to 90 percent.

United States Pharmacopeia

Beginning in 1918, USP zinc oxide was produced using a newly installed melting pot. In this process, zinc vapor was produced from a boiling bath of zinc metal. The addition of air caused the zinc vapor to burn, oxidize, and precipitate as flakes as it cooled. The resulting zinc oxide flakes were collected in a baghouse. A settling chamber to collect impure zinc oxide also may have been used prior to the baghouse. This circuit shut down in 1925 resumed operation in 1927, and remained operating until the entire plant shut down in 1945 (Addendum to unpublished document, 1937; Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008).

Kadox

In 1923, Kadox was produced using newly installed electric furnaces to melt and vaporize zinc metal. The addition of the furnaces increased the plant's overall capacity (Addendum to unpublished document, 1937; Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008).

Horsehead Zinc Oxide

According to NJZ records, the Florence plant may have produced Horsehead brand zinc oxide from 1910 (or before) until 1923 and from 1933-43. The plant used the established

method of furnacing charges of zinc oxide ores from New Jersey mixed with anthracite or coal in stationary-grate furnaces, volatilizing the zinc, and combining zinc fumes with introduced air. The resulting reaction formed zinc oxide flakes as the material cooled which were captured in a baghouse and packaged for sale. It is not known if the stationary-grate furnaces were replaced with more efficient furnaces using travelling grates when the plant restarted production of Horsehead brand zinc oxide in 1933.

Emission Estimates

Zinc losses to the atmosphere as dust, fumes, and gas during zinc oxide production using the indirect French process were approximately two percent of the recovered zinc in zinc oxide, mostly from leaks in conduits, the bag room, and packaging products for shipping and distribution.

Losses from the furnacing of New Jersey ores to produce Horsehead brand zinc oxide using the American process was higher, possibly 5 percent. Sources of fugitive and stack emissions included unloading feedstock at the site, drying and preparing charges for the furnace, loading, stirring charges during furnacing, and unloading the zinc-depleted charges, leakages from the furnace stack, conduits, baghouse, and packaging products for shipping and distribution. Greater losses were experienced with the use of stationary-grate furnaces when compared to traveling grates because the furnace charge need to be manually loaded and unloaded for each cycle. Using these estimates, roughly 2,000 short tons of zinc equivalents were emitted to the atmosphere from an estimated production of 84,000 short tons of zinc oxide containing about 68,000 short tons of zinc. Owing to the absence of actual production statistics, this estimate is based on numerous assumptions and should be considered with caution.

Other than zinc; fugitive and stack emissions in dust, fumes and gas, from the Florence plant were essentially devoid of deleterious metals and sulfur. High purity zinc metal was used to produce FPO, and oxide ores from New Jersey, which were used to produce APO, were highly valued because of their absence of materials that negatively affected the quality of zinc products, such as cadmium, lead, and sulfur.

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Zinc Metal and Zinc Oxide Plants of the Lehigh Zinc Company and Friedensville Zinc Company, Lehigh County, Pennsylvania

Introduction

The historical Friedensville Mining District is located about 5 miles south-southwest of Bethlehem, Pennsylvania. Most of the zinc and zinc oxide recovered from the ore extracted by the mining activities in the Friedensville Mining District of Pennsylvania were treated at the smelters located in Bergen Point, New Jersey and South Bethlehem, Pennsylvania in the early years of production to about 1900; and at the Palmerton, Pennsylvania smelter until 1983. Ore production in the District was not continuous over this span of years. Figure 20 is a photograph of an early underground mine in the District taken in 1915.

In the 1880s, there were several small roasting, zinc metal, and zinc oxide plants that operated on an intermittent basis within the Friedensville District. They were located at the Ueberroth, New Hartman, and Old Hartman mine sites, and possibly at the Correll-Saucon mine site, all of which are within one-half mile of each other. Identifying the history of ownership of the properties is complicated by leasing arrangements, foreclosures, and corporate takeovers. The properties were consolidated when they were purchased by the New Jersey Zinc Company in 1899, and they remained idle until 1958 when they began producing again, as the Friedensville Mine (Schanz, 1963, p. 9).

From the limited amount of available data, it does not appear that any of the zinc metal or zinc oxide plants operated for any length of time, perhaps 3 years or less. The mines focused primarily on the extraction of nonsulfidic zinc ores; however, in the early 1880s, the roasters may have been used to treat some ores prior to shipment to other zinc metal and zinc oxide plants. Some open-roasting of sphalerite occurred at sites within the District and could have occurred at or adjacent to these sites, but the locations are not clearly documented.

Historical information pertaining to the pyrometallurgical operations at the sites was limited. The zinc ore at Friedensville was recognized for producing high-purity zinc metal and zinc oxide owing to the virtual absence of any deleterious metals such as arsenic, cadmium, and lead in the ore (Bob Smith, Geologist, Pennsylvania Geological Survey, oral communication, August 9, 2004). Zinc was therefore the primary metal released to the atmosphere as dust, fumes, and gas. Sulfur was also released from sphalerite, primarily from any roasters located at any of the sites. However, the open roasting of ore may have been the most significant emission source of sulfur, plus zinc, to the atmosphere at any site where it occurred. Emissions to the atmosphere as a result of burning coal and wood as a fuel and coal as a reductant also occurred.

Technical data and production statistics related to the roasters, zinc oxide, and zinc metal plants were insufficient for

estimating total zinc and zinc oxide production, and to develop an estimate of zinc emissions. Considering the intermittent nature of the pyrometallurgical plants, the production of the two zinc-based products and atmospheric emissions were not significant, however the release of sulfur, plus zinc from heap-roasting, also not quantified, could be of some significance.

Ueberroth mine site (N40°33'56") (W075°23'52"); (40.565556) (-75.397778)

The Friedensville Zinc Company purchased the mine from the Lehigh Zinc Company in 1881 (Miller, 1924, p. 57) and erected a roaster and a small zinc metal smelter in the same year adjacent to the company's Ueberroth open pit and underground mines. Ingalls reported that a small zinc metal plant was constructed at the site in 1888 and began operating at the end of the year, but closed a year or so later (Ingalls, 1908; p.287). This conflicts with the date published by Miller, unless it was a new plant, misidentified, or the date of one is in error. Although not stated in the literature, it is possible that some ore was reduced in the Ueberroth's roaster prior to shipping. No information on the capacity and production of the pyrometallurgical plants was encountered.

The Ueberroth mining operation was the largest in the Friedensville District. Most of the mined ore was transported to New Jersey for smelting until about 1885 or 1886, after which the ore was treated at the Ueberroth plant or at the facility at South Bethlehem, Pennsylvania (Miller, 1924, p. 57; Miller, 1941; p. 330).

The Ueberroth mining operation extracted ores up until about the year 1900 (Miller, 1924; p. 80).

Old Hartman and New Hartman mine site at N40°33'16" (40.554444); W075°24'18" (-75.405)

Also in 1881, the Friedensville Zinc Company constructed a roaster, zinc oxide furnaces, and baghouse at the site occupied by the Old Hartman and New Hartman mines. The mines were purchased as part of the same agreement with the Lehigh Zinc Company in 1881 (Miller, 1924, p. 57). As with the Ueberroth mine site, most of the mined ore was transported to New Jersey for smelting until about 1885. Although not stated in the literature, it is possible that some ore was reduced in the roaster prior to shipping to New Jersey. The ore was apparently treated at the company's zinc oxide facilities at the Hartman site after 1885 and until about 1890, and/or at the zinc plant located at South Bethlehem, Pennsylvania (Ingalls, 1908; p. 287, Miller, 1924, p. 57; Miller, 1941; p. 330).

Correll (Saucon) mine site (N40°33'35") (W075°23'54"); (40.559722) (-75.398333)

Ingalls (Ingalls, 1908; p. 287) stated that the Lehigh Zinc Company constructed a beneficiation plant, smelter, and oxide

plant at the Correll Mine; also known as the Saucon mine prior to 1880. No collaborative information of the plant's existence was discovered through research. However, the roaster and oxide plant at the New Hartman property was located about 200 feet west of the Correl property line and this may have caused some confusion.

Map Number (fig. 1)

9

Feedstock, Production Technology, and Atmospheric Emissions

Few specific details on the design of the operations used to roast ore and produce zinc and zinc oxide at the sites were available, but given the time period and their limited use, they were likely small and relatively inefficient. Ores recovered from the surface and in the near-surface areas of underground mines consisted of sphalerite and sphalerite altered to hemimorphite and smithsonite. The chief ore mineral 200 feet below the surface was sphalerite. In the early years of the district (1850s), the oxide ore, containing about 40 percent zinc, was amenable to producing zinc metal or oxide without roasting. Through the use of selective mining techniques, these high-grade ores were nearly exhausted by the late-1870s. Subsequently, sphalerite ores averaging about 20 percent, associated with pyrite, zinc predominated (Smith, 1977; p. 142).

Roasting

It was necessary to roast sphalerite ores and carbonate ores before they could be used for the manufacture of zinc metal or zinc oxide. During this period there were two methods employed for roasting ores at Friedensville, reverberatory-furnace roasting and heap or open roasting.

High grade sphalerite ores and high grade concentrates produced through jigging were sent directly to reverberatory roasters where, after a period of up to 24 hours of roasting, nearly 95 percent of the contained sulfur was removed. By the 1930s, these types of furnaces were used only in sparsely populated areas because of the high amounts of sulfurous gas emissions (Fairlie, 1936). Ore was loaded manually and unloaded from the roasters. Virtually all of the burned sulfur and a significant amount of dust containing zinc were emitted to the atmosphere during the process, because there were neither emission controls nor acid plants.

Hand-picked, high-grade ores were sometimes heap-roasted or sent directly to the reverberatory roasters. Lower grade ores also were heap roasted, and depending on the amount of sulfur removed were sent to either the furnaces to produce zinc oxide or were re-roasted in the reverberatory furnaces and sent to the zinc metal plant (Miller, 1924, p. 334; 350). In the 1870s, the heap roasting process in the Friedensville District was described at the Ueberroth site as

ore piled in mounds that measured 26.5 feet x 14.5 feet and 8 feet high suspended on iron grates and underlain by a wood fire (Miller, 1924; p. 334). The piles would be disturbed from time-to-time to ensure burning of the sulfur contained in the ore. Applying the dimensions of the mound and incorporating several assumptions, such as angle of repose, void space, sulfur content, percent ore in relation to gangue, and specific gravity it was estimated that perhaps 30 short tons of sulfur could be eliminated during heap roasting and emitted to the atmosphere. Stated more simply, for every 100 short tons of sphalerite containing 32 percent sulfur that was open roasted, approximately 30 short tons of sulfur was released to the atmosphere, assuming that 95 percent of the contained sulfur was eliminated through burning. The roasting process could last from as little as 10 days to as long as 70 days (Austin, 1909; pp. 84-85). Heap roasting in general was considered a nuisance owing to the generation of sulfurous emissions which damaged crops, livestock, and vegetation (Austin, 1909; p. 84).

Except for the Ueberroth site, there was no information stating that heap roasting was performed at the two other sites, although it is not unlikely because it was practiced in the District.

The absence of data did not permit an estimate of sulfur and zinc emissions generated during roasting.

Zinc Oxide Production Technology

The process for producing zinc oxide is described in detail in other parts of the study. In brief, zinc oxide was produced by loading a mixed charge of calcined or roasted zinc ore or oxide ore with a reductant, usually coal, onto a stationary grate that was heated above a layer of coal. Zinc fumes generated by volatilization were mixed with air and cooled through a series of conduits. Zinc oxide flakes formed that were captured in cotton bags as the air current carrying the flakes was passed through them. The number of bags in a baghouse could reach several hundred, although the oxide plant at these plants was likely much smaller. Zinc escaped as dust, fumes, and gas during unloading ore, preparing charges, loading and emptying the furnace, through cracks in the furnace, leakages from conduits and in the baghouse; and through packaging of the zinc oxide product in barrels.

Production data were insufficient to estimate losses through atmospheric emissions during the period the oxide plants operated.

Zinc Metal Production Technology

Information pertaining to the technical details of zinc metal production at the Correl (Saucon), Hartman, or the Ueberroth sites was not encountered in the literature. The typical design of a zinc metal plant during this period included the use of horizontal retorts containing a mixture of reduced or oxide ore and a reductant, usually coal. The retorts were

heated externally in a furnace containing the retorts. As the temperature of charge in the retorts exceeded the boiling point of zinc it formed a metal vapor which condensed to a liquid metal in a condenser at the end of the retort from the molten zinc was collected and poured into molds.

Zinc emissions as dust, fumes, and/or gas were generated during different stages required to produce zinc. These included the unloading of ore, preparation of the charges, loading and emptying the retorts, losses through cracks in the retorts and complete failure of retorts; and escape of fumes during retorting from the mouth of the retort.

Production data were insufficient to estimate losses contained in atmospheric emissions during the period the oxide plants operated, but was probably quite low.

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Monaca Zinc Smelter, Josephstown, Beaver County, Pennsylvania

Introduction

The Monaca electrothermic zinc smelter, operating since 1931, used primary zinc sulfide concentrate as all or part of its smelter feedstock from 1931–2002, supplied almost continuously from company-owned mines in New York and Missouri, and in many years purchased ore and concentrate from domestic and foreign mining operations owned by other companies. In addition, the plant also processed secondary-sourced feed in the form of high-zinc drosses and skimmings since at least the mid-1940s. Dross assayed about 95 percent zinc and skimmings from 65–85 percent zinc (Ingalls, 1903, p. 579). By the 1980s, in response to the increased costs of environmental compliance, lower zinc prices, and available secondary zinc sources, the ratio of primary zinc concentrate feed to secondary zinc feed began to decrease. In 1985, about 20 percent of the operation's zinc production originated from secondary sources and about 80 percent from concentrate. In 1990, production from concentrate and secondary feed were approximately equal and by the late-1990s the secondary feed was responsible for about two-thirds of the plant's zinc production (Terry Beckwith, Director of Quality Assurance, Monaca Plant, PA, Horsehead Industries, oral commun., 2007). Electric arc furnace residues or dusts (EAF dust) have been received in increasing amounts since the mid-1980s. In 2006, the smelter relied entirely on secondary sourced-zinc feed, mostly as EAF dust. Monaca is recognized as the world's largest recycler of zinc-bearing materials. In addition to slab zinc, zinc oxide, zinc and powder and other zinc-based products the plant has produced refined cadmium, distilled mercury, sulfuric acid, and a lead cake byproduct containing copper, indium, lead, precious metals, and zinc sulfate.

It was calculated that the smelter's total zinc production for the period 1931–2006 was approximately 9.6 million short tons of zinc in slab, oxide, and powder; and 8.8 million short tons of zinc equivalents for the period 1931–2002, after which the plant no longer treated primary zinc concentrates, relying on secondary material entirely as feedstock.

Based on limited data and numerous assumptions it was estimated that between 260,000 and 350,000 short tons of zinc equivalents as dust, fumes, and gas may have been emitted to the atmosphere from the zinc plant for the years 1931 through 2002, the last year sulfidic concentrates were processed as a component of the plant's feedstock. Based on limited data, it was calculated that roughly 63,000–94,000 short tons of sulfur, equivalent to approximately 126,000–188,000 short tons of sulfur dioxide, were emitted to the atmosphere primarily from the treatment of concentrate and production of acid during the period 1931–2002.

Materials contained in reductant and coal for energy and steam production are not included in atmospheric emission estimates.

Map Number (fig. 1)

10

Location

The Monaca smelting facility is located in the city of Josephstown, Pa. at N40°40'16" (40.67111); W080°20'50" (-80.334736) and occupies an area of approximately 263 acres (EMJ, 1964).

Years of Operation

The plant began producing zinc oxide as the primary product and byproduct sulfuric acid for the local steel industry in 1931. The plant continued to operate as of 2008, but has undergone significant technical modifications and treats only secondary material.

Ownership

1931–81—St. Joe Lead Corporation (renamed St. Joe Mineral Corporation in 1972).

1981–87—St. Joe Mineral Corporation (wholly owned by Fluor Corporation).

1987–2003—Zinc Corporation of America (ZCA).

2003—Horsehead Corporation, (Horsehead Industries, the parent company of ZCA, went bankrupt and its assets were acquired by Horsehead Corporation. (Horsehead Corporation, 2008, Company website at <http://www.horsehead.net/ourcompany.html>).

Primary Products

Zinc metal
Zinc oxide
Sulfuric acid

Plant Feedstock

The Monaca smelter at Josephstown, Pa. originally was constructed by the St. Joe Lead Corporation to produce zinc oxide from primary zinc sulfide concentrates. By 1936, the plant started producing zinc metal from the concentrates. In the 1940s the plant's feedstock also included material from secondary sources, primarily high-grade dross and skimmings. Dross assayed about 95 percent zinc and skimmings from 65–85 percent zinc (Ingalls, 1903; p. 579). By 1980, the plant was treating about 20 percent secondary feed and 80 percent concentrate. A generalized process flowsheet of the Monaca

plant during this period is presented as figure 34. It was during the late-1980s and into the early 1990s that a major effort was undertaken to treat calcined EAF dust and purchase secondary zinc materials that were mostly oxidic to recover contained zinc (Williams, 1990). The percentage of secondary feed continued to grow and in 1990 was approximately equal to primary zinc feed. By the late 1990s, the feed was approximately one third EAF dust, one third dross, skimmings and other secondary material, and one third zinc sulfide concentrate (Terry Beckwith, Director of Quality Assurance, Monaca Plant, PA, Horsehead Industries, oral commun., 2007). In 2002, the plant relied solely on secondary sources of zinc, when roasting of primary feed was discontinued. Figure 13 is a generalized flow showing the recovery of zinc and various byproducts produced from recycling EAF dust.

Primary Zinc Concentrate Grades and Sources of Primary Feedstock

Information on primary feed sources, concentrate chemistry, and tonnages for many of the years that the smelter treated zinc sulfide concentrates was unavailable. Sufficient data was found in the company's annual reports and other sources; however, to determine that roughly half of the plant's primary zinc concentrate feed originated from company-owned zinc mines located in the Balmat-Edwards District in Saint Lawrence County in upstate New York. The district included the Balmat (1930-2001), Edwards (1915-80), Pierrepont (1982-2001), and Hyatt (1974-98, on an intermittent basis) mines, located in close proximity to each other. Over the life of the operations, these mines produced approximately 43 million short tons of zinc ore averaging 9.5 percent zinc head grades and a zinc concentrate grading about 55 percent zinc. Lead concentrates containing some zinc were also produced (Internet Bankruptcy Library (IBL), 2002). Approximately 7 million short tons of concentrate containing about 3.3 million short tons of zinc were produced through about 2002, with most of it reporting to the smelter in Josephtown. Like many smelters located on or near access to ports, the Monaca plant was able to supplement feed from company-owned sources by purchasing zinc concentrates on the world market.

The following is a generalized timeline showing primary zinc concentrate source-related information for the Monaca Smelter as found in published literature but does not fully represent all sources, tonnages and chemistries, due to the limitations of available data.

From the time the smelter first opened up until the early 1940s, virtually all of the plant's zinc concentrate originated from the Balmat-Edwards District (Lund and others, 1970). Supplemental zinc concentrates produced from the Minerva No.1 zinc-fluorspar mine, near Cave In The Rock, in southern Illinois were shipped to the Josephtown smelter by barge, in varying amounts, in some years from 1943 through 1976 and again from 1989 until 1996 (Mindat.org, 2008; U.S. Bureau of Mines 1956, p. 406), when the mine closed. The actual

amount of concentrate received from the operation in total or in specific years was not available. Tables 10 and 11 show assays of zinc concentrates produced at the Balmat facility, much of which was shipped to Monaca for smelting.

The need to increase zinc production to meet the increase in demand for zinc-containing material to support the country's material requirements for World War II, and the inability for some zinc operations to reach European smelters because of difficulties in transocean transport because of hostilities resulted in the purchase of additional zinc concentrates from Canada, South America, and from other domestic mining operations. The company's 1948 Annual Report stated that the plant received approximately 63,000 short tons of concentrate from its New York mining operations and an additional 120,000 short tons from other foreign and domestic mining operations.

In the 1950s, in addition to the feed received from the Balmat-Edwards District, concentrate continued to be shipped to the plant from zinc mining operations from other U.S. and foreign sources. During this period, concentrate feed averaged about 56 percent zinc, 32 percent sulfur, and also contained unspecified, but potentially recoverable amounts of cadmium, lead, mercury, and iron, with traces of copper and silver (St. Joseph Lead Company, 1956).

In the early 1960s the Monaca smelter continued to receive concentrates from the Balmat-Edwards District in New York. In 1961 and 1962, zinc concentrate from the Austinville and Ivanhoe mines in Virginia were treated at several smelters, including the Monaca smelter (U.S. Bureau of Mines, 1963; p.1120), but the amount received and treated at Monaca was not available. The smelter also received zinc concentrates from the Indian Creek and the Leadwood mines in Missouri during this period and from other states and foreign countries, but again, the amounts treated are unspecified (U.S. Bureau of Mines, 1963; p. 889, p. 903). In 1969, it was reported that the plant received concentrate from 15 sources and blended them, based on their chemistry into three types of concentrate, each suitable for a separate type of zinc product (Lund and others, 1970, p. 553). Table 12 provides grade data for the three types of blended concentrates (Lund and others, 1970).

The "cleanest" concentrates, containing little or no cadmium lead, or other impurities were sent to the zinc oxide and high grade circuits. Other concentrates were also blended to meet the specification of Intermediate and Prime Western grade products. It was stated that 99 percent of the mercury, 96 percent of the sulfur, 90-94 percent of lead, 34-35 percent of tin and 18-19 percent of the cadmium were eliminated from the feedstock while roasting during the same time period (Lund, 1970; p. 551).

In the mid to late-1970s, virtually all of the concentrate produced from the Company's mines in the Balmat-Edwards District was shipped to the Monaca smelter and comprised almost half of the concentrate supplied to the smelter. During this period significant amounts of feed were received from other domestic and international zinc operations. The balance of the plant's primary feed continued to originate from other

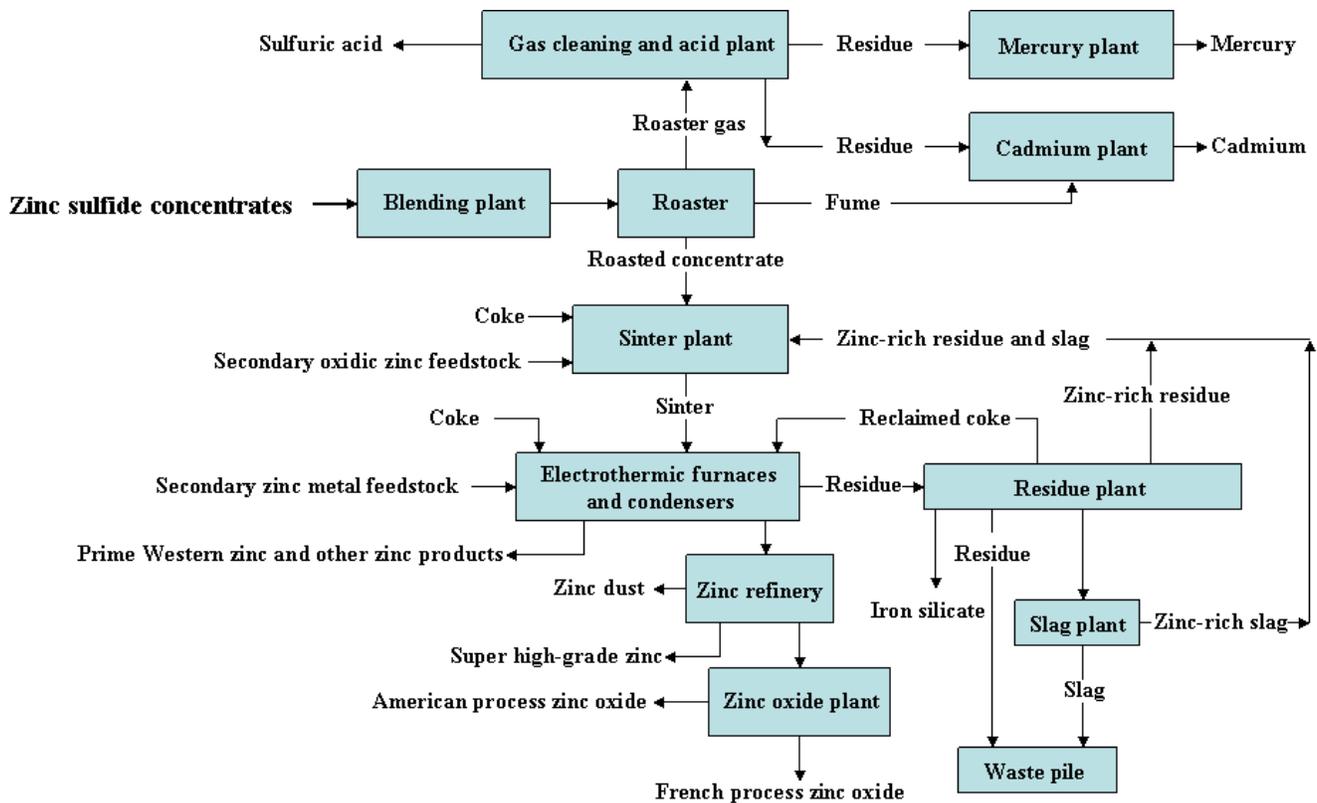


Figure 34. Generalized flow of sulfidic primary zinc and secondary zinc feedstock at the Monaca zinc plant as it existed in the 1970s (Modified from Bounds, 1983).

Table 10. Assay results from a sample of zinc concentrate produced from ores at the Balmat Mine, New York. Mercury content was not reported. (Adapted from Rodier, D.D., 1990, An overview of silver and trace metal recovery strategies in the zinc industry, in Lead-Zinc '90, Anaheim, Calif., February 18-21, 1990, Proceedings: Warrendale, PA., The Minerals, Metals & Materials Society, p. 57-85).

Zinc, pct.	Sulfur, pct.	Iron, pct.	Cadmium, pct.	Copper, pct.	Lead, pct	Indium, pct	Silver, g/mt
55.5	31.3	4.8	0.11	0.09	0.7	0.004	14

Table 11. Balmat-Edwards concentrate grades received at the Monaca zinc plant in 1989 (Williams, 1990, p. 443)

Zinc (%)	Iron (%)	Silica (%)	Lead (%)	Mg (%)	Calcium (%)	Cadmium (%)	Mercury (%)
56.0	5.0	2.0	0.90	0.90	0.70	N/A	N/A

Table 12. Three types of primary zinc concentrates blended at the Monaca zinc plant in 1969 for the production of specific types of zinc metal products. From: Lund, R.E., Winters, J.F., Hoffaker, B.E., Fusco, D. M. and Warnes, D.E., 1970, Josephtown Electrothermic Zinc Smelter of St. Joe Minerals Corporation Monaca, Pennsylvania, in Cigan, John M. and Cotterill, Carl H. ed., p. 555 Lead & Zinc, v. II: New York, NY, The American Society of Mining, Metallurgical, and Petroleum Engineers, Inc.; p. 549-580).

Zinc concentrate type and zinc product	Zinc (%)	Lead (%)	Cadmium (%)	Mercury (%)	Sulfur (%)
High grade concentrate	56.0	0.50	0.22	0.013	31.0
Intermediate concentrate	52.0	0.30	0.25	0.012	31.0
Prime Western concentrate	54.0	0.30	0.35	0.004	31.0

domestic operations, such as those in Missouri, and foreign suppliers (Bureau of Mines, 1977, p. 998; 1977 St. Lead Company Annual Report).

Zinc concentrate from the Balmat-Edwards District, which included the Pierrepont Mine, continued to be a primary source of primary feed for the smelter through the 1980s and until the closure of the last roaster in 2002. Supplemental feed was purchased on the market when needed. The amount of primary sourced feed was decreasing, as feed from secondary sources increasingly displaced it.

Mercury eliminated by volatilization from concentrates during roasting reported to the gas purification circuit leading to the acid manufacturing section. In 1969, 9,700 kg were recovered as “condensed” and bottled mercury (Lund, 1970; p. 557) validating that mercury was indeed contained in pre-roasted concentrates. Mercury was also reported in the Toxics Report Inventory (TRI), in varying amounts from different sources, in all of the years reported in the TRI for Monaca (1987-2005). Balmat ores sampled by Schwartz, and considered to be the average mercury content of the ore body, contained an average of 1,200 ppm (0.12 percent) of mercury (as a replacement of zinc in sphalerite), which is considered among the highest among sedimentary exhalative-type zinc deposits in North America (Rytuba, 2003). Applying this mercury estimate to the total ore production at the Balmat Mine, discussed earlier, results in a total of approximately 40,000 short tons of mercury contained in mined ore of and, if the same mercury content is assumed for the ore production for the entire district, 52,000 short tons. Most, but not all of the district’s zinc production reported to Monaca. The average assay of the three types of blended concentrates did not exceed 130 ppm (0.013 percent) mercury. This suggests one or more of the following: (1) the mercury content in the samples used by Schwartz did not represent the numerous ore bodies mined in the District; (2) there were significant mercury losses during the beneficiation of the ores (unlikely); (3) the blending of concentrates received from other sources greatly diluted the mercury contained in concentrate, or the concentrate grades reported in table 12 are not representative of the plant’s actual feed stock and; (4) a large percentage of mercury reported with the lead concentrates shipped from the Balmat-Edwards District to the lead smelter at Herculaneum, Mo.

Secondary Feedstock

Treating secondary material usually has cost and technical advantages over smelting of primary zinc sulfide concentrates for several reasons. They include elimination of roasting and its resulting sulfurous and other emissions that can be environmentally problematic and costly; feed is readily available in proximity to the smelter, and are relatively high grade; and the amount of electric-arc furnace dust (EAF dust) reporting to waste storage facilities is reduced.

The Monaca smelter has treated secondary zinc-bearing materials since at least 1946 when the plant processed zinc dross (1946 Saint Joseph Annual Report); however, the

amounts of material fed to the plant was rarely published. Although no mention was found in the literature pertaining to secondary feed prior to this, it is likely that at least some secondary-sourced materials were treated earlier, especially when zinc production was increased during World War II.

By 1969, secondary material, which may have comprised roughly 30 percent of total zinc production, consisted mostly of dross and skimmings. The proportion of zinc production originating from secondary sources relative to concentrates derived from ore has increased dramatically during the last two decades. Approximately 70 percent of the zinc produced at the facility in the late 1980s originated from secondary sources. The year 2002 marked the last year that the plant processed primary zinc concentrates consisting chiefly of the mineral sphalerite. In that year, only about 20 percent of total zinc production was recovered from concentrates, the balance originated from recycled material.

Purchased secondary materials, such as dross and skimmings are combined with the blue powder that is recovered in the carbon monoxide scrubber at the Monaca plant. Some of the dross and skimmings, assaying as high as 98 percent zinc, were fed directly to the electrothermic furnaces in the smelter, furnaces in the refinery, and to the Larvik furnaces for the production of zinc oxide and zinc metal (St. Joseph Lead Company, Zinc Smelting Division, 1956). Dross assayed about 95 percent zinc and skimmings from 65-85 percent zinc (Ingalls, 1903, p. 579).

In the year 1980, the United States Environmental Protection Agency (USEPA) listed EAF dust, the product of condensed fumes of volatized metals and minor amounts of materials derived from the degradation of refractories, and chemicals added in electric arc furnaces during steel-making, as a hazardous waste because of its potentially toxic components. EAF dust typically contains, among other elements, cadmium, calcium, chlorine, fluorine, iron, lead, and zinc. In 1990, the USEPA placed a ban on disposing untreated EAF dust in landfills (James, 1990; Mosher, 1990; USEPA, 1990). These regulatory actions stimulated interest in development or improvement of existing technologies to recover metal values, such as cadmium, chromium, iron, and zinc contained in EAF dust through recycling. The majority of calcined EAF dust treated at Monaca originates from the company’s sister plant at Palmerton, Pa. Additional sources of EAF dust feed for the Monaca facility has been received from steelmaking plants in Beaumont, Texas; Calumet, Ill.; Rockwood, Tenn.; and other U.S. producers (U.S. Bureau Of Mines, 1989, p 1,190; Don Freshcorn and James Reese, Horsehead Corporation, written communication, 2008).

Smelter Products and Production Estimates

Annual and total production statistics for zinc, as metal, oxide, and powder were not available for all of the years the facility has operated. Information was collected in annual reports, journals, publications of the U.S. Bureau of Mines, and from discussions with representatives of the Horsehead

Corporation, the current plant operator. In some cases, production statistics for slab zinc, zinc oxide, and powder were published as a combined number.

Using these data and estimations, it was calculated that the smelter's total production for the period 1931–2006 was approximately 9.6 million short tons of zinc equivalents (zinc in slab, oxide, and powder) and 8.8 million short tons of zinc equivalents for the period 1931–2002, after which the plant no longer treated primary zinc concentrates, relying on secondary material entirely as feedstock.

Until the year 2006, the percent distribution between slab zinc and zinc oxide over the life of the operation was roughly 70 percent slab zinc and 30 percent zinc oxide, expressed as contained zinc, and from 1988 through 2006, zinc metal averaged 60 percent of total zinc product. The balance was virtually all zinc oxide.

Zinc Oxide

The Monaca smelter was placed into production in 1931 to produce zinc oxide using the American process. In later years, the capacity to produce zinc oxide using the “French process” was added. Using published and unpublished data it was estimated that approximately 3.2 million short tons of zinc oxide, containing about 2.6 million short tons of zinc was produced from 1931 through 2006. Approximately 3.0 million short tons of zinc oxide containing about 2.4 million short tons of zinc was produced through the year 2002, when the plant ceased treating primary zinc concentrates as a component of its feedstock.

Zinc Metal

Zinc metal, often referred to as slab zinc, was first produced at the Monaca plant in 1936 (U.S. Bureau of Mines Minerals Yearbook, 1937, p. 201). The plant was designed to produce three types of zinc slab products concurrently for much of its operating life; high grade zinc, Prime Western (which contains a relatively small percentage of cadmium and lead), and minor amounts of tailor-made zinc alloys containing lead and cadmium. Annual production of zinc metal increased from approximately 10,000 short tons in the mid-1930s and expanded to approximately 40,000 short tons in the 1940s. As a result of plant expansions, zinc metal production exceeded 100,000 short tons in most years from the 1950s through the late-1970s, and for a period in the late 1960s through the mid-1970s approached 200,000 short tons per year. During the 1980s and through 2006, annual zinc metal production averaged about 90,000 short tons, but has generally trended downward over the last ten years. It was estimated that the Monaca plant produced about 6.8 million short tons of zinc metal over its life and about 6.4 million short tons of zinc through 2002, after which no primary concentrates were roasted.

Zinc dust was produced at the plant since at least 1985. Its manufacture appears to have never exceeded 4,500 short tons in any year through 2006 and averaged less than 2,500

short tons per year. Zinc powder production was minor and was included in the slab zinc production estimate.

Sulfuric Acid

Sulfuric acid was recovered from 1931-2002 from the sulfur contained in roaster gas, the entire period that roasting of zinc concentrate was performed. In 1931, the plant produced about 10,400 short tons of sulfuric acid from about an equal amount of concentrate. In 1963, 235,000 short tons of concentrate were roasted and 211,930 short tons of sulfuric acid were produced, and in 1969, it was reported that 309,000 short tons of sulfuric acid was produced from 349,000 short tons of concentrate (Lund, 1970; p. 557). From 1988-2002, acid production was reduced to an average of about 92,000 short tons per year, including about 4,500 short tons that were used internally. The reduction mostly reflects the decrease in the roasting of sulfidic concentrates, although a decrease in overall zinc production was responsible in small part.

Recovery of sulfur in roaster feed to sulfuric acid was 90 percent in the late-1960s (Cigan and Cotterill, 1970 p. 557). The balance was contained in calcine, emissions, flue dust, and other residues.

Major improvements were made to the acid plant in 1970 to meet more stringent environmental standards requiring reductions in sulfur dioxide emissions. Plant modifications probably resulted in an increase in sulfur dioxide recovery to perhaps 98 percent with a commensurate increase in acid production per unit of concentrate treated, however no statistical data was found in the literature to support this assumption. In 1990, it was reported that the acid plant was modified with the addition of a tail gas plant (Williams, 1990, p. 447) to further reduce emissions. This resulted in an increase in sulfur recovery per unit of concentrate roasted, as sulfuric acid, although other sulfur-rich products such as elemental sulfur and gypsum can be recovered as saleable products from tailing gas plants. Sulfuric acid production ended in 2002, when concentrates were no longer roasted and therefore no longer supplying sulfur dioxide. Using historical acid production and sales data, it was estimated that the ratio of sulfuric acid production to concentrate over the period acid was produced was roughly 1:1. Applying this ratio resulted in a calculated estimate of nearly 10 million short tons of sulfuric acid produced over the acid plant's 72-year operating life.

Cadmium, Lead, and Other Metals and Nonmetals

Information related to byproduct production, including cadmium, lead, and mercury were rarely published. Byproduct recovery of metals was initiated in the year 1937; the year after slab zinc was produced initially, and continued until 2002. Byproducts were recovered by distillation of acid plant residues, leaching of dusts, and by gravity and magnetic separation of furnace residues.

It is estimated that annual cadmium production for the years 1937-48 was approximately 150 short tons per year. Cadmium production was reported to have doubled in 1949,

as a result of expansion of recovery circuits in the leach plant (St. Joseph Lead Company Annual Reports, multiple years). In 1963, 810,920 lbs (368 metric tons) of cadmium from 235,000 short tons (213,000 metric tons) of concentrate, (Engineering and Mining Journal, 1964; p. 109) was recovered, and in 1969, 573 short tons (520 metric tons) of cadmium were recovered from approximately 349,000 short tons (317,000 metric tons) of zinc concentrate (Lund and others, 1970). Using a ratio of concentrate to recovered cadmium of about 600:1 and the broad assumption that the cadmium was derived exclusively from concentrate, although EAF dust can contain some cadmium, it was estimated that roughly 16,000 short tons (14,000 metric tons) of cadmium metal was potentially recoverable from about 9.8 million short tons of zinc concentrate from 1937 through 2002. Because of limited data, cadmium production estimates did not account for changes in concentrate chemistry (including cadmium content) variations in recovery circuit efficiency or other factors potentially affecting output. Further, it was assumed for the estimate that the secondary materials treated in the furnaces did not produce recoverable cadmium.

Lead was recovered as a lead sulfate residue, following the recovery of cadmium in the leach plant, and sold to other facilities for processing. The “lead cake” contained other metals including gold, indium, and silver (Lund and others, 1970; p. 563).

In 1969, 1,818 short tons (1,650 metric tons) of lead cake were reportedly produced at the Monaca plant (Lund and others, 1970, p. 564). The residue typically assayed approximately 32 percent lead, 8 percent zinc, 0.7 percent cadmium, 0.13 percent indium, 0.3 percent copper, 67 troy ounces/short ton (2.3 kilograms/metric ton) silver, and 0.12 troy ounces/short ton (4 grams/metric ton) gold. Using this data, and the tonnage of lead cake produced in 1969, the leach plant processed residuum that contained a total of approximately 580 short tons (530 metric tons) of lead, 143 short tons (130 metric tons) of zinc, 13 short tons (12 metric tons) of cadmium, 2.2 short tons (2 metric tons) of indium, 5.5 short tons (5 metric tons) of copper, 4.4 short tons (4 metric tons) of silver, and 225 troy ounces (7 kilograms) of gold in that year.

In 1969, an experimental mercury recovery circuit at Monaca reportedly produced 10.7 short tons (9.7 metric tons) of mercury from the distillation of residues collected from the scrubbers treating the roaster gases that were directed to the acid plant (Lund and others, 1970; p. 557). No other data were encountered in the literature pertaining to annual or total mercury recovery for any years since 1969. The amount of mercury potentially recoverable from this material was relatively significant. Two-hundred and seventy-four samples collected from the ore bodies comprising the district contained mercury values up to 17,915 ppb and averaged from 5 to 829 ppb (Jessey, 1974). Sampled ores from the Balmat Mine, a significant source of Monaca’s feedstock, was determined to contain an average of 1,200 ppm (0.12 percent) of mercury, (as a replacement of zinc in sphalerite) and was believed by the author to be representative of the ore body. The ore body is

considered to have among the highest mercury levels among sedimentary exhalative-type zinc deposits in North America, if not the world (Jolly and Heyl, 1968; Rytuba, 2003). Applying this estimate to the historical ore production at the Balmat (Internet Bankruptcy Library, 2002), results in contained mercury in mined ore value of approximately 40,000 from the Balmat ore body and 52,000 short tons of contained mercury for the total estimated ore production in the district. Most, but not all of the district’s zinc production reported to Monaca. The assay of the three types of blended concentrates received by Monaca did not exceed 130 ppm (0.013 percent) mercury (see table 12). Numerous reasons can explain an apparent disparity in the data which can include one or more of the following: (1) the mercury content in the ore samples used by Schwartz did not represent the numerous ore bodies mined in the District, or perhaps the blended samples of concentrates were not representative; the chemistry of ore bodies is rarely homogenous; (2) there were significant mercury losses during the beneficiation of the ores (unlikely); (3) the blending of concentrates greatly diluted the mercury contained in concentrate or concentrate grade data were inaccurate or not representative and; (4) mercury reported with the lead concentrates that were shipped from the Balmat-Edwards District to the smelter at Herculaneum, Mo.

As previously mentioned furnace residues are treated by a variety of methods to recover zinc-rich material for recycling in the sinter plant and carbon for addition to charges for the electrothermic furnaces. As part of the process, byproduct ferrosilicon was recovered as a saleable product, and slag containing low zinc values was sold for railroad ballast and other purposes (Lund and others, 1970; p. 561).

Technology

The Monaca zinc facility has undergone numerous and significant changes since its initial construction in 1931, when it processed solely zinc concentrates with an annual design capacity of approximately 5,000 short tons of zinc equivalents as zinc oxide. By 2006, the modernized and redesigned plant had entirely shifted away from treating zinc concentrates and produced 138,835 short tons of zinc equivalents from secondary materials of which about 56 percent was zinc metal, 44 percent was in zinc oxide, and less than 0.5 percent in zinc powder. Although the plant retained the technology using electrothermic furnaces, advances in technology, increases in capacity, types of materials treated and products produced, and compliance with environmental regulations contributed to changes in the initial plant design.

Fairly detailed descriptions of the equipment and technologies employed at the facility were published in 1956 by the St. Joseph Lead Company (St. Joseph Lead Company, 1956), in 1964 by the Engineering and Mining Journal, in 1970 by Lund and others, and in 1990 by Williams, published in Lead-Zinc 1990. Little detailed technical data describing the operation were found in the literature for other years, although information on expansions and other major changes

in the operation were published in Minerals Resources of the United States and Minerals Yearbooks; annual publications by the U.S. Bureau of Mines and the U.S. Geological Survey; and company annual reports.

Until 2002, when treating sulfur-rich zinc concentrates was entirely discontinued, the plant's major processing facilities consisted of concentrate handling and preparation; roasters to produce calcine from zinc concentrates; a sulfuric acid plant using the sulfur-rich off-gases from the roaster plant to produce acid; a sinter plant to prepare the calcined material for the smelter furnaces; a furnace plant using electrothermic furnaces to treat sinter for the recovery of zinc and zinc oxide, and a leach plant to produce several byproducts from process residues. Since 2002, the plant has primarily consisted of feed preparation (EAF dust, dross, and other secondary material), sintering, furnacing using electrothermic furnaces, and refining. Electric Larvik furnaces were added in 1978 to produce additional zinc oxide. A brief description of the major facilities used for recovering zinc and other products representing the period when the operation processed concentrate and secondary materials follows.

During the first 20–25 years of the operation, there were considerable material losses through fugitive dust, fumes, and vapor. Overall zinc recovery probably averaged less than 93 percent. In 1969, overall zinc recovery at the Monaca smelter improved to 96.6 percent. The relatively high recovery was attributed to the addition of extensive dust collection equipment, installation of more efficient furnaces, and the treatment of secondary feedstock, which was initiated in 1965 (Lund and others, 1970). Since 1969, the increase in secondary feed, use of more efficient equipment, including that required by environmental legislation, have probably increased overall zinc recovery to approximately 97.5 percent. Figure 13 is a generalized figure of the process flow for treating EAF dust and figure 34 is a generalized flow diagram showing the flow of sulfidic primary zinc and secondary zinc feedstock at the Monaca zinc plant as it existed in the 1970s and represents most of its production history (Modified from Bounds, 1983).

Concentrate Handling

Until the early 1940s, and from the early to mid-1980s to 2002 the company-owned Balmat-Edwards, Pierrepont, and Hyatt mines were the principal suppliers of primary zinc concentrates to the smelter, but for the period in between, the plant also received concentrate feeds from up to 15 different sources (Williams, 1990). Because of the variation in the chemistry of concentrates during this period it was necessary for the purpose of producing high grade, intermediate, and Prime Western zinc to blend concentrates based on their constituents (lead, iron, cadmium, copper, manganese, indium, and tin) from which calcine was produced in the roasters.

Roasting

Until the early 1940s the plant relied on one roaster to process the Company's concentrate supplied from the

company's mines in upstate New York. By the mid-1940s the plant had built and added a new furnace to produce Prime Western zinc directly, and by the late-1960s, additional roasters had been added to accommodate the different concentrate blends to produce sinter for the production of the plant's major zinc products; "High Grade" zinc, Prime Western zinc, and zinc oxide (see table 12). During this period the roasting was accomplished by multiple hearth furnaces that processed high grade and intermediate zinc concentrates; fluid bed roasters which "finished" high-grade partially-roasted concentrates, and a flash roaster, which produced a high-lead calcine from concentrates blended for the purpose of producing Prime Western zinc. During the 1970s, approximately 94 percent of the lead, 20 percent of the cadmium, 99 percent of the mercury, and 96 percent of the sulfur contained in the concentrates were removed. More than 90 percent of sulfur contained in the concentrate was captured for use in the acid plant. The metals were recovered from scrubber liquors and residues produced in the circuits prior to acid-making (Bounds, 1983). All three types of roasters operated until 1980 when concentrate feed was supplied solely by the company's mines in upstate New York. Afterwards the plant reverted to using only the fluid bed roaster (Williams, 1990).

In the late 1970s, St. Joe invested 6.6 million dollars to reduce emissions and expected to spend an additional 2.8 million dollars over the next 3 years to further reduce sulfur dioxide emissions and particulate emissions (St. Joseph Annual Report, 1978, p. 10).

Multiple-Hearth Roasters

The multiple hearth roasters (MHR) were the original type of roasters used at the facility, but over time new and larger MHR were added and modifications on previously installed roasters took place. In addition to reducing the sulfur content in the intermediate and high grade concentrates, the MHR, through careful temperature control, eliminated virtually all of the lead by vaporization. This was important in order to produce high quality zinc and zinc oxide products later in the zinc refining step. The partially desulfurized concentrate (PDC), derived from the high grade concentrate produced in the MHR retained about 22 percent sulfur from the original 31 percent, a nearly 30 percent decrease, but less than 0.013 percent lead, a greater than 97 percent decrease. (Lund and others, 1970). The roasting of the PDC was completed in the fluid-bed roaster. See table 13.

The calcine produced from the roasted intermediate concentrate in the MHR, which originally contained 52 percent zinc, 0.3 percent lead, 0.012 percent mercury, and 31 percent sulfur; assayed 64 percent zinc, 0.035 percent lead, 0.0001 percent mercury, 1.5 percent sulfur, and 0.25 percent cadmium (Lund and others, 1970). See table 13.

Fluid-Bed Roaster

The fluid-bed roaster (FBR) was constructed at Monaca in 1956 for the purpose of lowering costs and to more

Table 13. Assays for selected materials in partially desulfurized concentrate (PDC) and calcines (roast) at the Monaca plant (adapted from Lund and others, 1970, p. 555).

PDC ¹ and calcine product types	Zn %	S%	Cu %	Cd %	Pb %	Hg %
PDC ¹	59	21.9	0.25	0.22	0.013	0.0002
High grade	68	1.5	0.26	0.22	0.035	0.0001
Intermediate	64	1.5	0.26	0.25	0.35	0.0001
Prime Western	62	2.5	--	0.40	1.40	0.0003

¹ PDC – Partially desulfurized concentrate.

effectively delead concentrates for the eventual purpose of producing high grade zinc products and zinc oxide. The FBR was the second part of a two-stage roasting process that used an MHR that treated the high grade zinc concentrates as a first step, described in the preceding paragraph, that removed most of the sulfur and volatilized most of the lead. This material, termed the partially desulfurized concentrate, was then directed to the FBR that more completely delead and desulfurized the material thereby producing the calcine for sintering. The high grade calcine output from the FBR assayed 68 percent zinc, 1.5 percent sulfur, and 0.0001 percent mercury. In 1970, there were three fluid-bed roasters, each capable of roasting 250 short tons of material per day, but by the 1990s with significantly less concentrate to be treated, the plant operated only one of the roasters and used oxygen enrichment to increase plant capacity. All roasting was discontinued in 2002 when the plant no longer treated concentrates and instead relied on zinc recovered from primarily EAF dust, plus other purchased recyclable zinc-rich materials. The fluid-bed roaster was the only one of its kind that remained into the 1980s, as all of the others had been shut down.

Flash Roaster

The flash roasters were introduced in 1947 and were used for desulfurization of concentrates by roasting. The roasted product was intended for the production of Prime Western zinc, because some lead and other materials, considered deleterious, were contained in the final product and acceptable for use in certain markets. In addition to concentrate, all of the flue, boiler, and Cottrell dusts (which contained cadmium, lead, zinc, and other metals) recovered from the three roasting circuits were fed to the flash roaster (Lund and others, 1970; p. 555). Table 13 shows assays roast products that were produced at the Monaca plant and table 14 shows a sample assay of the dust recovered from the roasters that contained relatively high levels of mercury relative to the feedstock. Table 15 shows the effectiveness of removing impurities during the roasting (calcining) process of high grade and intermediate grade material.

Waelz Kilns

Since 1982, the Waelz kilns at the nearby company-owned Palmerton plant have played an important role by

supplying the largest proportion of zinc-rich feed derived from EAF dust to Monaca (Horsehead Corporation Web site). The Waelz kilns at Palmerton recover nonferrous metals, mostly as oxides, which are part of a mix composed of EAF dust, anthracite, and fluxes. The volatilized metal oxides are cooled and recovered in a baghouse. The captured material is collected and placed in a kiln for calcining where, through careful temperature control, the cadmium and lead are fumesd, recovered, and shipped for processing. The remaining material is taken from the kiln and shipped to Monaca. In the mid-1980s approximately 180,000 metric tons (nearly 200,000 short tons) of calcined EAF dust was shipped to Monaca from Palmerton (U.S. Bureau of Mines Minerals Yearbook, 1987, p. 936) on an annual basis. More than 1 million short tons of zinc product have been recovered from EAF dust at Palmerton through 2005 (Horsehead Company website). Prior to treatment in the kilns the EAF dust contains approximately 20 percent zinc and is upgraded through the process to approximately 59 percent zinc.

Sinter Plant

The Dwight-Lloyd downdraft process sintering plant's purpose was to produce a charge for the electrothermic furnaces by agglomerating and heating a controlled mixture of zinc calcine and secondary zinc feed, coke, silica, furnace residue from the leach plant (supplies moisture and zinc for pelletizing the calcine mixture), low-grade sinter products, dust, and other zinc-rich material. Depending on its composition, secondary material could serve as feed to the sinter plant before furnacing or fed directly to the furnaces.

Four types of sinter were produced. They were (1) high grade soft sinter (the first step in producing high-grade hard sinter); (2) high-grade hard sinter (which is made from purer material, including lead-free dusts); (3) intermediate sinter and; (4) Prime Western sinter. The high-grade soft sinter was an intermediate product in the two-step sintering process for producing high grade hard sinter for feed to the electrothermic furnaces, so only three types of sinter reported to the furnaces; high grade, intermediate, and Prime Western. The compositions of feedstock supplied to the sintering machines are shown in table 16.

The intermediate and Prime Western (contains some lead, cadmium, and other impurities) sinters were produced by agglomerating the respective calcines and other materials to

Table 14. Analysis of flue dust recovered from calcining of concentrate at the Monaca plant. (Lund, R. E., Winters, J. F., Hoffaker, B. E., Fusco, D. M. and Warnes, D.E., 1970, Josephstown Electrothermic Zinc Smelter of St. Joe Minerals Corporation Monaca, Pennsylvania, in Cigan, John M. and Cotterill, Carl H. ed., *Lead & Zinc, v. II: New York, NY, The American Society of Mining, Metallurgical, and Petroleum Engineers, Inc.*, p. 555; p. 549-580, 1970).

Element	Zinc	Mercury	Lead	Sulfur	Lead	Copper	Tin	Cadmium
Percent	54	0.03	1.4	7.0	1.4	0.40	0.01	0.41

Table 15. Percent elimination of impurities during roasting at the Monaca plant (adapted from Lund and others, 1970; p. 556).

Circuit	Hg%	S%	Pb%	Sn%	Cd%
High grade	99	96	94	34	18
Intermediate grade	99	96	90	35	19

Table 16. Sinter feed mix at the Monaca plant, percent (Cotteral and Cigan, 1970, p. 559).

Zn grade/metal	Calcine (%)	Return fines (%)	Bag filter dust (%)	Furnace residue (%)	Coke breeze (%)	Sand %	Oxidics (%)	Soft Sinter (%)
High grade hard	9.8	52.6	--	8.6	2.7	1.0	--	25.3
High grade soft	35.7	48.5	10.8	--	5	--	--	--
Intermediate	25.3	55.8	9	6	2	0.9	1	--
Prime Western	17.4	60.5	7	7.6	.2	0.6	6.7	--

Lund, R. E., Winters, J. F., Hoffaker, B. E., Fusco, D. M. and Warnes, D.E., 1970, Josephstown Electrothermic Zinc Smelter of St. Joe Minerals Corporation Monaca, Pennsylvania, in Cigan, John M. and Cotterill, Carl H. ed., *Lead & Zinc, v. II: New York, N.Y., The American Society of Mining, Metallurgical, and Petroleum Engineers, Inc.*, p. 549-580, 1970).

specific charge chemistry into pellets. Silica sand was added to the mixture, and upon sintering was converted to a hard sinter product. The hard sinter for making Prime Western zinc contained 56 percent zinc, 0.33 percent lead, 0.017 percent cadmium, plus other material, and serves as a portion of the feed mixture to the electrothermic furnaces, as does the intermediate grade sinter, containing 57 percent zinc, 0.037 percent lead, 0.015 percent cadmium, plus other material.

To produce high grade zinc, silica sand was not added prior to sintering the High Grade calcine. Without the addition of silica, the initial sinter product was a soft sinter cake that is separated into two fractions: an upper part, with relatively high zinc content (64 percent) and purity; and a lower part that is less pure, containing less zinc. The lower part of the soft sinter was recycled as a component of the blend for making sinter charges. The high grade soft sinter was first ground, and silica and additional high zinc-bearing material added and then the mixture was resintered. The resulting hard sinter was fed to the electrothermic furnaces. The three types of sinter produced and their compositions are shown in table 17.

Prior to 1979, there were nine sinter machines. From 1979 until the 1990s there were three sinter machines. In the

1990s the three were replaced with one, which produced a single sinter product which was mixed with secondary material to feed the electrothermic furnaces (Don Freshcorn, James Rees, Horsehead, Corporation, written commun., 2009). A typical assay of the single sinter product is shown in table 18.

Electrothermic Furnaces

Since 1937, the plant has used electrothermic furnaces for producing zinc oxide and various grades and alloys of zinc metal. Prior to 1937, zinc oxide was the chief product, but for the balance of the operating life of the operation the majority of the furnaces have been dedicated to the production of zinc metal. The furnaces are electrothermic and work on the principle of using heat buildup from electrical resistance through the zinc sinter resulting in the reduction and vaporization of the charge. Over time, the number, size, and other modifications of the applied technologies have taken place in response to increased costs, improved technologies, and regulations, but the plant continues to produce zinc products using essentially the same processes.

The principal materials fed to the individual electrothermic smelter furnaces are composed of different types of sinter,

Table 17. Sinter types and assays of selected materials at the Monaca plant in 1969 (Cotteral and Cigan, 1970, p. 560).

Sinter type	Zn %	Cd %	S%	Pb %
High-grade hard	58.6	0.006	0.10	0.006
High-grade soft	63.6	0.012	0.36	0.005
Intermediate	57.1	0.015	0.15	0.037
Prime Western	55.5	0.017	0.15	0.33

Lund, R. E., Winters, J. F., Hoffaker, B. E., Fusco, D. M. and Warnes, D.E., 1970, Josephtown Electrothermic Zinc Smelter of St. Joe Minerals Corporation Monaca, Pennsylvania, *in* Cigan, John M. and Cotterill, Carl H. ed., *Lead & Zinc, v. II*: New York, NY, The American Society of Mining, Metallurgical, and Petroleum Engineers, Inc., p. 549-580, 1970).

Table 18. Sinter product assay at the Palmerton plant in 1989 (Freshcorn and Reese, oral commun., 2009).

Aluminum (%)	Calcium (%)	Iron (%)	Lead (%)	Magnesium (%)	Silica (%)	Zinc (%)
5.0	2.5	8.0	1.0	1.3	4.0	48

depending on the desired zinc products (oxide and metal; and coke, although other zinc-bearing materials in varying amounts over the years have also frequently been added to the mixture. Generally the mixture is retained in the furnace for approximately 22 hours. Blue powder was recovered from carbon monoxide in the zinc metal furnaces. A portion of the slag produced in the manufacture of zinc metal and zinc oxide was reprocessed because it contained unburned coke and zinc (St. Joseph Lead Company, 1956).

Prime Western and other grades of zinc metal are produced in electrothermic furnaces, by heating the sinter mixture to the point of producing zinc vapor in a carbon monoxide atmosphere, thereby preventing oxidation, and directing the vapor to a molten zinc bath where the zinc vapor condenses on contact. Molten zinc is directed to cooling wells where it is tapped and poured. The carbon monoxide gas is scrubbed to recover "blue powder," a zinc dust which condenses in suspension from the zinc vapor and is sent for recycling through the zinc recovery process.

Two zinc oxide products were produced at the facility by two separate methods; the American and French processes. Zinc and zinc oxide were produced in the refinery using the French process. The less pure zinc oxide product of the two was produced using the American process, in which High Grade sinter and coke was heated in electrothermic furnaces. In this process the zinc was volatilized in a carbon monoxide atmosphere, mixed with air to convert the carbon monoxide to carbon dioxide and the zinc vapor to zinc oxide. The carbon dioxide was cleaned and vented, and the resulting zinc oxide fumes collected in a baghouse. The zinc oxide produced with this method contained about 0.010 percent cadmium and 0.009 percent lead.

Zinc oxide production using the American process ceased in 1979 at Monaca (U.S. Bureau of Mines Minerals Yearbook, 1980). The closure of the circuit was part of an industry-wide trend in the United States of discontinuing the roasting and furnacing of zinc concentrates to produce zinc oxide.

Two new refinery columns for producing French process zinc oxide were installed in the late-1980s and 1990s to treat the increasing amount of EAF dust-derived zinc (Don Freshcorn, James Rees, Horsehead Corporation, written commun., 2009).

Larvik Furnaces

The Larvik furnaces, which began operating in 1982, are used to produce zinc dust and zinc oxide products. The feed for Larvik furnaces consists of dross and other zinc rich secondary materials. Typical modern dross compositions assay from 85-98 percent zinc, with varying amounts of aluminum, copper, lead, and other metals. The materials are added as batches to the melting section bath, where convective heat from the next section is sufficient to melt the incoming feed. Tramp iron is periodically raked from the bottom of the bath and floating oxidic zinc is removed from the surface and recycled through the smelter. Molten metal flows continuously to a vapor section, where it is heated until it boils. The zinc vapor exits the furnace and is piped downstream to the zinc dust production facilities where the fumes condense to zinc metal or sent to a combustion chamber to produce zinc oxide (Don Freshcorn and James Reese, Horsehead Corporation, oral commun., 2008). Impurities accumulate in the molten metal bath and are drained off at intervals and sold to the recycling industry (Williams, 1990). Supplemental zinc oxide can also be produced in the Larvik furnaces, when needed (Williams,

1990). From 1988 through 2006, approximately 44,000 short tons of zinc dust were produced. The amounts have dropped considerably over that time, ranging from a high of 4,968 short tons in 1989 to 691 short tons in 2006 (Sharon Lewis, Horsehead Corporation, written commun., 2008). The average annual production during this period was approximately 2,200 short tons of zinc powder.

Zinc Refinery

The zinc refinery came on line in 1959 and has been modified over time, but the principle of vertical distillation, in use for the prior 40 years remains essentially the same (Lund and others, 1970). The following briefly describes the process used to produce Special High Grade zinc and high-purity zinc oxide (French Process zinc oxide) in the refinery.

In the refinery, the molten feed is boiled to produce cadmium, lead, and zinc vapors through careful monitoring of temperature. The vapors are precipitated in condensers and then reboiled in another chamber where, through careful temperature control, the cadmium and some zinc is boiled off, enriching the remaining molten material in zinc. The molten mixture, which is virtually depleted of cadmium and lead as a result of longer residence time in the column, is tapped from the bottom resulting in a Special High Grade zinc of 99.995 percent zinc with the balance comprised of approximately equal amounts of cadmium and lead, plus iron (Lund and others, 1970).

The French process zinc oxide is produced by vaporizing the molten high grade zinc metal in externally-heated boilers which is combined with air. The resulting zinc oxide fumes are collected in a baghouse and packaged. The zinc oxide produced by the French Process needs to meet stricter standards than that produced by the American process. French process derived zinc oxide assayed 0.0006 percent cadmium and 0.0015 percent lead, and significantly less copper, iron, and manganese than zinc oxide derived by the American process (Lund and others, 1970; p. 574).

Leach Plant

The leach plant originally was constructed at the Monaca facility in 1937, the same year that the plant began producing slab zinc. The leach facility treated several materials recovered during the steps required to produce zinc and zinc oxide. These materials consisted mostly of dusts and fumes collected from the sinter plant, and scrubber liquor recovered in the acid plant. Occasionally, small amounts of purchased materials containing cadmium (Lund and others, 1970, p. 553; 562) also were treated in the plant. The combined pyrometallurgical and hydrometallurgical processes are described in detail by Lund and others, 1970; Williams, 1990).

In brief, the process entailed heating the collected fumes and dust resulting in a mixture rich in cadmium sulfate (which is water soluble); dissolving the material in water, adding sodium bichromate, which causes lead to precipitate as a residue or "lead cake;" and then adding zinc powder to

the remaining solution causing the cadmium to precipitate as a sponge and producing a zinc sulfate rich solution. In the 1960s, the cadmium sponge was heated and cast into forms, and for additional purity was sometimes distilled in retorts, but by the 1990s, cadmium sponge was the final product. The zinc sulfate liquid was used as source of moisture for forming pellets in the sinter plant and the lead-rich residue also produced during the process, which, in addition to lead, gold, silver, and indium, were sold (Williams, 1990, p. 448). The plant shut down in 2002 when concentrate was no longer a component of feed for the facility.

Sulfuric Acid Plant

The sulfuric acid facility was part of the original smelter's construction in 1931. Overall, the plant was similar to other sulfuric acid plants associated with the roasting of sulfur-rich mineral concentrates. In order to produce marketable sulfuric acid, it must meet certain specifications. To accomplish this, sulfur-rich off-gases from the roasters must be cleaned of dust and fumes containing zinc, cadmium, and other materials. The gas-cleaning process at the plant was accomplished by passing roaster off-gases through cyclones, electrostatic precipitators, and settling chambers and sprayed with scrubber liquor. Scrubber liquor was recovered from the settling chambers, thickened and sent to the leach plant for recovery of zinc and cadmium. The cleaned gas was heated and in the presence of air and a catalyst formed sulfur trioxide which was then contacted with weak sulfuric acid. The sulfur trioxide reacted with the weak sulfuric acid forming strong sulfuric acid.

The acid plant underwent modifications to accommodate the roasters' increased capacity to treat concentrates, as technologies advanced, and as environmental regulations became more stringent. In the early 1970s, the old plant was replaced with a new acid plant (Williams, 1970) which was later modified with a tail gas plant (Williams, 1990, p. 447) to improve acid production and further reduce emissions by converting sulfur dioxide gas to sulfuric acid. The acid plant closed in 2002 when concentrates ceased to be roasted. For the entire period, over 90 percent of the sulfur contained in material fed to the roaster was recovered in acid.

It was reported that in 1969, an experimental plant was installed to recover mercury from the gases and fumes produced from roasting. Details on the plant, its production life, and production statistics, save one year, were not available.

Atmospheric Emissions of Dust, Fumes, and Gas

Capturing and mitigating dust, fumes, and gas emissions have multiple benefits. They can be recycled within the facility or sold, thereby generating revenue and conserving material use, and reduces environmental and health risks through proper disposal and treatment of wastes. Historically, atmospheric dust, fumes, and gas emissions produced by the Monaca smelter have been generated through the physical movement of feed materials, including the offloading and

stockpiling of zinc concentrates and secondary feed; feed preparation and handling; and processing of material through the roasting, sintering, furnacing, and the final product preparation step. Over the life of the operation, the dusts, fumes, and gases generated at Monaca contained cadmium, carbon, copper, iron, lead, mercury, silica, and zinc, as well as other materials. The Balmat-Edwards deposits, a major source of concentrate to Monaca, also contained fluorine-bearing minerals, but data on concentrate content were not available (Plimer, 1984).

Bag filters, Cottrells and other types of precipitators, cyclones, scrubbers, and settling chambers are examples of the types of technologies that have been used at Monaca since the 1930s to recover dust, fumes, and gases generated primarily from the thermal processing of material. In addition to the dust recovered from the individual sections of the plant, there are numerous bag filters that collect process dusts generated by mechanical action in the sinter, residue, and furnace sections of the plant (Lund and others, 1970; p. 561). Modifications to these types of equipment, plus additional equipment have been installed as a result of technological advances incited by the opportunity to generate revenues from improved recoveries and in response to changes in environmental regulations.

Roasters and the Sulfuric Acid Plant

Sulfur-laden gases were directed to the acid plant beginning in 1931. In 1970, it was reported that the dust suspended in sulfur-rich roaster gases were collected using cyclones and Cottrell electrostatic precipitators prior to being sent to the acid plant. The captured dusts were fed to the flash roaster with zinc concentrates while other collected material was treated in the leach plant for the recovery of products consisting of or containing cadmium, mercury, zinc, and lead. The roaster gases were directed to the acid plant where they were further cleaned by a scrubber. The primary purpose of the equipment was to ensure that the gas was sufficiently cleaned to produce acid that met the specifications of buyers and, in later years, to also meet environmental regulations. Bounds (1983) reported that for some undefined period leading up to the late-1970s approximately 90 percent of the sulfur contained in concentrate was converted to sulfuric acid in the acid plant. The balance of the sulfur was contained in air emissions, calcine, residues, and other plant outputs. The addition of a fifth acid unit in the late-1970s enabled the plant to comply with environmental regulations and brought sulfur collection efficiency to “better than 99 percent” (Bounds, 1983). In the 1980s, the acid-plant effluent gas was vented through a 400-foot stack (Bounds, 1983). The addition of the stack suggests that not all of the sulfur reporting to the acid plant was converted and that some was released, perhaps as tailing gas.

Sinter Plant

In the 1960s, the off-gases generated in the sintering machines were directed through settling chambers, where the offgases were cooled; followed by Cottrell electrostatic

precipitators. Prior to this period, dusts generated by the sintering machines were released to the atmosphere (St. Joseph Lead Company, Annual Report, 1964) and probably were a significant source of atmospheric emissions of cadmium, lead, sulfur, zinc, and other materials, such as fluorine and mercury. Fumes recovery by the electrostatic precipitators in the sinter plant ranged between 90 and 95 percent, and more than 98 percent of the fumes passed on to the bag filters (which were added in the 1980s) were reportedly captured (Don Freshcorn and James Reese, Horsehead Corporation, written communication, 2009).

The fumes and dusts recovered by these methods were treated in the leach plant for recovery of cadmium, lead, zinc, and other metals either at the plant or by another company that purchased the material. Each of the three sinter circuits had its own environmental bag filter (as opposed to those specifically used to recover zinc oxide product). Process air drawn through the sinter bed was treated by electrostatic precipitators.

Dusts captured by the filters contained about 58 percent zinc and were fed back to the sinter circuit from which it was captured (Lund and others, 1970). Later, in the 1990s the three circuits were replaced by one circuit, which further reduced overall emissions (Williams, 1990). It is not known what amount of the sulfur contained in gases from the sinter plant was removed over the life of the operation.

Furnace Plant

Gases exhausted by the electrothermic furnaces that produce zinc metal, consisting of mostly carbon monoxide generated from the burning of coke in the furnace feed, are water scrubbed, and then used as fuel for preheating material prior to smelting. The captured solids (blue powder), assaying approximately 80 percent zinc, are recovered in clarifiers that replaced the settling ponds that were previously used. The captured material serves as furnace feed.

The American process zinc oxide furnaces, shut down since 1979, also produced gases during the volatilization of zinc in sinter and burning of coke; however, the addition of air converted the carbon monoxide component of the gases to carbon dioxide gas. The cooled gases and zinc oxide fumes passed through cyclones that removed oversized materials and impurities. The remaining fumes and gases entered the bag-house where filter bags collected zinc oxide and the cleaned gases vented to the atmosphere.

Zinc Refinery

The vertical distillation method uses zinc metal containing minor impurities as feedstock and produces high purity zinc metal and high purity zinc oxide (French process). The columns of the distiller are heated externally. Zinc fumes that are generated from boiling the zinc produce high-grade zinc oxide when mixed with air. The zinc oxide is propelled by air and captured in bags and the filtered air is vented to the atmosphere.

The refinery also produced high-purity zinc metal by boiling impure zinc in an oxygen-deprived atmosphere. The resulting zinc fumes condensed and cooled to a solid form.

It is likely that less than one or two percent of the zinc, cadmium, or other metals put through the refinery are emitted to the atmosphere in the refining process.

Fugitive and Stack Emission Data and Estimates

In 1987, individual plant emission data became widely available for many types of facilities in the United States as part of the Environmental Protection Agency's (USEPA) Toxic Release Program following the establishment of the Emergency Planning and Community Right-to-Know Act of 1986. Prior to this date, publicly available information on emissions for individual plants was rarely published. The 2005 report for Monaca includes estimated releases of numerous compounds in air emissions (fugitive and stack), surface water discharges, and releases to land, underground injection, and transfer of material offsite for the years 1987-2005 (USEPA, 2008). The data spanning the years reflect the changes in the type and amounts of materials treated during the plant's transition using decreasing amounts of zinc concentrate to the period after 2002 when concentrates were no longer treated and the roaster and other parts of the plant closed or were modified. Table 19 shows emissions for selected years prior to and after the 2002 closure of the roaster which was used to roast concentrates. The list of metals in the report includes cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc (USEPA, 2008). Stack and fugitive zinc emissions for 1987 through 2005, the years for which TRI data for Monaca are available, averaged approximately 3.9 pounds for every short ton of zinc equivalent produced for a total of approximately 5,000 short tons of zinc over the 19 year period. The transition from treating zinc concentrates as a decreasing proportion of the plant's feed is reflected by the decrease in the amount and components of atmospheric emissions resulting from the closure of the roaster and other aspects of the plant. In 1987, when approximately 40 percent of the feedstock supplied to the plant was comprised of zinc concentrate and the balance included calcined EAF dust and other secondary material, fugitive and stack emissions were approximately 7.3 pounds of zinc per short ton of zinc equivalent produced at the plant, or approximately 380 short tons for the year. In 1987, approximately 15 percent of zinc emissions were from fugitive sources compared to less than 1 percent in 2005. The elimination of concentrate handling, blending and roasting, plus changes in the sintering process were the major contributors to the significant decrease. Additional and improved emission reduction equipment also likely contributed. If one were to extrapolate 1987 zinc emissions on a unit of zinc produced over the life of the property, (although in 1987 only 40 percent of the plant feed was zinc concentrate which produced more emissions at the site owing to handling and roasting, legislated pollution controls were in place, and technologies were more efficient), roughly 34,000 short tons of zinc could have

been emitted as fugitive and stack emissions from 1931-2006. Considering the previously mentioned factors, this estimate is probably conservative.

Using USEPA and data collected from literature and industry contacts (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; James Reese, Horsehead Corporation, oral commun., 2008), it was estimated that from 1931 through 2002, the Monaca plant released about 3 or 4 percent of the amount of zinc equivalents produced during the period when primary sulfidic concentrates comprised a portion of the plant's feed. Considering the time period, similarity in zinc sulfide feed, and technologies employed at Monaca and at Palmerton, it was calculated using these assumptions that between 260,000 and 350,000 short tons of zinc equivalents as dust, fumes, and gas may have been emitted to the atmosphere from 1931 through 2002, the last year sulfidic concentrates were processed.

James Reese, Director of Environmental Health and Safety, Horsehead, Corp, Monaca, PA stated that in the year 2007 the plant was permitted to release up to 429,000 pounds of zinc annually as atmospheric emissions, although the plant actually released less (James Reese, Horsehead Corporation, oral commun., 2008). Although concentrates are no longer roasted at Monaca, the regulations for the State of Pennsylvania permits the atmospheric emission of 3 pounds of material for each short ton of concentrate roasted (James Reese, Horsehead, Corporation, oral commun., 2008). The roaster could not be used for the last few years, however, because its emissions have been banked.

For a discussion on emissions banking see http://www.baaqmd.gov/pmt/emissions_banking/index.htm and <http://www.baaqmd.gov/dst/regulations/rg0204.pdf>.

Applying this estimate to the amount of concentrate roasted over the operation's life (nearly 10 million short tons), approximately 30 million pounds or about 14,000 metric tons of material would have released, through fugitive and stack emissions by the roasting facility. However, applying this estimate over the life of the operation is not reflective of actual emissions since the operation was not required to meet increasingly stringent environmental legislation until the late-1960s. Pennsylvania regulations (25PA code 123.13) allow the sinter plant to release 2 pounds of zinc for every ton of product produced. The varying types and mixes of sinter make calculation of contained zinc and estimates of emissions difficult. Emissions were also produced from EAF dust and secondary feed material that supplemented production, which beginning in 2002, virtually replaced all production from zinc concentrate. Calculating emissions from this portion of the feed is also difficult because of variation in feed amounts and grade. The entire facility is currently permitted to release up to 429,000 pounds of zinc per year, although actual atmospheric emissions are considerably less, as shown in table 19.

In 1998, the Department of Environmental Protection for the State of Pennsylvania reported that carcinogenic or potentially carcinogenic metals contained in compounds emitted from this facility amounted to 410,000 pounds of cadmium,

Table 19. Combined air stack and fugitive emissions for selected compounds, except where noted for selected years 1987-2005 at the Monaca, Pa. facility. Units are kilograms of metal content in compounds. Values are rounded to the nearest hundred kilograms.

Type of compound	1987	1991	1995	1999	2003	2005
Cadmium	2,000	400	300	200	300	200
Chromium	NR ¹	<50	100	100	100	100
Lead	15,600	6,300	5,000	4,100	4,000	3,800
Mercury ²	NR	100	100	100	<50	<50
Zinc ³	331,400	231,800	259,500	190,700	202,400	200,700

¹NR=Nothing reported; ²Data reported as stack emission only. ³Data reported as zinc in dust and fumes in 1987; zinc in compounds, and dust and fumes in 1991 and 1995; and zinc in compounds in 1999, 2003, and 2005. Data modified from Toxic Release Inventory, Envirofacts Report, Horsehead Corp. Monaca Smelter, 2007 http://oaspub.epa.gov/enviro/tris_control.tris_print?tris_id=15061ZNCCR300FR.

516,000 pounds of nickel, and 40,000 pounds of lead. These metals were contained in all forms of emissions (including fugitive, point source, disposed off site, and discharged in water). The vast majority of these releases were contained in waste; primarily slag and other plant-generated solid waste residues.

In 1998, compounds containing approximately 10,400 pounds of lead, 800 pounds of nickel, and 633 pounds of cadmium were released into the air as point and nonpoint emissions (Department of Environmental Protection for the State of Pennsylvania, 2008).

The TRI data shows that mercury values contained in atmospheric emissions were dissipated by the plant's stacks. No fugitive emissions were reported. Reported stack emissions were quite variable ranging from a high of 250 pounds in 1991 to a low of 14 pounds in 1992, but averaged 112 pounds per year and totaled 1,777 pounds for the years 1988 through 2005. Stack emissions were not reported for the years 1987-90 because of one or more factors including the following: mercury was not contained in the feed, or mercury was effectively recovered as a byproduct or contained in waste or residue shipped offsite for disposal or processing. The relation of atmospheric emissions to feed and plant operations is unclear. However, if the reported mercury content in concentrate was estimated at 0.010 percent, or 100 ppm, and applied to the concentrate treated over the life of the operation, approximately 1,000 short tons reported to the roaster. A portion of this may have been emitted to the atmosphere since the flue dust was reprocessed at temperature that would have resulted in volatilizing the metal. In 1969, mercury recovered from flue dust, which assayed 0.03 percent mercury, and treated in a pilot plant, was reported to have yielded 9.7 metric tons of mercury. Approximately 320,000 short tons (290,000 metric tons) of concentrate were treated in that year, suggesting that if the average concentrate contained between 0.004 and 0.013 percent mercury (Lund and others, 1970; p. 555), it contained between 12 and 38 metric tons of the metal. The balance of

mercury not recovered in that year, between 2.3 and 28 metric tons was probably contained in atmospheric emissions and in residues deposited on and off-site. Assuming that the range of grades reported for 1969 was representative for the years 1931-2002, between 400 and 1,300 short tons (360 and 1,180 metric tons) of mercury may have been passed through the plant's roaster. It is not known how much mercury was recovered or emitted to the atmosphere over this time period, but it is likely that more than 90 percent was captured.

By 2005, the plant was no longer receiving primary zinc concentrate that required roasting. Smelter feed was approximately 60 percent calcined EAF dust and 40 percent purchased secondary material. In that year, fugitive and stack zinc emissions were reduced to approximately 3.2 pounds per short ton of zinc produced at the plant or about 1.6 percent.

The appearance of chromium and nickel in emissions since 1994 may reflect refractory material contained in calcined EAF dust from processing recycled material at Monaca containing stainless steel or plating, and in EAF dust from recycling stainless steel or plating at EAF steel plants.

Reductions in cadmium and lead also reflect the reduction in contributions from concentrate feed since the metals are common constituents in zinc concentrate, but are also contained in calcined EAF dust.

Sulfur Emissions

Based on limited data, it was calculated that roughly 63,000–94,000 short tons of sulfur, equivalent to approximately 125,000–188,000 short tons of sulfur dioxide, were emitted to the atmosphere primarily from the treatment of concentrate and production of acid during the period 1931-2002. The estimate was based on the following assumptions: (1) an average of approximately 2 to 3 percent of the sulfur contained in zinc concentrate was released to the atmosphere during the unloading and preparation of ore and concentrate, roasting, sintering, and acid-making processes over the life of the

operation; (2) the facility treated an estimated 9.8 million short tons of sulfidic concentrates for the period 1931-2002; and; (3) concentrates contained an average of 32 percent sulfur. Materials contained in reductant and coal and consumed for energy and steam production and other additives used in the smelting process were not included in the emission estimates.

Energy Sources and Type

The major departments of the operation use or at one time used coal and/or coke, electricity, carbon monoxide, and natural gas in various applications to supply energy. The roaster used gas when initially fired-up, but thereafter was heated exothermically. Byproduct carbon monoxide collected from the zinc condensers in the furnace section supplies the heat required for pelletizing the sinter and to heat the boilers in the refinery. Electricity for the facility and the electrothermic furnaces is produced by a company-owned onsite coal-fired electric generating plant built that was placed in service in 1958 to supplement purchased electricity (James Reese, Horsehead Corporation, oral commun., 2008). In the 1980s or 90s, in order to meet environmental regulations, the plant switched over to low sulfur coal and, among other modifications, was re-designed to have the ability to substitute natural gas for coal (Williams, 1990; p. 440). In 1978, it was reported that the power plant required 16.3 million dollars in pollution control systems to reduce sulfur dioxide emissions, 50 percent to be borne by the Department of Interior (St. Joseph, Annual Report, 1978, p. 11).

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Langeloth, American Zinc and Smelter Corporation, Washington County, Pennsylvania

Introduction

The Langeloth plant was originally constructed to meet the Nation's increasing demand for zinc leading up to and during World War I (Jolly, p. 72). The Langeloth zinc plant operated from 1914 through 1947 and was similar in design to the Donora zinc smelter facility (Engineering and Mining Journal, 1927, p. 649). The plant closed in December 1947 (Cotterill, 1950, p. 28), following a six month labor strike which interrupted production in 1946. The closure coincided with the closure of other zinc smelting plants in the United States that were phasing out the use of horizontal retorts in favor of more efficient vertical retorts.

It was estimated that Langeloth's total zinc equivalent production over its 34-year life was roughly 900,000 short tons and during that time period about 36,000 short tons of zinc equivalents potentially were emitted to the atmosphere through fugitive and stack emissions as a component in dust, fumes, and gas (see figures 35a and 35b).

Map Number (fig. 1)

11

Location

The plant was located in Langeloth, Washington County, PA at N40°21'54" (40.363506); W080°24'51" (-80.414167).

Years of Operation

The plant operated from 1914 to 1947 with only minor interruptions.

Owner-Operator

1914–47—American Zinc and Chemical Company (AZCC). AZCC was a subsidiary of The American Metal Co. Ltd.

Primary Products

Zinc metal
Zinc oxide
Sulfuric acid

Feed Sources and Types

Information on Langeloth's sources of feeds, amounts, and their chemistry was incomplete. The Langeloth plant was

originally built to use concentrates produced through gravity means, such as jigging and tabling, from ores from the Joplin, Mo. area and in Wisconsin. In the 1920s and 1930s, a portion of the facility's feed was made up of zinc sulfide ores and or zinc sulfide concentrates or both from the Pecos polymetallic mine in New Mexico (U.S. Bureau of Mines Minerals Yearbook, 1934, p. 79). From the year 1927 through 1938, the Pecos mine produced more than 187,000 short tons of zinc contained in concentrates (Harley, 1940). The mine operated during the years 1927-39 and 1943-44. The actual amounts of material received by the smelter during this period were not available. In 1928, flotation zinc concentrates from New Mexico were described as a major source of Langeloth's feed (American Society of Mechanical Engineers, ASME, 1928). Ores from the Pecos mine contained copper, antimony, arsenic, cadmium, lead, and zinc and other materials, including mercury (McLemore, 2001, p. 9).

Sulfide ores from the Joplin-Miami district reportedly were roasted at Langeloth until 1927 (Wormser, 1923). The reported ore grades for the District's reserves in 1934 was 4.0 percent zinc and 1.0 percent lead. (Keiser, 1934; p. 397), but ore grades produced from the mines were probably much higher.

Langeloth received zinc concentrate feed from the Tri-State District in 1940 and may have also received zinc concentrates from southern Illinois and Wisconsin (U.S. Bureau of Mines Minerals Yearbook 1941, p. 265).

In 1942, the plant received "several hundred tons of zinc concentrate" from the Valzinco Mine, a volcanogenic massive sulfide deposit, in Spotsylvania County, VA. In addition to the zinc, the concentrate contained cadmium, copper, gold, lead, and silver mostly in sulfide minerals, along with pyrite. (U.S. Bureau of Mines Minerals Yearbook, 1943, p. 360). No reports concerning recovery of metals other than zinc were available.

Plant Capacity and Production Estimates

Langeloth's zinc production was estimated for nearly the entire time that the plant operated because production data were reported for only one year (Cotterill, 1950). The total number of installed retorts and total distilling plant capacity data was published for a limited number of the 34 years in which the plant operated. Calculations used to estimate historical zinc and sulfuric acid production are based on published capacity and production data, the reported number of installed retorts and furnaces, the fraction of retorts employed in distillation, utilization estimates of installed capacity, typical retort production capability, metallurgical recoveries and ore grades for the time period and other factors. Some production estimates for Langeloth also incorporated major economic or political cycles on a national level that effected plant output, such as reduced production during periods of economic slow downs, or conversely, an increase in production during war time when metal demand was high. Local phenomena that affect production levels, such as a labor strike at the plant, also were considered in production estimates.

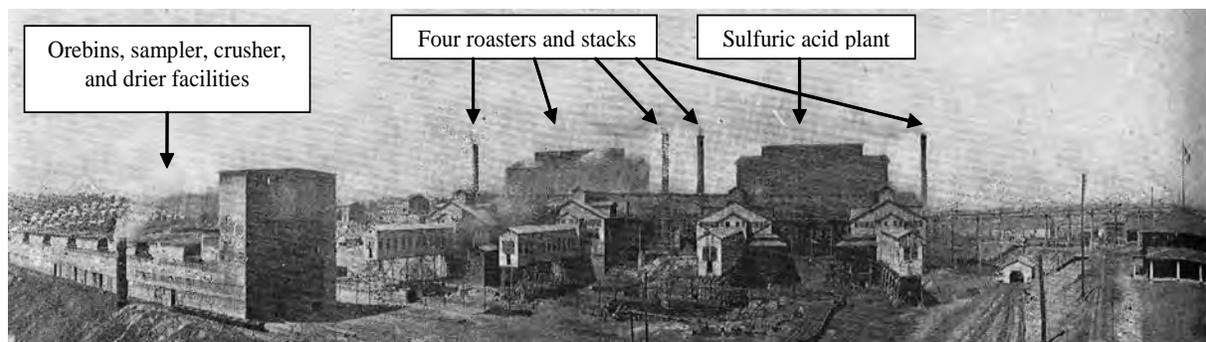


Figure 35a. Langeloth zinc smelter in Langeloth, Pennsylvania, circa 1923. Note plant emissions from crusher and drier, roasters and roaster stacks (Photograph adapted from Wormser, 1923). Photo used courtesy of Engineering and Mining Journal, 2009.

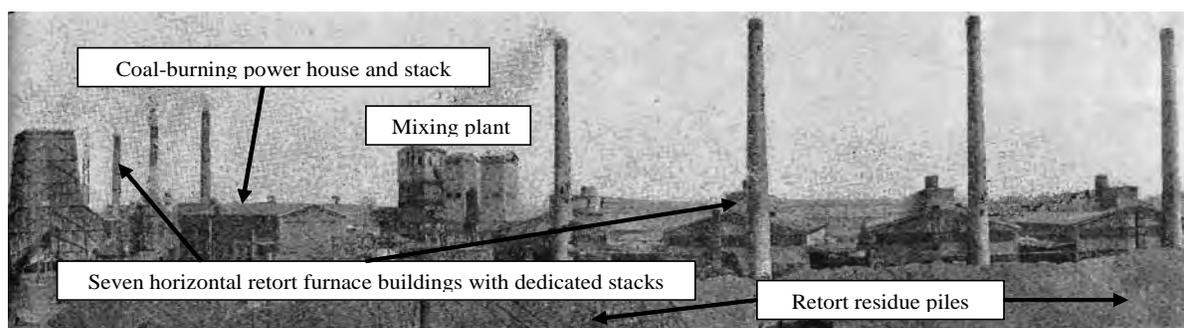


Figure 35b. Langeloth zinc smelter in Langeloth, Pennsylvania, circa 1923 showing major plant facilities. Although somewhat difficult to discern because of the poor quality image, plant emissions can be clearly seen from the power plant stack and retort furnace stacks in the original image. (Photograph adapted from Wormser, 1923). Photograph used courtesy of Engineering and Mining Journal, 2009.

Roasting

In 1919, the roasting portion of the facility had published an estimated annual production capacity of 60,000 short tons of ore (Palmer, 1919). Annual ore roasting capacity was published in the Yearbook of the American Bureau of Metal Statistics in the early 1920s. Annual capacity estimates ranged from a low of 58,400 short tons in 1924 to a high of 62,000 short tons in 1921, and averaged about 59,000 short tons (American Bureau of Metal Statistics, 1923). Assuming the average zinc content for sphalerite and concentrate was 55 percent, the feed would have contained approximately 32,000 to 34,000 short tons of zinc with recoveries generally exceeding 92 percent. Metal recoveries improved over time as cleaner-higher grade zinc concentrates produced by flotation became more available, coupled with advances in smelting technology.

In 1928, Langeloth's roaster reportedly had an annual capacity of 70,000 short tons of ore or concentrate per year, or

200 tons a day, yielding 35,000 short tons per year of slab zinc after distillation suggesting an uppermost limit for annual zinc production during the period (ASME, 1928).

Retorting (Reduction)

In 1914, during start-up, one of the four furnaces at Langeloth containing 864 retorts and had a design capacity to treat 20 short tons per day of ore and concentrate (Ingalls, 1914). Assuming a feedstock grade of 55 percent zinc, 85 percent furnace availability for the four furnaces, and an overall zinc recovery of 90 percent, potentially 3.6 short tons of zinc could be recovered per retort per year or about 12,000 short tons of zinc at full effective capacity. Effective capacity is the amount of material the plant can process or produce in a given period under normal operating conditions. The USGS reported that the original number of horizontal retorts "contemplated" for the facility was 3,456 (U.S. Geological Survey, 1914, p. 644), however, only 880 retorts were installed

in that year (U.S. Geological Survey, 1916, p. 891). In 1915, furnaces containing 3,648 retorts were completed and plans were announced to double the production of zinc and sulfuric acid (U.S. Geological Survey, 1916, p. 893). By mid-1916, the number of installed retorts at the facility had increased to 6,384 with furnaces under construction to accommodate 912 retorts. (U.S. Geological Survey, 1917, p. 951). At the close of 1917, the installed retort capacity reached its historical high at a reported 7,296 (MR, 1917), but zinc production was not stated. Smelting capacity for 1917–19 was reported at 7,296 retorts (Roush, 1921; p. 717).

In 1923 and 1924, the number of retorts in use was reported by the USGS at 5,168, and for the years 1925 through 1934, the last year that retort data was published by the U.S. Bureau of Mines; 4,864 retorts were reported as “in use” (U.S. Geological Survey, 1927–28; U.S. Bureau of Mines, 1934–35).

In 1928, annual plant capacity was published as 35,000 short tons of slab zinc, from treating 200 tons of ore or concentrate on a daily basis in the roaster (ASME, 1928). No details concerning the derivation of the statistic are available; however, the estimate appears reasonable assuming an average concentrate grade of 55 percent zinc and an overall zinc recovery of 85–90 percent. The statistic suggests an uppermost limit for annual zinc production in the late-1920s and a possible plant expansion from earlier years.

An alternative method to check estimated plant capacity utilization was accomplished by examining nameplate capacity, number of retorts, and retort utilization. The plant’s published annual design capacity of 35,000 short tons of distilled zinc was based on using all furnaces containing 7,296 retorts, or approximately 4.8 short tons of zinc per retort per year. Considering that actual furnace utilization was about 85 percent because of the batch process used in horizontal retorts, breakage, and furnace cleanout and repair; annual effective production capacity per retort for Langeloth would have been approximately 4.1 short tons of recovered zinc per year for each retort operated. This estimate is comparable with other zinc plants using horizontal retorts during the period.

The American Bureau of Mining Statistics Yearbooks also published Langeloth’s daily zinc average total retort production capacity for some years during the 1940s. Estimates ranged from 100 short tons of zinc per day in 1940 to a high of 122 short tons of zinc per day in 1947. The estimates did not include downtime required for repairs and other technical factors. Given the previous information, the plant’s optimum annual zinc production during the 1940s would have ranged from approximately 31,000 to 38,000 short tons, assuming an 85 percent furnace.

Market conditions, labor issues, and other nontechnical events and conditions that can affect production were not considered in the calculations; however, it can be safely assumed that the plant achieved maximum capacity, at least for some periods, during World War II and low production in the early 1920s and early 1930s, for example, owing to depressed national economic conditions.

The American Bureau of Mining Statistics also published the number of retorts at Langeloth for many of the years that the plant operated. The statistics, however, appeared inconsistent in some years for at least two reasons. The number of retorts reported for the facility at the depth of the Depression and at the peak of World War II are within 10 percent of each other, an unlikely production scenario, and they were much less than the installed capacity of nearly 7,296 retorts. Further, U.S. zinc production in 1931 was operating at less than 50 percent of capacity, and in 1944 was operating at about 90 percent of capacity. Some of the tables published by the American Bureau of Mining Statistics were accompanied by a footnote that stated that plant capacity “is meaningless, except as an indication of plant magnitude” (American Bureau of Metal Statistics, 1946). They are helpful in this regard, as the estimates provide an insight for the upper limit of production estimates and an approximation of production during periods of known maximum output, such World Wars I and II.

Annualized distilled zinc capacity published by American Bureau of Metal Statistics for the period 1940–46 ranged from a low of 36,500 short tons in 1940 to a high of 44,500 short tons in 1946. The range of effective capacity for those years probably was on the order of 31,000 and 38,000 short tons of zinc, respectively.

Although the American Bureau of Mining Statistics published annual retort distilling capacity of Langeloth as 78,000 short tons of roasted ore or concentrate for most years for the period 1928 through 1947 (containing approximately 43,000 short tons of zinc of which approximately 35,000 short tons could be potentially recovered (based on 55 percent zinc, 90 percent recovery and 85 percent plant utilization), production data was never provided.

In 1947, the year the plant closed, annual capacity was reported as 45,000 short tons of refined Prime Western Grade zinc (Cotterill, 1950). The source of the statistic was not revealed in the study.

Production Estimates

Zinc Metal

Although, there were published data on the facility’s annual zinc roasting and distilling capacity in the literature, only one zinc production statistic was encountered. In 1950, Cotterill stated that Langeloth’s zinc production for the year 1945 was 38,000 short tons. The source of the estimate was not specified.

Most of the production estimates for other years was based on the number of retorts reported as in use, or the number estimated be in use, and the estimated cumulative annual production per retort. In 1913, the U.S. Geological Survey estimated that the average annual production capacity of retorts in a zinc spelter plant were from 3.5 to 4.25 short tons per retort (U.S. Geological Survey, Mineral Resources of the United States, 1914). In 1919, it was reported that the

Langeloth smelting plant had the annual capacity to produce from 36,000 to 48,000 short tons of zinc metal (Palmer, 1919). The effective capacity for 1921 was approximately 4.1 short tons of zinc per retort for Langeloth, but the number of retorts operating was not available, and was likely well below capacity because of the low level of the country's industrial activity during this period. The estimate applies nationally as the total zinc production in the United States using horizontal retorts in 1921 and the number of retorts recorded in use that used coal as fuel, like Langeloth, was also 4.1 short tons of zinc per retort. Average productivity for horizontal retorts using similar feed type and technologies from other sources was also used to estimate production (Roush, 1915; Hofman, 1922; Twitchell, 1912; Stander, 1913; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; Robert Kuba, Horsehead Corporation, oral commun., 2008; U.S. Bureau of Mines, Minerals Yearbook, 1934; U.S. Geological Survey, Mineral Resources of the United States, 1913;). The zinc production estimates for Langeloth are based on an estimated 4 short tons of zinc per producing retort per year for the period 1914–19, and 4.5 short tons of zinc per operating retort per year for the years 1920–47. The higher production per retort reflects process improvements, cleaner-higher grade ores, and increased use of high-grade concentrates produced by flotation. In some years, the USGS and USBM Mineral Resources of the United States published the number of retorts operating at the end of certain years; however, inclusion of this statistic in the publication ceased in 1934.

The zinc capacity and production of the smelter was probably increased in the late-1930s or early 1940s, like most smelters in the United States, in response to an anticipated increase in zinc demand brought on by WWII. It was possible for production to have exceeded the plant's design capacity if the operators modified schedules to increase output. Operating at this level, however, can have negative consequences resulting in equipment failures and lower productivity as a consequence of lower metal recovery.

Zinc production estimates in certain years were compared to U.S. industrial activity in the zinc smelting industry. For example, zinc production was relatively low during the Great Depression. Only one-third of the Nation's horizontal retorts were used in 1932 (U.S. Bureau of Mines, Minerals Yearbook, 1934, p. 79), and for 1934 the U.S. Bureau of Mines reported that overall horizontal retort utilization was less than 50 percent, because of the introduction and startup of more efficient vertical retorts and poor general economic conditions (U.S. Bureau of Mines, Minerals Yearbook, 1935, p. 113). The U.S. economy began to recover in the mid-1930s, and by the late-1930s the U.S. zinc industry had ramped up to supply zinc in support of increased demand for materiel by the United States government and its allies in World War II. For the years 1939 through 1945 annual production was estimated at 38,000 short tons of zinc metal.

In 1947, the year the facility shut down, annual zinc capacity was rated at 45,000 short tons (Cotterill, 1950, p. 26), but production probably was less than one-half of that because

of labor strikes and plant decommissioning activities during the last year of the facility's operation. It was estimated that Langeloth's total zinc equivalent production over the 34-year life of the zinc smelter was roughly 900,000 short tons. This estimate is uncertain to the degree that actual production data were unavailable and because numerous other factors that likely affected plant production were not known. The unknown conditions include company specific and general economic and labor conditions, company decisions, availability and nature of feed and technical factors such as plant efficiency, breakage of retorts and furnace repair or rebuilding.

Zinc Dust, Zinc Oxide, and Zinc Sulfate

References up to the year 1921 were found in the literature pertaining to the company's ownership of facilities to produce zinc dust, zinc oxide, and zinc sulfate, although it did not specifically state if they were located on the Langeloth smelter site. In 1919, it was reported that the plant had the monthly capacity to 500 short tons of zinc oxide per month and from 150 to 200 short tons of zinc dust. It does not describe if the zinc oxide was produced by either the American or French process. Zinc sulfate production was described as "intermittent (AIME, 1921; Palmer, 1919; Weed, 1920)." The limited mention in the literature suggests the products may not have been produced in years following 1920.

Sulfuric Acid

Sulfuric acid [usually 98 percent pure-commercial grade sulfuric acid (66 degrees Baume')] was recovered as a byproduct of smelting sulfidic zinc ores and concentrates as its commercial value was recognized, especially in the steel industry.

The acid plant at Langeloth started operating in 1915 (U.S. Geological Survey, Mineral Resources of the United States, 1917, p. 951) and continued to operate until the plant's closure in 1947. In 1919, the plant was reported to possess the monthly capacity to produce up to 8,500 short tons of 60° Baume' (Be) sulfuric acid and the ability to convert up to 3,500 short tons of the acid to 66° Baume' (Be) sulfuric acid (Palmer, 1919). In 1928, the sulfuric acid plant was reported to have an annual capacity to produce 70,000 tons of 66° Baume' (Be) sulfuric acid (98 percent pure-commercial grade sulfuric acid; the standard from smelting zinc sulfide feed) from an equal amount of roasted ore and concentrate roasted, or about 2 short tons of acid per short ton of recovered zinc, at full design capacity (American Society of Mechanical Engineers (ASME), 1928). The ratio was comparable to other sulfuric acid operations that relied on roasting sulfidic zinc ores and concentrates, and the addition of sulfur burning to increase the sulfur content of gases directed to the acid plant. Using zinc production, mass balances, a 32 percent sulfur content in the roaster feed stock and a 95 percent sulfur recovery, and the addition of supplemental sulfur, it was calculated that Langeloth may have produced approximately 1.5–2 million short tons of 66° Be sulfuric acid at 98 percent purity over its

34-year operating period containing roughly 550,000 short tons of sulfur.

In addition to the considerations given for the total historical zinc production estimate, additional caution for the sulfuric acid approximation should be considered, since no production data were provided in the literature and not all generated sulfuric roaster gases may have been directed to – or used in the acid plant on either a regular or intermittent basis. Acid plant shut downs and inefficiencies were not considered in the estimates, nor was the use of supplemental sulfur burning for acid making.

Other Products

In 1921, the Langeloth facility was described as producing four short tons of zinc sulfate (about 40 percent zinc) per day by combining impure zinc oxide produced in the zinc oxide plant, and sulfuric acid. Other than this one mention, there were no other references to zinc oxide production, or lead for that matter, discovered in the literature. The resulting precipitate was filter pressed from which a “cake” containing zinc oxide, zinc and lead sulfate, and other impurities were fed back to the Wetherhill grate in the oxide plant where zinc and lead were volatilized. Except for 1928, no statistical data on annual production or the years that the materials were produced were available (Ralston, 1921).

In 1928, the works had a reported annual capacity of 3,000 short tons of zinc sulfate (about 40 percent contained zinc) and 1,200 short tons of sodium bisulfate, (American Society of Mechanical Engineers (ASME), 1928).

The sodium bisulfate, referred to as niter cake, was produced from sulfuric acid and salt and had a wide number of applications including use in metallurgical processing (such as pickling), as a component for the manufacture of hydrochloric acid, and converting ammonia to ammonium sulfate at coking plants.

As mentioned, the literature reported that lead was contained in residues and fed back to the retorts, however, information referring to production or sales of other metals or non-zinc containing metal-based materials was not discovered in the literature.

Technology

When newly constructed the plant was described as being very similar in design to the Company’s plant at La Salle, Ill. (Ingalls, 1914). The three major facilities making up the zinc production process included an ore handling facility, roasters, distillation furnaces using horizontal retorts, and a sulfuric acid plant (figure 35a and b).

Ore was unloaded from railroad cars into concrete bins from which a bucket crane took the ore to the crushing and sampling mill. The ore was crushed and dried (in a

Ruggles-Coles cylindrical drier) before screening. The gases from the drying process were then sent through a sheet steel dust-collecting chamber, and discharged through a chimney (Ingalls, 1914). The collected dust was likely recycled as feed to the roaster.

Initially, two Hegeler muffle roasting furnaces of standard design were used (Engineering and Mining Journal, 1914, p. 986). Each furnace was double, seven hearths high, with individual hearths 6 foot 1 inch by 80 feet, and each furnace had a dedicated gas producer measuring 9 x 15 ft. which was burned in the flues under the fifth, sixth, and seventh hearths. Secondary air was then added and gas passed from the flues to the chimney. In 1914, a roaster treated about 55 tons of ore per day and used about seven tons of coal as fuel, producing 4.5 percent sulfur dioxide, by volume, in the roaster off gas. The roaster gas was directed through flues for acid production (Ingalls, 1914). Generally, with a sulfur dioxide content of 4.5 percent, supplemental elemental sulfur burning was required to bring the level of the gas directed to the acid plant to about 6 percent.

In the 1920s, according to the Bureau of Metal Statistics (BMS), there were 4 roasters with a combined annual capacity to roast approximately 62,000 short tons of sulfidic zinc ores and concentrates.

In general, sulfuric acid plants during this time period passed the sulfidic roaster gases through a centrifugal dust catcher to the Glover tower, where dust settled in large lead-lined chambers. The dust chambers were set directly over the tunnel which runs under the roasting furnace and were hopped to one point for easy cleaning. The cleaned gases were directed to Gay-Lussac towers where the gases were contacted with water. Acid was stored in lead containers that could accommodate seven short tons of the product (De Wolf and Larison, 1921).

Retorting

The reduction of the zinc contained in the charges was accomplished using four blocks of furnaces containing a total of 3,456 retorts (U.S. Geological Survey, Mineral Resources of the United States, 1914). The furnaces were fired with producer gas that contained horizontal retorts charged with a mixture of roasted ore or concentrate, or both with coal or anthracite. Following volatilization of zinc from the charge, it was subsequently condensed as molten metal in condensers, tapped, and poured into molds. Combustion gases in the retort furnaces were passed through a Rust boiler to capture heat and then directed up a brick chimney one-hundred and twenty-five feet high (Ingalls, 1914, p. 985-989). Most of the zinc fumes escaping from diffusion, cracked, and broken retorts likely escaped to the atmosphere through the furnace stack.

On Site Energy Sources and Types

The Langeloth zinc smelter was unique in that it was built on top of an exploited coal seam. Beginning in 1914, the coal from the underground mine supplied the facility with lump coal and slack (Ingalls, 1914; Poellot, 1975). Slack is a term used to describe coal fragments that are less than one-half inch in size.

The Langeloth plant generated its own electrical power using waste heat from the distillation plant to heat boilers that generated steam to drive two 2,000 kilowatt turbines (Palmer, 1919). Excess power was provided to the town.

Emissions

No emission studies pertaining to Langeloth were encountered in the literature. Emission estimates were developed using data related to comparable zinc smelting operations that operated contemporaneously using similar sulfidic feedstock and plant equipment, such as the Palmerton plant. By applying the Langeloth data and data collected from the other sources, it was estimated that an amount equivalent to about 4 percent of the zinc produced at Langeloth, or 36,000 short tons of zinc equivalents were emitted to the atmosphere through fugitive and stack emissions as a component in dust, fumes, and gas over the 34-year period that the plant operated. Because the Langeloth facility manufactured sulfuric acid, zinc losses through atmospheric emissions were lower than other plants treating sulfidic ores that did not produce acid. In the process of acid-making, the suspended materials contained in the roaster off-gases were removed to a great extent by various processes to ensure that the sulfuric acid met industry specifications for purity.

Sulfur

More than 90 percent of the sulfur contained in the ores and concentrates fed to the roasters was recovered in the sulfuric acid plant when operating at full efficiency. To estimate the amount of sulfur equivalents emitted to the atmosphere requires data pertaining to numerous factors. The major factors, in no particular order, include: (1) the sulfur content of ores and concentrates treated; (2) efficiency of sulfur removal during roasting; (3) an estimate of the percentage sulfur in roaster gases recovered and used in the acid plant; (4) the capacity of the acid plant; (5) determination if there was supplemental burning of sulfur to upgrade gases; (6) effectiveness of sulfur recovery in the acid plants; and (7) the amount of sulfur retained in residues. Other accountable amounts of captured sulfur to be considered include sulfur incorporated in zinc products, sulfur contained in waste residues and losses during outdoor storage of concentrate and concentrate drying. Sulfur emissions were estimated considering these criteria and were supported in part by discussions with industry experts (Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008; James Reese, Horsehead Corporation, oral commun., 2008).

In the case of Langeloth, it was estimated that: (1) approximately 1.7 million short tons of ore and concentrate were treated over the life of the operation; (2) the ores and concentrates contained an average of 32 percent sulfur; (3) supplemental sulfur burning was used; (4) 90-93 percent of the sulfur was recovered in the acid plant; (5) 2 percent of the contained sulfur in the ore and concentrate reported to waste residues and lost during outdoor storage; (6) 5 percent of the total sulfur contained in concentrate was emitted to the atmosphere through losses during roasting, retorting, and acid production and; (7) sulfur contained in products other than sulfuric acid were not considered.

Using these factors it was estimated that roughly 27,000 short tons of sulfur equivalents contained in sulfur compounds, including sulfuric acid mist generated at the acid plant, was released to the atmosphere over the 34-year period the plant operated. Reliable data for estimating additional atmospheric emissions from supplemental sulfur burned for acid making was not available, however an amount on the order of 5,000 short tons, or possibly more of sulfur could possibly have been released based on analogous acid producing operations, such as at the Palmerton plant (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

Plant operations can be affected on a day-to-day basis by ore and concentrate compositions, economic conditions, policies and regulations, technical problems, and other factors. For these reasons the estimate should be considered with some caution.

Other Metals

Although information on the sources and amounts of zinc feed Langeloth received is limited, it is probable that the feed contained other metals besides zinc and sulfur, which were possibly emitted to the atmosphere during various stages of the processing of feedstock. The plant's primary zinc product was likely Prime Western grade zinc, considering the sources of feed and because it was not refined. The material sent for smelting from New Mexico contained copper, antimony, arsenic, cadmium, lead, and zinc and other materials, including mercury (McLemore and Branvolf, 2001, p. 9). The ores and concentrates shipped from the Tri-State District contained cadmium, copper, lead, and other materials (see tables 3, 5, 8, and 20).

A study published in 1941 sampled ores and zinc metal applying various assaying techniques. All 6 ore samples contained cadmium ranging from 0.04 percent, up to 0.31 percent and averaged 0.13 percent. Lead content in the ore ranged from 0.12 percent up to 1.58 percent, and averaged 0.44 percent. Two zinc metal samples contained an average of 0.07 percent cadmium and 0.36 percent lead (Oshry, 1941). The author does not imply that the samples were representative of all feed or zinc product, but does suggest that because some of the feedstock contained these elements, some could have been emitted to the atmosphere.

Table 20. Average assays of 30 shipments of sphalerite from the Joplin, Mo. mining district, taken around 1900 (Ingalls, 1906).

Element or compound	Zinc	Iron	Lead	Cadmium	Copper	Arsenic	Phosphorous	Cobalt, manganese, and nickel
Content, percent	58.4	1.853	1.37	0.36	0.03	0.0159	0.00073	Trace

Note of Interest

In 1999, the Pennsylvania Department of Environmental Protection (PADEP) requested information on the zinc smelting operations operated by the former American Zinc and Chemical Company (AZC) – a subsidiary of the American Chemical Company Limited (Amco) (Wilson, 1987, p 8), a site owned at the time by Cyprus Amax, and a subsidiary of Phelps Dodge. The site encompassed the former Langeloth zinc smelter facility operated by the former AZC and some or all of a contiguous, currently operating molybdenum refinery formerly owned by the Climax Molybdenum Company, which was indirectly owned by Cyprus Amax. The AZC, which was dissolved in 1951, was also a subsidiary of a corporate predecessor to Cyprus Amax. In discussions with Cyprus Amax in 2001–02, PADEP informally indicated it expected Cyprus Amax to investigate and remediate negative environmental conditions at the AZC site. A preliminary investigation of the site determined that remediation of the site could cost from 18 million to 52 million dollars. (Phelps Dodge Corporation, 2002).

The Langeloth Metallurgical Company LLC has roasted and recovered metals from spent catalysts and other secondary materials on the previous smelter site for use as additives in the steel manufacturing industry beginning in 1986 through at least 2007 (Langeloth Metallurgical Company, 2004).

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Palmerton Zinc Smelter, Zinc Corporation of America (ZCA), Carbon County, Pa.

Introduction

The Palmerton zinc smelting complex is located in Palmerton, Carbon County, Pennsylvania; about 80 miles north of Philadelphia. The Palmerton plant was originally constructed in 1897 and gradually replaced zinc production from New Jersey Zinc Company's (NJZ) Newark and Jersey City smelters in NJ, and the Bethlehem smelter in Pa. (Dunn, 1995, p. 211). NJZ selected the site because it was close to sources of critical materials, such as anthracite and zinc ore, had an established infrastructure, and was near to the markets for its products. The West Plant first produced zinc oxide in late-1898 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008) treating zinc ore and concentrate from New Jersey and closed in 1987. Sulfide concentrates were first treated in 1903 at the West Plant, after undergoing installation of new equipment which included a roaster and acid plant. Primary zinc metal production ended in 1980 (Robert Kuba, Horsehead Corporation, oral commun., 2008).

The East Plant was constructed in 1910-11 (Dunn, 1995, p. 159, p. 183) and was originally designed to treat non-sulfidic ores and concentrates. It opened in 1911 and treatment of primary zinc-sourced concentrates was discontinued in 1981. The plant was expanded to treat zinc sulfide ores and zinc sulfide concentrates (mostly sphalerite) beginning in 1916 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). The acid plant was located at the East Plant and closed along with the sinter plant at the end of 1980 (Robert Kuba, Horsehead Corporation, oral commun., 2008; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). A French process oxide plant closed in the 1990s, while the Waelz furnaces continue to operate using primarily EAF dust as feed from which a calcined zinc product is shipped to the Monaca, PA smelter and byproduct slag and some impure metal compounds are produced.

By this time, zinc used in the French process oxide plant was no longer derived from primary zinc ores and concentrates treated at Palmerton.

The major final products produced at the West Plant included lithopone [a zinc-based pigment produced in combination with barium sulfate (barite)], slab zinc, spiegeleisen, zinc oxide produced using the American process; refined zinc and zinc dust, cadmium metal, sulfuric acid, and other zinc-based products (Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008). Final products produced at the East Plant were primarily zinc oxide (Dunn, 1995, p.183), sulfuric and hydrochloric acid, ammonia, cadmium and lead, spiegeleisen, and other zinc products such as zinc sulfate, zinc chloride, high- and low-lead zinc oxide, and ferroalloys. Intermediate products used to produce zinc metal and zinc oxide were also produced at the East Plant.

Palmerton was noted for the purity of its "Horse-Head" and the "Bertha" brands of slab zinc (spelter). In October 1981, the Palmerton plant changed ownership and modified to produce only zinc oxide, powder, and dust (U.S. Bureau of Mines Minerals Yearbook, 1981). In the early 1980s, legislation was passed that prohibited placing EAF dust in landfills. This legislation resulted in the modifications of Palmerton's Waelz kilns and calcining kilns to treat EAF dust; a waste produced in steel plants. By 1986, the plant was totally dependent on secondary material as feed. The treatment of this material ultimately resulted in the recovery of zinc and other metals, primarily cadmium and lead. The Monaca plant receives a substantial portion of its calcined EAF dust feed from the Palmerton plant as a calcined zinc product. In addition, the Palmerton facility produces metal powder in zinc alloys using mostly EAF dust and other secondary material as feedstock.

Little or no defoliation of forests adjacent to the smelter facility was apparent when aerial photos taken in 1938 were studied. The declining condition of the forests were first observed in aerial photos taken in 1950 and appeared to noticeably advance in subsequent aerial photographs (U.S. Environmental Agency, 1987) (see figure 36). In 1979, the United States Environmental Protection Agency (USEPA) notified the New Jersey Zinc Company that the agency had determined that stack and other types of smelter plant-derived emissions containing cadmium, copper, lead, manganese, sulfur, zinc, and other elements were contaminating an area surrounding the facility area. As with other zinc plants employing similar technologies, such as the Donora Zinc Works, the likely major contributors to atmospheric emissions and contamination of the plant's surroundings included cokers, horizontal retorts, roasters and acid plants; and sinter plants (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). In 1982, the site was proposed to be listed on the U.S. Environmental Agency, Superfund National Priority List and was formally added to the list in 1983 (U.S. Environmental Agency, 2007). Subsequently, studies estimated that approximately 260,000 short tons of zinc were released into the atmosphere for an 80 year-period that the Palmerton plant treated primarily zinc ores and concentrates. Primary ores were treated as a portion of the plant's feedstock through 1986.

Toxic Release Inventory data for the years 1993-2005 reported that a total of 3,269 pounds of zinc from the processing of EAF dust contained in fugitive and stack were emitted to the atmosphere. Based on historical statistics and estimates based on plant design, the plant produced approximately 8.2 million short tons of zinc equivalents nearly all of which was recovered from primary zinc ores. Of this total production, about 5.2 million short tons was zinc metal produced from 1899 through the year 1986 using horizontal and vertical retorts and 2.9 million short tons of zinc equivalents in zinc oxide. Approximately 286,000 short tons of zinc were emitted to the atmosphere as a result of treating the feedstock. Since the year 1986, nearly all zinc production has been derived from secondary materials, such as EAF dust and scrap.



Figure 36a. 1950—White arrow points to southwest end of East Plant at the Palmerton Smelter, Palmerton, Pa. Photograph shows apparent changes to the density of forest growth adjacent to the Palmerton zinc plant. (Adapted from a photo provided courtesy of Steven Klassen, U.S. Fish and Wildlife).

Figures 37 and 38 are photographs of the East and West Plant at Palmerton taken circa 1965, and figures 39 and 40 are photographs of remaining facilities at the West Plant taken in 2008 and 2009. Figures 41-43 illustrate the process flows for different ore types practiced at the Palmerton facility.

Map Number (fig. 1)

12

Location

The plant was located on the outskirts of Palmerton, Pa. at approximately N40°48'05" (40.801389), W075°36'38" (75.610556) (U.S. Geological Survey, 2004). The smelter facility is located at N40°49'59" (40.833333); W075°40'00" (-75.666667) (Dunn, 1995, p. 182).

The waste pile is located adjacent to the East Smelter at N40°48'29.99" (40.808331); W075°35'0.02198" (-75.583339) (U.S. Environmental Protection Agency, 2004).

Alternate Names

Palmerton Zinc Smelter
 Palmerton Zinc
 Zinc City
 Palmerton West Plant
 Palmerton East Plant

Years of Operation

Palmerton's West Plant began operating in October, 1898 and closed in December 1986 (Pennsylvania Department of Health, 1987; Arthur W. Larvey, Consulting Chemical



Figure 36b. 1977—White arrow points to southwest end of East Plant at the Palmerton Smelter, Palmerton, Pa. Photograph shows significant changes to the density of forest growth adjacent to the Palmerton zinc plant from the image taken in 1950. (Adapted from photo provided courtesy of Steven Klassen, U.S. Fish and Wildlife)

Engineer, written communication, 2008). The East Plant was placed into production in 1911 and ceased treating primary zinc feed after 1981. Although most of the equipment used for treating primary zinc feed was shut down by 1981 at the East Plant, modifications to the Waelz kilns allowed for the treatment of EAF dust and other secondary zinc sources. The plant continued to operate in this capacity in 2008.

Ownership

Early-mid 1890s – Lehigh Zinc and Iron Company;
 Sterling Iron and Zinc Company.
 1898—Palmerton Land Company.
 1898—New Jersey Zinc Company (NJZ) (Dunn, 1995, p. 182).
 1974—NJZC—Gulf & Western (NJZ merged with G&W).
 1981—Horsehead Industries Inc. (HII) (HII changed its name to NJZ in 1981). 1984 - NJZ changed name

back to HII (Pennsylvania Department of Conservation and Natural Resources, 2003).

1987—Zinc Corporation of America (ZCA) (HII merged with St. Joe to form ZCA) (Morning Call, 2003).

2003—Horsehead Corporation, (Horsehead Industries, the parent company of ZCA, went bankrupt and its assets were acquired by Horsehead Corporation (Horsehead Corporation web site at <http://www.horsehead.net/ourcompany.html>).

Primary Products

Zinc metal
 Zinc oxide
 Spiegeleisen
 Sulfuric acid



Figure 36c. 1999—White arrow points to southwest end of East Plant at the Palmerton Smelter, Palmerton, Pa. Photograph shows continuing change of the density of forest growth adjacent to the Palmerton zinc plant from the images taken in 1950 and 1977. (Adapted from photo provided courtesy of Steven Klassen, U.S. Fish and Wildlife)

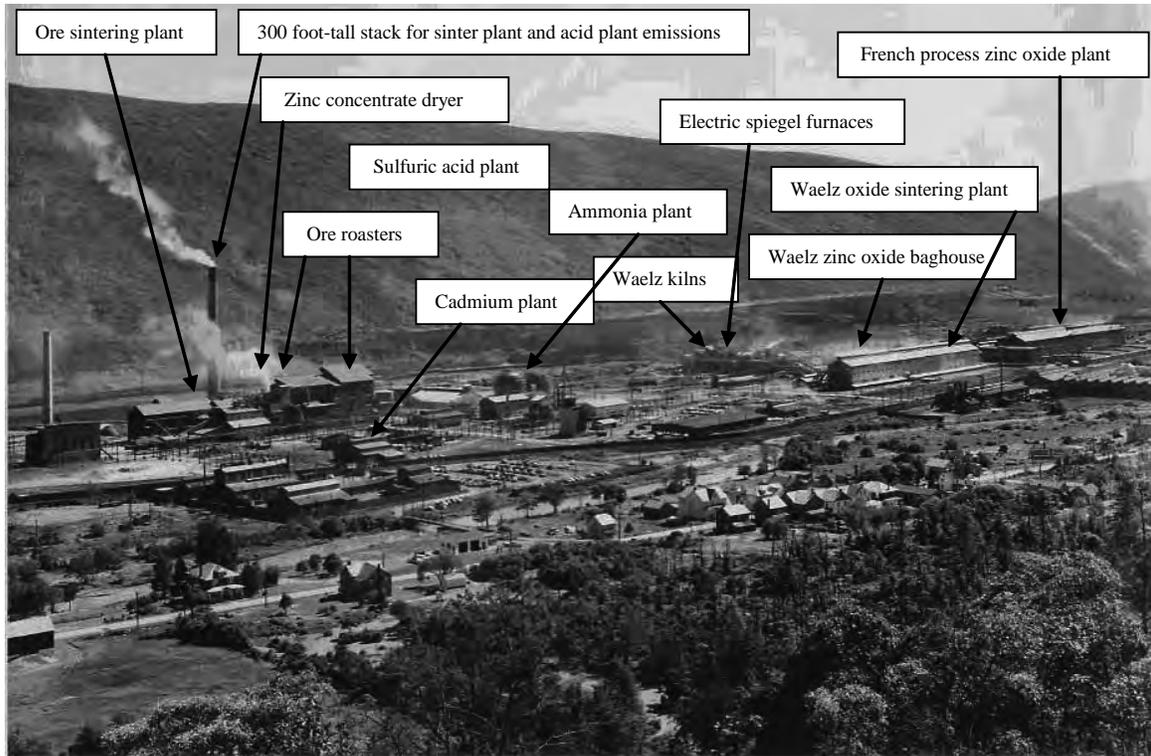


Figure 37. East Plant at the Palmerton, Pa. zinc facility (circa 1965) looking southwesterly with the plant's major facilities identified. (Modified from a photograph provided courtesy of Arthur W. Larvey, Consulting Chemical Engineer, 2009).

Types and Sources of Primary and Secondary Feedstock

The Palmerton facility was built and designed to accommodate a variety of primary zinc ores and concentrates that contained carbonate, silicate, oxide, and sulfide minerals, plus scrap and other materials associated with the feed. Although much of the plant's feed originated from company-owned mines, concentrate was purchased on a world wide basis ranging from the spot market to long-term contracts.

Most of the oxide and silicate ores treated for the production of zinc oxide and some zinc metal at Palmerton, especially in the years prior to 1949, originated from mines in the Sterling, New Jersey area (Dunn, 1995) from 1899 to around 1986, when the Ogdensburg, New Jersey mine closed.

Some hemimorphite may have been treated from Pennsylvania and other states. Although the Sterling ores (mostly franklinite and willemite) were known for their relatively high zinc content and purity, there were deleterious elements present in the ore bodies, primarily cadmium and lead, but much lower than that contained in sulfide ores and concentrates. These metals occurred in galena to a small extent and

hardystonite (a lead-rich calcium zinc silicate) to a greater extent (Dunn, 1995, p. 211). The presence of the metals negatively affected the desired specifications of the plant's zinc products. In the 1920s, the Franklin ores reportedly contained an average lead content of 0.049 percent and presented a problem for producing high grade zinc products in the smelter (Dunn, 1995, p. 213).

Zinc carbonate ores, primarily smithsonite, and the concentrates derived from the ores are known to have originated from Virginia and as distant as Thailand (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). These ores also may have contained cadmium, lead, and other metals, but usually to a lesser degree than sulfide ores.

Company data suggests that from 1900-80 roughly 3 million short tons or 60 percent of the 5.2 million short of slab zinc was recovered from an estimated 6 million short tons of sulfidic ore and concentrate processed at Palmerton's roasters. Although statistics are not available to account for the balance of feed material that comprised the difference, it likely consisted of ores and concentrates from New Jersey especially in Palmerton's early years, purchased calcines, and secondary material.



Figure 38. West Plant at the Palmerton, Pa. zinc smelter (circa 1965) looking southwesterly with the plant's major facilities identified. (Modified from a photograph provided courtesy of Arthur W. Larvey, Consulting Chemical Engineer, 2009.)

Sulfide ores and concentrates were shipped to Palmerton from Pennsylvania, Tennessee, Virginia, several Western states, and from other countries beginning in 1903. Canadian and South American ores and concentrates comprised the greatest percentage of imported feed. Other sources of primary feedstock, some of which may have been significant, included, but were not limited to Africa, Australia, Bolivia, Canada, Chile, Ireland, Mexico, Peru, Spain, and Thailand. Sphalerite was the primary ore mineral contained in the ore and concentrate feeds. In addition to zinc and sulfur, the concentrates often contained metals such as cadmium, copper, indium, iron, lead, mercury, and other metals. Arsenic also was contained in some ores and concentrate, but less frequently than the aforementioned.

In the 1920s, sulfide concentrate feed to Palmerton amounted to about 15,000 short tons per year and slowly increased to about 18,000 short tons per year by 1939. In the 1940s, average annual sulfidic concentrate feed increased to about 40,000 short tons, as the plant expanded in response to the raw material requirements of WWII. A major increase in

zinc sulfide feed occurred as the plant expanded beginning in 1950. In the 1950s the plant was receiving an average of about 125,000 short tons per year of feed with a further increase in the 1960s to an average of approximately 200,000 short tons of sulfide concentrate per year.

The plant underwent changes in the 1970s in response to new federal regulations relating to emissions and started treating higher tonnages of secondary material. As a result, the average feed of sulfidic concentrate from 1970 through 1980, the last year the roaster operated, dropped to an average of about 165,000 short tons per year.

The increase in the amount of zinc recovered from sulfide ore and concentrate is apparent when examining historical concentrate supply and production of total zinc. Zinc recovered from roasted sulfide ores and concentrates comprised less than 20 percent of total production from primary sources from 1900-25; and 70 percent for the periods 1926-49 and 1950-80. Although high-purity zinc was produced from refining, most zinc metal sold was Prime Western grade.



Figure 39. Photograph taken in 2008 of the baghouses, located at the western end of the West Plant and indicated by the vertical black arrows, were used to recover zinc oxide by the American Process. The buildings were constructed in the early 20th century. The area between the large baghouse and the river, indicated by the horizontal arrows, was occupied by the zinc oxide furnaces. The low buildings behind the baghouses were used for warehousing, bagging areas for zinc oxide, and other purposes. The plant was permanently shut down in 1987. The building is visible at the far right in figure 38. (Photograph provided courtesy of Rich Pace).

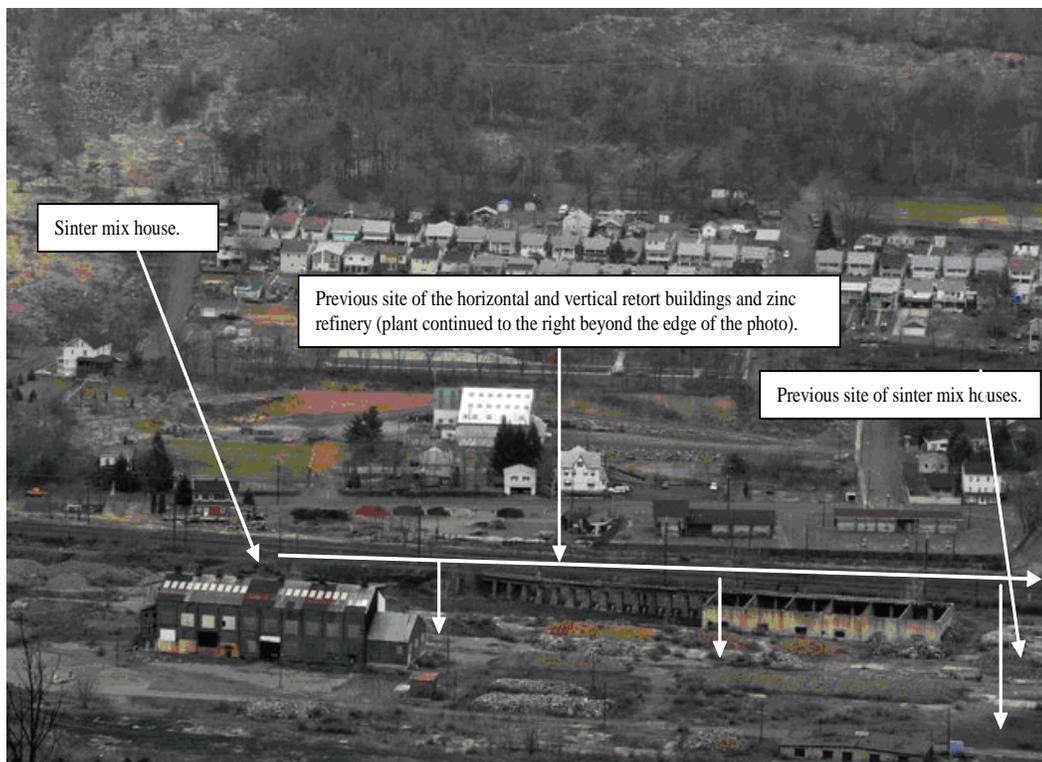


Figure 40. Photograph taken in February 2009 of the east end of the inactive West Plant at the Palmerton, Pa. zinc plant where the sinter was mixed with anthracite and coal before being briquetted and fed to the cokers and then the vertical retorts (indicated by arrows). The plant was permanently shutdown in 1987. (Photograph courtesy of Rich Pace.)

Generalized flow of primary sulfidic feedstock at the Palmerton Smelter for the period 1903-1980

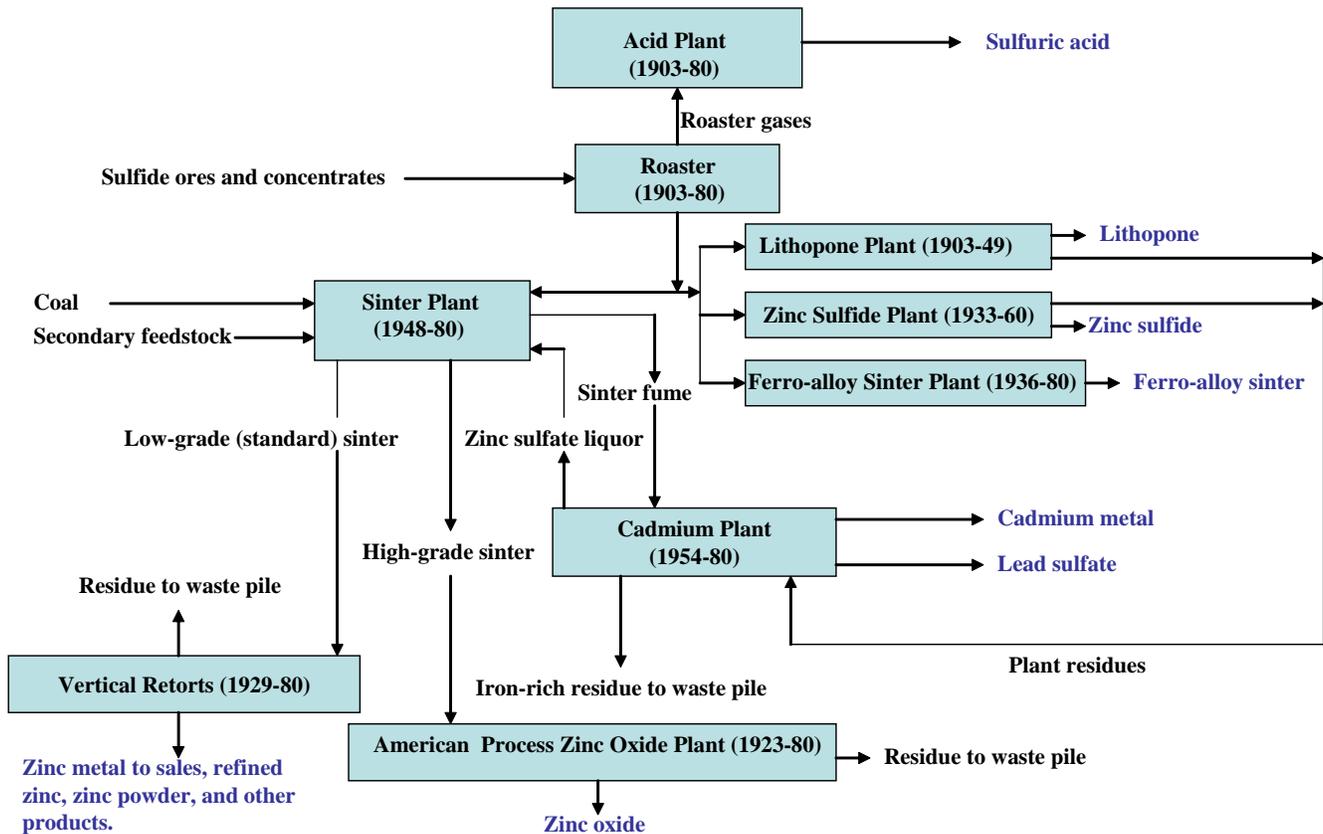


Figure 41. A generalized flow diagram of the circuits treating primary sulfidic zinc feedstock through the year 1980. Saleable products are in blue.

In the 1980s, the processing of secondary materials became an increasingly important source of the plant's feed. By 1987 it was solely dependent on secondary sources, with the great majority consisting of EAF dust.

Primary Feed Sources

The following information was collected from published and unpublished sources, and provides details on the origin and types of ores and concentrates treated at the Palmerton facility beginning with the opening of the plant until its discontinuation as a primary zinc smelter. The New Jersey Zinc Company was a vertically integrated company and owned a number of metal mines, as well as smelters and refineries throughout the United States during its nearly 100-year history. The flow of zinc ores and concentrates to specific processing facilities and data pertaining to the amounts, composition, and the length of time that operations supplied feed

to the smelter were published infrequently. NJZ did not often provide this type of information in their annual reports.

The West Plant initiated production in 1898 and produced zinc oxide and spelter (two years after opening) from smithsonite and subordinate hemimorphite originating from the Friedensville District, PA (Shelov, p. 5). A small acid plant was constructed in 1903, suggesting that local sphalerite ores from the mines near Friedensville were being roasted at Palmerton. Zinc silicates and oxides mined in New Jersey were sent to the East Plant for initial treatment. The Sterling concentrates were 30 percent franklinite, 32 percent willemite, and 2 percent zincite (Shelov, p. 6). Each mineral has different zinc content.

A transition in ore feed started around 1916 as the zinc carbonate reserves in the area were becoming exhausted, and sphalerite was becoming the chief zinc mineral from the Friedensville District (Oyler, p. 5). Some of the sulfide ores were reportedly pre-roasted upon delivery to the facility (Hofman, 1922, p. 290).

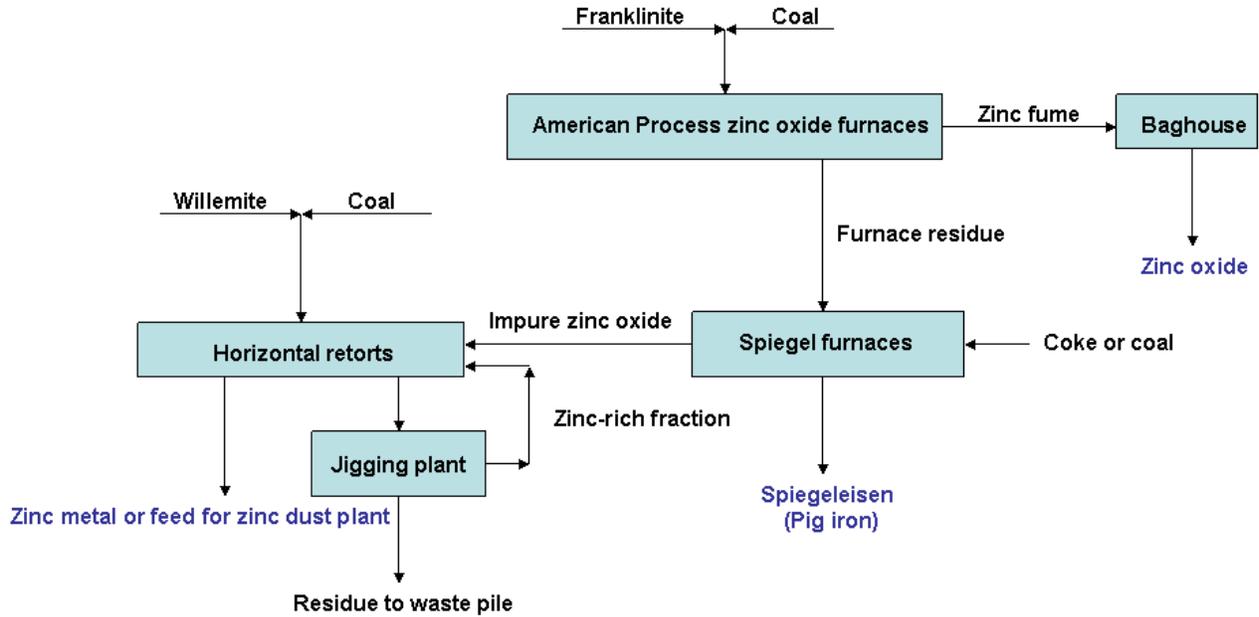


Figure 42. Generalized flow diagram of the circuit used to treat zinc oxide and zinc silicate ores from the Franklin and Sterling Hill Mining District in New Jersey at the Palmerton Smelter. Saleable products are in blue.

Generalized Process Flow of Mixed New Jersey Ores at the Palmerton Smelter

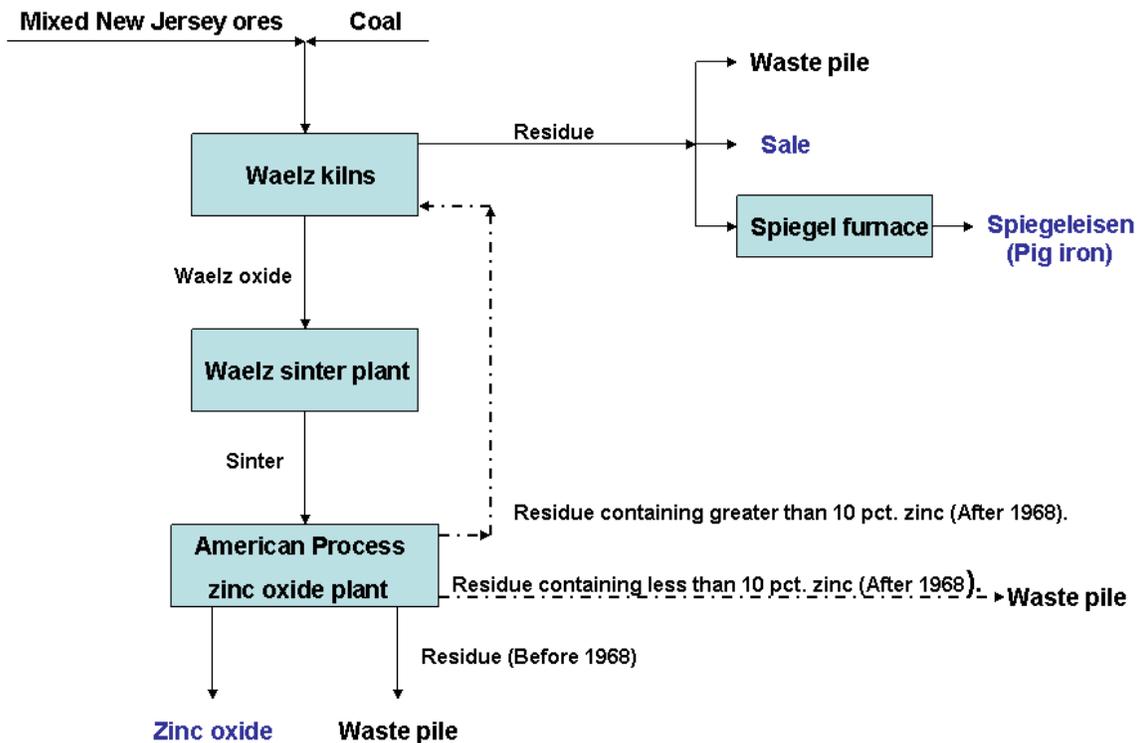


Figure 43. Generalized flow diagram of the circuit used to treat mixed zinc ores from the Franklin and Sterling Hill Mining District in New Jersey at the Palmerton Smelter. Saleable products are in blue.

The Austinville Mine and plant may have supplied some zincite and carbonate ores when the mine was first developed by NJZ in the early 1900s. The mine became a source of sphalerite ore and concentrate to the Palmerton plant as its production expanded in the 1920s and continued to be a supplier of feed, averaging about 20,000 short tons of concentrate per year to the smelter until NJZ closed the mines in the district in 1981. The Company's Austinville mines shipped a total of about 1 million short tons of sulfidic concentrate feed to Palmerton, making it the second largest single concentrate source.

Shipments of ores or concentrates or both from the Franklin area also constituted a long-term and significant supplier of tonnage to the Palmerton plant. Feed consisting primarily of franklinite and willemite, and to a much lesser extent zincite, started around 1904, as evidenced by the installation of spiegel furnaces. New Jersey ores and concentrates continued to serve as an important source of feed until the closure of the Ogdensburg Mine located in the Sterling Mining District in New Jersey in 1986. Statistical data pertaining to historical ore and concentrate deliveries from New Jersey were unavailable, but probably totaled from 18 to 22 million short tons, from which roughly 5 million short tons of zinc was recovered. Beginning in 1913, willemite was recovered from waste piles at the Franklin-Sterling District, having previously been discarded, and shipped to Palmerton (Dunn, 1995, p. 211) to be used as feed to the horizontal retorts. The mix of zinc ores from New Jersey during the early part of the 20th century were not suited for the production of spelter because of the high percentage of franklinite (high iron to zinc ratio) contained in the ore mixture. The New Jersey mines continued to supply Palmerton with ore or concentrate until 1986, when the Ogdensburg Mine located in the Sterling District, New Jersey closed. Early Sterling ore concentrates were 30 percent franklinite, 32 percent willemite, and 2 percent zincite. The balance was a gangue of carbonates and silicates (Shelov, 2001, p. 6), but were later separated through technical advances using magnetic separation into three types; franklinite; a mix of franklinite, assorted zinc minerals, and gangue; and willemite (Dunn, 1995, p. 198). It was only after the development of the Wetherill magnetic separation process that enabled the removal of franklinite, that high-quality spelter could be produced on a relatively large scale. Franklinite was used to produce impure zinc oxide and the remaining residue was used to produce spiegeleisen. In the 1940s, the franklinite was used to produce zinc oxide and spiegeleisen and the willemite-zincite was used to produce high grade slab (U.S. Bureau of Mines Minerals Yearbook, 1948) in the horizontal retorts. In the late-1950s or early 1960s, a new beneficiation plant was installed at the mines from which a single mix of ore minerals was supplied to the Palmerton plant from the Franklin-Sterling mines. In the early 1970s, ores were shipped directly from New Jersey to Palmerton and averaged 19.5 percent zinc (McMahon and others, 1974). The mixed feed continued until the mine's closure in 1986 (Dunn, 1995; p. 203).

Palmerton expanded its capacity in the years leading up to and during WWII in order to meet the increased demand for zinc. The Empire Zinc Company's mines, in the Hanover District, the largest zinc producing area in New Mexico, supplied zinc concentrates to Palmerton as early as 1918 and continued on an intermittent basis until 1951 (U.S. Bureau of Mines, 1940, Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). In 1942, zinc carbonate ore from the Austinville lead-zinc District (U.S. Bureau of Mines Minerals Yearbook, 1942, p. 360) was treated at the plant and sphalerite concentrate, containing lead and cadmium was shipped from Austinville, Virginia (U.S. Bureau of Mines Minerals Yearbook, 1942, p. 360).

Other documented contributors of feed to the West Plant during the 1940s and into the 1950s included domestic mining operations in Colorado, New Mexico, Pennsylvania, Tennessee, Virginia (U.S. Bureau of Mines Minerals Yearbook, 1946, U.S. Bureau of Mines Minerals Yearbook, 1948), and Wisconsin. Cotterill (p. 25) stated that New Jersey ores fed vertical retorts, and the company's Virginia mines supplied horizontal retorts in 1945. The literature does not specifically state how much, specific origin of the ores, but mines in Sterling and Austinville, respectively, were the likely sources. In addition to these mines, sulfide concentrates were shipped for treatment at Palmerton from operations in Colorado and perhaps 40 or more other operations in response to increased zinc demand to support the war effort. Reportedly, the facility also received zinc carbonate ore amounting to less than 1,000 short tons from the Cripple Creek Mine in Wythe County, Va. (U.S. Bureau of Mines Minerals Yearbook, 1942, p. 360). In 1949, Palmerton reportedly received zinc ore or concentrate from the following sources (1)-mines in central New Mexico (Magdalena District which mined ores assaying 7.0–8.4 percent zinc (U.S. Bureau of Mines Minerals Yearbook, 1981, p. 1) less than 10,000 short tons; (2) Austinville, Virginia 10,000–50,000 short tons, from ores assaying 3.0 percent zinc, 0.5 percent lead (U.S. Bureau of Mines, 1978, p. 1, 3) - Ducktown, Tennessee - from ores assaying 0.8 percent zinc and 0.79 percent copper (U.S. Bureau of Mines Minerals Yearbook, 1990; (3) less than 10,000 short tons; (4)- Franklin and Sterling, New Jersey-40 percent franklinite, 23 percent willemite, less than 1 percent zincite, and 36 percent combined gangue silicates and carbonates (Baum, 1953, p. 1,208), greater than 100,000 short tons; (5)-Friedensville, Pennsylvania, greater than 100,000 st (U.S. Bureau of Mines Minerals Yearbook, 1951, p VI-24–VI-25); and (6) Leadville, Colorado (U.S. Bureau of Mines Minerals Yearbook, 1951, 1954, 1955, 1956). From 1949 through 1971, the Paragsha zinc mine in Peru supplied up to 22,000 short tons of zinc sulfide concentrates annually and contained 46.77 percent zinc, 32.0 % sulfur, 2.1 % lead, and 0.16 % cadmium (New Jersey Zinc, 1957). The Cerro Mine in Peru also supplied feed from the late 1940 until 1957 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

Predominant sources of sulfide-based feed in the 1950s continued to be the Austinville mines, VA; and the Buchans

and Quemont Mines, in Canada. In the late 1950s, concentrates from the Friedensville mines in PA became an important source of feed. Zinc oxide ores continued to be shipped from New Jersey. The Jefferson City, TN Company-owned mines began supplying concentrate to Palmerton in 1956 and continued until 1979. During the 24 years these mines supplied about 500,000 short tons of zinc sulfide concentrate.

In the early 1960s, NJZ's Palmerton and St. Joseph's Monaca smelters received sphalerite concentrates from the Ivanhoe and other mines in the Austinville lead-zinc District in Va. (Mineral Industry of Virginia, p. 1,067; U.S. Bureau of Mines Minerals Yearbook, 1960-63). In 1961, the Palmerton reportedly received concentrate derived from ore averaging 6.7 percent zinc (McMahon and others, 1974) from Friedensville, PA. Concentrate was also received from many other sources including Austinville, VA; Jefferson City and Treadway, TN; Canon City and Gillman, CO; and other domestic and foreign sources (U.S. Bureau of Mines Minerals Yearbook, 1962-63). The Sterling Mine in New Jersey was closed in 1958, but reopened in 1961 and renewed shipping feed to the Palmerton plant (Horsehead Industries, Inc, 2008). In 1966, the Sterling Mine was delivering approximately 19,000 short tons of ore per month to the Palmerton Smelter, averaging 18.5 percent zinc. The Sterling Mine closed in 1986 marking the end of underground zinc mining in New Jersey (Dunn, 1995; p. 150; U-Haul, 2008).

From 1958 (U.S. Bureau of Mines Minerals Yearbook, 1959) until the roasters closed in 1980, approximately 1 million short tons of zinc sulfide concentrate was shipped to Palmerton from the company's Friedensville mine. The company-owned mine was the largest single supplier of sulfide concentrate feed to Palmerton totaling more than 1.1 million short tons of ore and concentrate. In the early 1970s, Buchauer reported that the plant was processing sphalerite concentrates assaying 55 percent zinc, 31 percent sulfur, 0.15 percent cadmium, 0.30 percent lead, and 0.40 percent copper (Buchauer, 1973). In 1978, 80 percent of the concentrate treated at Palmerton originated from company-owned mines, of which the New Jersey mines made up the greatest portion.

Nearly 80 years of virtually uninterrupted zinc feed from the NJZ mines in Austinville, Va., came to an end when the operation closed in 1981, followed by the closure of the Friedensville, PA mines in 1983. When the Sterling Hill Mine at Ogdensburg closed in 1986, it meant the end of all underground mining in New Jersey (U-Haul, 2008) and the end of a nearly 75-year period of nearly continuous zinc feedstock to Palmerton. The Palmerton ceased treating primary zinc feed in its roasters in 1981 and discontinued producing zinc oxide from New Jersey ores in 1986, which also marked the cessation of Palmerton as a primary zinc smelter.

Secondary Feed Sources

A diverse mixture of secondary materials was used over the years as feed to the Palmerton plant. The following are several examples. The Waelz kilns, which produced zinc oxide

and residue for use as feed for the production of spiegeleisen, relied primarily on ores and concentrates from Sterling, New Jersey, but additional feed sources supplied clinker from several sources over the course of many years and EAF in the 1970s.

Secondary feed to the vertical retorts for the production of zinc slab included scrap metal, and other zinc rich materials.

The cadmium plant, in addition to recovering cadmium from residues collected at Palmerton facility, treated fumes shipped from Canon City, Colo. and DePue, Ill. The French process zinc oxide plant complimented feed with zinc metal purchased from the U.S. Government strategic stock pile and from other companies (Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008).

In the year 1980, the USEPA listed EAF dust, the residue produced from electric arc furnaces in steel making, as a hazardous waste because of its potentially toxic components which include cadmium, calcium, chlorine, fluorine, lead, and zinc. In approximately 1990, a ban was placed on disposing untreated EAF dust in landfills (James and Bounds, 1990). These regulatory actions stimulated interest in development or improvement of existing technologies to recover metal values, such as cadmium, chromium, iron, and zinc contained in EAF dust through recycling.

Since 1982, the Waelz kilns at the Palmerton plant have played an important role by supplying the largest proportion of zinc-rich feed derived from EAF dust to the Monaca, Pa. zinc plant. Shipments from mini-mill steel producers are also treated at Monaca (Horsehead Corporation Web site). The Waelz kilns at Palmerton volatilize and collect the nonferrous metals, mostly as oxides, which are part of a mix composed of EAF dust; a carbon source, usually anthracite coal; coke, or petroleum coke (pet coke)] and, at times, silica flux. The volatilized metals were oxidized, and cooled causing the zinc oxide flakes to form, and recovered in a baghouse. The captured material was collected and placed in a kiln for calcining where, through careful temperature control, the cadmium and lead were fumed and recovered (see figure 13). The remaining material was taken from the kiln and shipped to Palmerton. In the mid to late 1980s, approximately 180,000 metric tons each year (nearly 200,000 short tons) of EAF calcine was shipped to the Monaca facility from the Palmerton plant (U.S. Bureau of Mines Minerals Yearbook, 1989, p. 936) for processing.

Historical Capacity and Production

There were little statistical data published on capacity or production pertaining to zinc metal, zinc oxide, lithopone, cadmium, lead, sulfuric acid, spiegeleisen and other products produced at the plant, although data were published pertaining to the number of available retorts and furnaces in USBM and USGS Mineral Yearbooks, company annual reports, and other published sources. When capacity or production statistics were published, they usually pertained to zinc metal and usually published as slab zinc or spelter. Only rarely did data pertain

to zinc oxide production or the other products produced at the Palmerton facility, which included cadmium and various zinc-based products. Zinc oxide production at Palmerton was significant, and described by Hofman (Hofman, 1922, p. 292), however, published data for estimating plant capacity and production in earlier years and years subsequent to the period around 1920 were not available. In addition, zinc oxide derived from zinc metal using the French process could also double account production estimates.

Fortunately, unpublished data on production of zinc, zinc oxide, and other products, as well as sources of feed, and technical aspects of the Palmerton facility, were provided by industry contacts.

Little statistical data referring to zinc and zinc oxide production and capacity were discovered in the literature. The paucity of statistical information required broad assumptions for developing production estimates. As previously mentioned, while “boiler plate” plant capacity data generally provides an uppermost limit for production estimates for parts of the operation, it does not account for important factors that relate to actual production. These factors include the amount, types, and grades of feed; capacity utilization; plant efficiency including improvements that increase productivity or problems that negatively affected production; the effects of economic conditions, such as costs for production, competition, zinc prices, and recessions; and political decisions, such as subsidies and war. For example, because of the Nation’s economic state in 1932, only 33 percent of the installed retorts at smelters produced zinc (U.S. Bureau of Mines Minerals Yearbook, 1934) and production increased to help meet the material requirements in World Wars I and II.

Zinc Metal

The primary zinc smelter underwent numerous expansions and modernizations over its production life. Essentially all of the company’s zinc metal produced from primary feed was produced at the West plant. The first horizontal retorts came on line in the early part of 1900. In 1901, there were approximately 1,400 horizontal retorts at the West Plant. By 1905, the number of retorts had doubled to nearly 3,000; and by 1912 had once again doubled to approximately 6,000 horizontal retorts (U.S. Geological Survey, Mineral Resources of the United States, 1912, p. 286; 1913; 1914, p. 643). The number of horizontal retorts remained relatively steady at about 7,000 from 1916 until the late-1940s, when replacements and increase in number and size of vertical retorts, originally introduced in the late-1920s to early 1930s, took place, thereby reducing the need for the less efficient horizontal type furnace (U.S. Geological Survey, Mineral Resources of the United States, 1910, 1911, 1916, 1920; U.S. Bureau of Mines, Mineral Resources of the United States, 1929, 1931; and 1935-38; Cotterill, 1950, p. 26; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

The year 1950 marked the end of using horizontal retorts to produce zinc (U.S. Bureau of Mines, Mineral Yearbook,

1950) because of their replacement by vertical retorts. Using a production estimate of 4 short tons of zinc equivalents per retort per year over the 50-year period the horizontal retorts were used, combined with unpublished production data, it was calculated that production capacity was roughly 1.1 million short tons of zinc produced from the facility’s horizontal retorts.

Vertical retorts of different sizes were used from 1929 until 1980 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Vertical retorts offered greater efficiency than horizontal retorts, having larger capacities and being able to be fed on a semi-continual basis. Initial production was based on sixteen vertical retorts. In 1936, twelve more vertical furnaces were added and by 1951 the number had increased to 43. From 1950 until 1980 the plant employed the use of 43 vertical retorts (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). The furnaces were designated as batteries A through E; A and B consisted of a total of 16 retorts that were charged with charges containing 6.6 short tons of zinc per day; C and D had 18 retorts that could contain 8.6 short tons of zinc per day; and E with 9 retorts that could contain a charge of 10.6 short tons of zinc per day (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Combined, the vertical retorts were filled with charges, containing approximately 356 short tons of zinc metal per day, or a weighted average of about 8 short tons of zinc equivalents per day per retort. It was estimated that the facility operated for 365 days per year, but under normal conditions no more than 3 of the 43 retorts were inoperative at any one time because of rebuilding or cleanup (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Furnace operators were hesitant to shut furnaces down once “fired” when operating below capacity because of potential damage from differential cooling. Using these data and an estimated 93 percent zinc recovery, combined with unpublished data, total production capacity over the 52-year period that vertical retorts were employed from 1929 through 1980 was approximately 4.6 million tons of zinc metal.

It was estimated that combined production capacity of zinc metal over the 81-year period from horizontal and vertical retorts may have been about 5.7 million short tons of zinc metal. Capacity estimates do not account for factors that affect production such as unanticipated technical and labor problems, policy or political events, and market conditions. Estimates of actual zinc metal production were available from unpublished historical records for the years 1920 through 1980, the last year of slab zinc production. Production estimates for the years 1900-19 were based on trend data from historical production statistics and technologies employed, such as the number and productivity of horizontal retorts. Using this information it was estimated that approximately 5.2 million short tons of zinc metal were produced for the years 1900 through 1980.

Zinc Oxide

The only statistic encountered in searches of published literature pertaining to zinc oxide capacity or production was in the 1980 USBM Minerals Yearbook. The 1980 production for Palmerton was stated as 79,000 short tons of zinc oxide containing up to 63,000 short ton zinc equivalents. The figure may include zinc oxide produced from slab zinc produced by the French process. During this period approximately 50 percent of domestic zinc oxide production in the United States originated from ores and concentrates, 20 percent from slab zinc, and the remaining 30 percent from secondary material. About 40 percent of domestic zinc oxide production in the United States was produced using the French process (U.S. Bureau of Mines, Mineral Yearbook, 1981).

The first zinc oxide furnaces at the West Plant started producing in 1899 and ended in 1951. During the first decade of the 20th century and into the second decade, oxide furnaces were added to the West plant. In the year 1911, oxide furnaces at the East plant came on-line. The plant was greatly enlarged during World War I to produce zinc oxide for rubber tires.

In the early 1920s, the Palmerton smelter was the leading zinc oxide producer in the eastern U.S. (Hofman, 1922, p. 286.). Hofman described the American process zinc oxide portion of the operation at the East Plant and West Plant of the Palmerton facility. Hofman described the East Plant zinc oxide facility as having 26 furnace blocks; each containing 4 hearths, and the West Plant containing 34 furnace blocks of 4 hearths each. Each hearth could process 3 charges in 24 hours. Three types of zinc-based charges were used, each with a reductant, such as anthracite: (1) franklinite (18.2 percent Zn) if only franklinite); (2) franklinite with mixed ore; and (3) zinc dust (70 percent Zn) (Hofman, 1922, p. 290). Using these data and an average zinc feed grade of 23 percent, an overall recovery of 90 percent and an average charge containing 1,800 pounds of zinc-bearing material (not including anthracite), total annual production from the two plants would have been no greater than 45,000 short tons of zinc equivalents in 56,000 short tons of zinc oxide. Hearth availability was assumed as 93 percent, but was likely considerably lower considering time for clean out and loading, repairs, and other technical requirements. The Palmerton plant also initiated the production of zinc oxide directly from zinc metal using the French process during World War I using electrical furnaces and continued, with major plant modifications around World War II, until 1981 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). A total of about 1 million tons of zinc oxide (800,000 short ton zinc equivalents) may have been produced over the period using the French process (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; Robert Kuba, Horsehead Corporation, written communication, 2008).

The methodology used to estimate zinc oxide production estimates at Palmerton, exclusive of that produced using the French process, was based on limited published data, unpublished data, and discussions with individuals familiar with

the history of the Palmerton plant. Using these data it was estimated that roughly 3.5 million short tons of zinc oxide or about 2.8 million tons of zinc equivalents were produced from primary zinc ores for the years 1899–1986, the last year ore (from the Ogdensburg mine in the Franklin-Sterling Mining District, New Jersey), was a component of feed to produce zinc oxide. About 70 percent of the American Process zinc oxide was produced from the New Jersey ores for the years 1981 through 1986, with the balance produced from EAF dust and possibly some other secondary materials. By the end of 1986, primary ores were longer treated at the Palmerton plant.

Lithopone

Lithopone was used as a pigment in rubber goods and other applications (Vacari and Brady, 2002).

Based on estimates and unpublished production data, approximately 680,000 short tons of lithopone, a compound consisting of about 70 percent barium sulfate and 30 percent zinc sulfide, containing nearly 140,000 short tons of zinc equivalents, were produced from roughly 350,000 tons of ore and concentrates roasted on site from 1903 until 1949. On average, the plant produced 5,000 short tons of product per year until about 1921 and expanded to about 30,000 short tons per year from 1922–31. From 1932 until the lithopone plant's closure in 1949, production dropped to an average of about 15,000 short tons of product per year.

Spiegeleisen

Spiegeleisen was first produced on a commercial scale in 1904 [there is one reference stating there was spiegeleisen production in 1899 (Shelov, 2001), but this may be erroneous] and continued, without interruption, until 1976 (Dunn, 1995; p. 203, and Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). The high-manganese iron product, used by the steel industry was produced using kiln residues initially in spiegel furnaces, but later in electric furnaces (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). The residues resulted primarily from the furnacing of ores and concentrates originating from the Ogdensburg and other mines in New Jersey.

Based on limited sources of published and unpublished data and discussions with industry contacts, it was estimated that approximately 3.6 million short tons of spiegeleisen were produced at Palmerton from 1904 through 1976, the last year of spiegeleisen production (Robert Kuba, Horsehead Corporation, written communication, 2008; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

Sulfuric Acid

Sulfuric acid was produced as a product of capturing sulfurous gases generated by the roasting of sulfidic ores and concentrates, plus contributions from the burning of supplemental sulfur. Acid was first produced in 1903. Production was initially quite low at about 1,500 short tons per year, but

was expanded soon afterward with the construction of larger roasters. During World War I, annual production of sulfuric acid reached nearly 30,000 short tons. These levels were not reached again until World War II when annual production reached nearly 40,000 short tons for a period of about 5 years. An expansion in roasting in the 1950s coinciding with the switch to using only vertical retorts resulted in acid production exceeding 100,000 short tons per year and by the early 1960s until the year 1971, annual acid production was exceeding 150,000 short tons. Average annual acid production from 1972 until 1980, the last year acid was produced because the plant's roasters were shut down, averaged nearly 120,000 short tons. Using published and unpublished data, and discussions with industry experts it was estimated that Palmerton produced about 4.7 million short tons of sulfuric acid, or about 1.6 million tons of sulfur equivalents (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; Robert Kuba, Manager of Technology, Horsehead Corp, oral communication, 2008) from the sulfidic portion of Palmerton's primary zinc feed and supplemental sulfur.

Other Products

The amounts and years produced of selected products are listed in table 21 by type, and tonnage. Except for spiegeleisen, which was produced from high-iron manganese zinc oxide ores, primarily franklinite; the majority of the plant's first-line byproducts were produced from the treatment of sulfidic ores and concentrates.

The plant's primary revenue was generated from the production of zinc metal (1900–80) and zinc oxide by the American Process (1899–1986) (Jolly, 1994 p. 72; Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008) from primary zinc ores and concentrate. Through the plant's history, however, other products produced as a byproduct of processing primary ores included ammonia and carbon dioxide (1962–80s), hydrochloric acid (1918–23), ferromanganese (1951–53), lead oxide (1913–62), low (1922–59) and high (1924–34) lead-content zinc oxide; lithopone (1903–49), zinc dust (1922–81), zinc oxide using the French process (1921–80s), and zinc sulfide (1926–60). Cadmium was recovered using pyrometallurgical processes at the West Plant from 1921–52 by treating residues collected at the lithopone plant, zinc sulfide plant, and other cadmium-bearing residues at Palmerton. Residues from other operations were also shipped to Palmerton for cadmium recovery. The same types of material were treated, along with fumes from the Palmerton, Depue, Ill. and Canyon City, Co.; sinter plant at the East Plant from 1955–80 using hydrometallurgical processes. A total of approximately 5,500 short tons of cadmium metal were recovered at Palmerton. Approximately 22,000 short tons of cadmium lithopone was produced at the East Plant from 1926–28 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Cadmium lithopone is a cadmium-rich barium sulfate, containing less than 40 percent cadmium sulfate that finds use as a yellow pigment.

Mercury was contained in some roaster feeds, and in a few cases, at relatively high levels in sulfidic feed purchased from South America (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008) and from Hyatt, New York. In early years most of the mercury was probably contained in the sulfuric acid, but in later years, some mercury was recovered in residues recovered by the waste water treatment plant. Mercury recovery at Palmerton was practiced in order to avoid contaminating the sulfuric acid. Mercury was collected in the Cottrell mist precipitators located after the scrubbers and before the acid converters and recovered in the wastewater plant (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Statistical data were not available.

Up through 1935 the plant had produced a diverse range of products that included albalith (a white zinc pigment), ammonia, cadmium, cryptone (a zinc sulfide pigment), hydrochloric acid, lithopone, spiegeleisen, sulfuric acid, zinc-based specialty alloys, zinc dust, and zinc sulfide (Historical Data, the New Jersey Zinc Company (NJZ) and Subsidiaries, internal company document, approximately 1935, with a handwritten note dated 1943, 17 p.; NJZ, 1935; U.S. Bureau of Mines, Mineral Yearbook, 1950).

In 1948, the Palmerton facility was producing byproduct cadmium, zinc pigments, lithopone, zinc sulfide, ferromanganese, luminescent pigments, metal powders, spiegeleisen [the first furnace was installed in 1904 and second in 1906 (Dunn, 1995, p. 216)] and sulfuric acid (The New Jersey Zinc Company, 1948, p. 25; Octagon, 2003; p. 2).

Technology

The Palmerton plant treated primary zinc ores over a period of nearly 90 years. During this period the plant went through numerous modifications that reflected advancements in process technologies, changes in feed types, responses environmental regulations, and changes in consumer demand that affected plant capacities, production, and product types. For example, total zinc recoveries probably ranged from approximately 85 percent during the earliest years of the operation to greater than 95 percent after about 1970. Recoveries depended on numerous factors including the type of ore treated, the efficiency of the technology used (time period and manner of operation), metal price, product type, and regulations.

Because of these factors the technical history of the plant is complicated. The following are general descriptions of the major types of technologies employed and the periods in which they operated at the East and West Plants at Palmerton over the nearly 90-year period that the plant treated primary ore as a component of its feed. Generalized flow diagrams of the plant's treatment of sulfidic feedstock and non-sulfidic mixed-ore feedstock from the Franklin and Sterling zinc mining district in New Jersey District are shown in figures 41 through 43. They cover the period following the discontinuation of using horizontal retorts in about 1930.

Table 21. Years and estimated amounts of selected products and byproducts produced at the Palmerton facility (Adapted and estimated from unpublished company data).

Years produced	Product	Estimated total production ¹ (thousand short tons)
1900-81	Zinc metal, zinc oxide (American process), and lithopone	8,100 (zinc equivalents)
1900-80	Zinc metal	5,200
1903-80	Sulfuric acid	4,700
1904-76	Spiegeleisen (pig iron)	3,600
1900-86	Zinc oxide (American process)	3,500 (2,800 zinc equivalents)
1921-81	Zinc oxide (French process)	1,000
1903-49	Lithopone ²	690 (140 zinc equivalents)
1943-81	Zinc powder	140
1920s-62	Lead oxide and lead-zinc oxide compounds (combined)	130
1921-52; 1955-80	Cadmium metal	5.5
1962- mid-80s	Ammonia	0.8

¹ Rounded to two significant figures. To convert zinc oxide to zinc equivalents, multiply by 0.81.

² A compound generally consisting of 70 percent barium sulfate and 30 percent zinc sulfide. Used as a pigment, in rubber goods, and other applications (Vacari and Brady, 2002). It was assumed that lithopone averaged 20 percent zinc.

In general, from 1900 through 1980, primary zinc metal recovery took place with the following steps: (1) ore or concentrate blending; (2) pyrometallurgical roasting (including Waelzing, calcining, and sintering); (3) pyrometallurgical distillation (in horizontal or vertical retorts), and; (4) further pyrometallurgical refining using a vertical distillation method. Acid production and recovery of other products were produced through the process.

The West Plant first produced zinc oxide in 1899 from burning ores in stationary grate furnaces and capturing zinc oxide fumes in baghouses (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008); relying mostly on zinc ores and concentrates from New Jersey. In the year 1900, willemite ores were furnaced in horizontal retorts for the purpose of producing zinc metal. Impure zinc oxide recovered from the spiegel furnaces were also fed to the retorts. Beginning in 1903, sulfide concentrates were treated to a limited extent for the production of zinc metal at the West Plant, after undergoing installation of new equipment which included a roaster, with supplemental burning of sulfur to enrich the gases; and a small sulfuric acid plant (the three units closed down around 1925). The West Plant roasted sulfide ores and concentrate until 1925. At this time, lithopone, zinc metal and zinc oxide also were being produced. The West Plant had used horizontal retorts since 1900 and vertical retorts that were first introduced in 1929 (USEPA, 1987; pp. 3-7; U.S. Geological Survey Report to the Secretary of the Interior 1898-1900, U.S. Geological Survey, Mineral Resources of the United States 1904-28, in U.S. Bureau of Mines, Mineral Resources of the United States, 1929-34; and U.S. Bureau of Mines, Minerals Yearbook 1935-80).

In subsequent years ores and concentrates were roasted at the East Plant. A sulfur burner to upgrade the roaster gases for the manufacture of sulfuric acid was incorporated as part of the operation. All of the roasters employed at Palmerton had a sulfuric acid plant to use roaster gases (Arthur W. Larvey,

Consulting Chemical Engineer, written communication, 2008). Most of the sulfide ore and concentrates treated at the plant averaged 55-58 percent zinc.

Hofman described a double furnace used in about 1920 at the West Plant as producing 7,100 lbs of spelter/day (Hofman, 1922, p. 175). The furnace contained 5 rows with 26 retorts in each row or 130 retorts per side.

The Conner-De Saulle furnaces at the Palmerton works had retorts measuring 57 inches long, 7 inches wide and 9 inches high, with a volume of approximately 1.64 cubic feet, zinc dose of 78 pounds, anthracite dose of 28 pounds with 24 retorts in a row, 5 rows for 120 retorts on a side. The furnace reportedly required 3,000 lbs of coal per ton of ore to manufacture producer gas (Hofman, 1922, p.173). Approximately 7,700 pounds of zinc metal could be produced over 24 hours from 10 tons of roasted ore (Hofman, 1922), and in later years roasted, and sintered ore.

Using the above data from Hofman, a maximum capacity would be about 30 pounds per retort per day or roughly 5 short tons per year at 365 days per year. Considering normal inefficiencies brought about by the short life of retorts, a matter of a few months, rebuilding of furnaces, repairs, and other events common to zinc smelters using horizontal, actual retort utilization during this period was probably between 80 and 90 percent with an effective capacity of about 4 short tons per retort/annum. The retorts used in the Conner-De Saulle furnaces had higher volume than some of Palmerton's competitors.

More efficient vertical retorts were first installed in 1929, marking the beginning of the phase-out of horizontal retorts. By 1950, all of the horizontal retorts had been abandoned for vertical retorts. The year 1951 marked the installation of the last vertical retorts for producing zinc metal. In 1960, all 43 vertical retorts which were previously using manufactured gas from coal as a heat source were refitted to burn natural gas. Vertical retorts were used over the next twenty years, until they were permanently shut down in 1980.

The lithopone plant initiated production in 1903 and closed in 1949. The facility used mostly roasted ores and concentrates, plus barite as feed. Products from the plant included lithopone, a compound consisting of about 70 percent barium sulfate and 30 percent zinc sulfide; a cadmium-rich residue that went to the West Plant cadmium plant; and a lead-rich residue that was used to produce lead oxide products.

Figure 42 is a flow diagram depicting the flow of New Jersey ores that were fed to the stationary grate oxide furnaces which operated from 1899 until the 1950s and the horizontal retorts that operated from 1900 until about 1950.

The East Plant initiated production of zinc oxide in 1910. Zinc oxide furnaces were improved with the installation of travelling-grate furnaces in 1923. By the mid-1920s, there were electric and pyrometallurgical furnaces in operation producing zinc oxide. The older stationary grate furnaces continued to operate until 1955. The travelling grate oxide furnaces installed around 1923 operated longer than the stationary grate furnaces and closed at the end of 1987. Around 1960, natural gas was installed for drying ore, briquetting coal, and sintering for zinc oxide production.

A roaster and acid plant were placed into operation in 1916 to prepare sulfide ores and concentrates as feed to the lithopone plant at the East Plant. In 1925, the roaster at the West Plant shut down and the East Plant became the place where all of the roasting of ore and concentrate would occur for the remaining life of the operation. The roaster plant was constructed with a larger capacity than the one situated at the West Plant.

In 1936, a sinter plant was installed to further reduce the sulfur content of Waelz oxides. A state-of-the-art flash (installed in 1949) and multiple-hearth roasters, sinter plant (1948), and sulfuric acid plants were added to the East Plant in the mid- and late 1940s. Electrostatic precipitators were installed on the sinter plants around 1953.

Waelz kilns were used primarily to produce impure zinc oxide and feed for the production of spiegeleisen in the spiegel furnaces. A Waelz kiln initiated production at the East Plant in 1929 with additional kilns installed in 1931, 1938, and 1965. The Waelz kilns were similar to rotary kilns currently used in the cement industry, but operated at about the same temperature of zinc's boiling point; about 1,800 degrees Centigrade. Generally the heat generated by the oxidation reaction supplied sufficient heat for vaporizing zinc, but additional heat for reducing zinc could be supplied by coal, gas, oil, or electric furnace gas. Waelz kilns were not equipped with environmental controls (U.S. Environmental Protection Agency, 1980).

The Waelz kilns were supplied with mixed zinc oxide ores, primarily as franklinite from Sterling, New Jersey; that were relatively high in iron and manganese. To a much lesser degree, feed to the kilns consisted of furnace and retort residues, and other purchased materials. Zinc fumes were collected in bag rooms and then fed to a Waelz sinter plant which opened in 1936. The impure zinc oxide was then fed to zinc oxide furnaces using the American process or, on an occasional basis, placed in vertical retorts at the West Plant from which slab zinc was recovered (Dunn, 1995, p. 203; Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

The remaining solid residues from the Waelz kilns contained approximately 20-24 percent iron and about 10 percent manganese and was fed to the spiegel furnaces from which spiegeleisen was produced.

Spiegeleisen was first produced in 1904 in furnaces using zinc oxide furnace discharge that was enriched in iron, silicon, and manganese, initially in spiegel furnaces, but later in electric furnaces (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008, Consulting Chemical Engineer, written commun., 2008). The spiegel furnaces produced spiegeleisen and waste. The waste was placed with other "spent" residues on a waste pile or sold for road use. In 1962 the original spiegel furnaces were replaced with modern electric-arc furnaces. At least one more furnace was added in 1964 along with additional Waelz kilns (NJZ Annual Report).

With the closure of the spiegeleisen plant in 1976, the Waelz kiln discharge was either placed on waste piles or sold as an aggregate as a component in asphalt and concrete, and as anti-skid applications (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008, Consulting Chemical Engineer, written commun., 2008). Figure 43 includes a generalized figure of the Waelzing process flow.

The cadmium plant which initiated production in 1954 treated fumes recovered from the Acid Sinter plant. The Acid Sinter plant was so named because of its location close to the acid plant. Acid was not used in the sintering process.

Table 22 is a list showing major types of equipment and dates relating to their installation and startup at Palmerton. The dates range from the plant's construction through the mid-1930s, with one exception; a handwritten entry dated 1943 referring to the West plant. The completeness of the table is not known, but it does illustrate the complexity and diversity of equipment for roughly one-third of the plant's history.

Table 22. A list showing major types of equipment and important dates relating to the installation and initiation of new equipment and processes at Palmerton's East and West plants. Completeness of table is not known. (Adapted from Historical Data, The New Jersey Zinc Company and Subsidiaries, internal company document, approximately 1935, with a later hand-written entry, 17 p.).

<u>Facility and equipment type</u>	<u>Year</u>
<u>Palmerton, Pa.—West Plant</u>	
Construction started	1898
First zinc oxide made in furnace blocks No. 5-8	1899
Oxide blocks No. 1-4 started	1900
First spelter made in furnaces 1 and 2	1900
Oxide blocks No. 9-16 started	1901
Spelter furnaces No. 3 and 4 started	1902
Oxide blocks No. 17-24 started	1903
Experimental roaster and sulfuric acid plant started	1903
Lithopone (zinc sulfide and barium sulfate) plant started	1903
Oxide blocks No. 25-28 inclusive started	1904
First spiegeleisen (pig iron) made in furnace No. 1	1904
Oxide blocks No. 29-34 started	1905
Spelter furnace 5 started	1905
Spelter furnaces No. 6-11 started	1906
Spiegel furnace No. 2 started	1906
Spelter furnace No. 12 started	1907
Spelter furnaces No. 3-24 started	1912
Zinc dust furnaces No. 1 and 2 started	1914
Spelter furnaces No. 25-28 started	1915
Spelter furnaces No. 29-30 started	1916
Zinc dust furnace No. 4 started	1916
First pharmaceutical grade zinc oxide made	1917
Spiegel furnace No. 1 rebuilt	1917
Zinc dust furnace No. 3 started	1917
Zinc chloride made in experimental plant	1917
Blast furnace gas firing of spelter furnaces started	1918
First zinc oxide made in experimental mechanical furnace	1919
Atomized zinc dust plant started	1919
Atomized zinc dust plant abandoned	1920
First metallic cadmium made	1921
Briquetting plant started	1921
Mechanical oxide furnace A started	1923
Mechanical furnaces B, C, and D started	1923
Furnaces No. 1 and No. 2 changed from C&D to Siemens type	1924
Furnace No. 3 changed from C & D to Siemens type	1925
Rebuilding spelter furnaces No. 7 and No. 9	1925
Dismantled experimental acid plant	1925
Dismantled barium building	1925
Oxide – Installed coke extractors	1926
Started die casting alloy plants “Zamak”	1926
Zamak (alloys for die casting) operation started	1926
Spiegel (high manganese pig iron)—Steinert burners installed	1926
Additional power transmission line installed	1926
Zinc sulfide product operation started	1927
Vertical spelter furnace—Construction began	1928

Vertical spelter furnace started	1929
Spiegel—Change house constructed	1929
Refining furnaces—Horizontal operation started	1931
Zinc sulfide product operation shut down	1933
Refining furnaces—Vertical liquation operation started	1935
Atomized metals powder plant began operation	1943 ¹

Palmerton, Pa. – East Plant

First zinc oxide made in blocks No. 45-54	1911
Oxide blocks No. 35-44 started	1912
Oxide blocks 55-60 started	1915
First lithopone produced	1915
Roaster plant on-line	1916
First sulfuric acid produced	1916
Oxide blocks No. 61-72 started	1917
Zinc strip mill started and first shipment	1917
Zinc strip mill—Additional capacity added	1918
First hydrochloric acid produced	1918
Pharmaceutical grade zinc oxide—Blocks 1-3 started	1918
First zinc chloride made	1919
Lithopone plant, Additional capacity added	1920
First albalith (zinc sulfide) produced	1920
First electric furnace zinc oxide produced	1922
Commercial zinc chloride plant closed	1923
Electric furnace for zinc oxide increased capacity	1923
Lithopone plant, additional capacity added	1923
Sheet zinc rolling mill erected	1924
Sheet zinc rolling mill began operation	1925
Oxide—Installation of coke extractors	1926
Cryptone (calcium oxide) operation started	1926
Lithopone—barium leaching plant expanded	1929
Lithopone—Rotary muffle installed	1929
Waelz plant—Construction started	1929
Waelz kiln #1 started	1929
Waelz kiln #2 started	1931
Zinc sulfide product plant started	1933

¹Hand written entry on original table added sometime after 1933. Note time gap with previous entry.

The following was extracted from Hofman, 1922 who described the Palmerton zinc oxide plant in a 1922 publication.

The Works started in 1900 and replaced the older plant at Bethlehem. In about 1920, there were 2 divisions; the older Western plant with 34 blocks of furnaces and the newer Eastern plant with 26 blocks. The Eastern plant received ore and roasted concentrate by rail. Furnaces of both divisions were alike. A furnace block was 45 feet long and 16.5 feet wide. Each furnace could treat 3 charges in 24 hours and each furnace contained four hearths. A hearth measured 19 feet by 6.5 feet by 5 feet 11.5 inches. An ore charge for each hearth weighed 2,700 lbs (900 anthracite and 1,800 franklinite); dropped through the hoppers and leveled to a thickness of 8 inches. The material was open burned for about 1.5 hours and then when the desired condition was attained, the zinc vapors were directed to a baghouse from which zinc oxide was recovered.

There were 3 grades of feed used. They included franklinite (18.2 percent zinc, 35 percent iron, and 3.6 percent silicon dioxide) from New Jersey, which was furnaced alone and the residue smelted for spiegeleisen; "half and half" (18.4 percent zinc, 15.2 percent iron, 12.2 percent manganese, 12.6 percent silicon dioxide, and zinc dust), and zinc dust (70.6 percent zinc, 20.1 percent iron, 8.9 percent manganese and 7.2 percent silicon dioxide). The zinc oxide product assayed 90 percent zinc oxide. Impurities included 0.25-0.33 percent sulfur trioxide, 0.10-0.50 percent water, and 0.05-0.3 percent lead oxide. The introduction of mechanical grates and sintering of briquettes was being considered at this time and was anticipated, if installed, to increase zinc recoveries to 90 percent of the contained zinc in the charge from the low to mid 80s used in the individual hearth charges (Hofman, 1922, p. 290-297).

The following description was mostly derived from Shelov (Shelov, 2001) and probably represents the plant's operation up to about 1980. By this time, the horizontal retorts had been dismantled for about 30 years, as a result of the start-up of the vertical retorts in 1950. The original Waelz kilns at the East Plant were used to process relatively lower-valued zinc oxide from complex oxide ores from the Company's New Jersey operations. In the mid-1960s, ore from Sterling Hill was crushed, sized, and railed directly to Palmerton, PA, and fed to the Waelz kilns with coal and sometimes small amounts of retort residues for the production of zinc oxide (Dunn, 1995; p. 203). While some of the impure zinc oxide recovered from the Waelz kilns was placed in retorts, most was used in the American process zinc oxide plant. In the mid-1980s, the kilns were modified to recycle EAF dust and other zinc-containing steel products for their zinc content (Shelov, p. 6). For most of the plant's history residues (20-24 percent iron, 10 percent manganese) produced from the kilns were used to make spiegeleisen. During periods of poor market conditions in the 1970s plant residue was hauled to the waste piles (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). During several periods between 1904 and 1976, a portion of the kiln residue was treated to make spiegeleisen, a 20 percent

manganese iron. Waelz kiln residue assayed approximately 1 percent zinc (Shelov, 2001, p. 13). Following Waelzing, the material was sintered. Sintered ore was combined with bituminous and anthracite coal, and formed into briquettes that were then sent to cokers and then sent to the slab zinc vertical retorts and the oxide plant at the West Plant to produce zinc oxide using the American process (Shelov, 2001, p. 8). The plant switched from coal-generated producer gas to natural gas in 1960 to heat the vertical retorts. There were 43 retorts with an annual capacity of approximately 110,000 short tons. Zinc recoveries using vertical retorts generally exceeded 93 percent (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; U.S. Bureau of Mines, 1974, p. 36).

The West Plant had an American process zinc oxide plant that used briquetted sinter plant material, and oxidized zinc ores from which zinc was vaporized, combined with oxygen and collected as zinc oxide (Shelov, 2001, p. 11). The zinc content of the "spent" briquettes from the vertical retorts and oxide plants ranged from 3 to 20 percent, but averaged about 3-4 percent, which reported to the waste piles (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Although efforts to process this material to recover zinc have been attempted several times, they have not been met with commercial success (Shelov, 2001, p. 10-22).

The U.S. Bureau of Mines reported that Palmerton underwent a large modernization program in the early to mid-1970s which included modifications of the roasting and sinter plant, revisions to the material handling systems, and extensive new dust control facilities. The modernization also included an expansion to zinc oxide production using the American and French methods (U.S. Bureau of Mines, Minerals Yearbook, 1973).

Details related to operational technologies used at Palmerton also are discussed in sections pertaining to production and plant emissions.

Onsite Energy Source and Type

Anthracite coal was used for manufacturing producer gas (Ingalls, 1906). Furnaces switched to using natural gas to fire the furnaces around 1960.

Emissions

Several studies have been undertaken examining the emission types and amounts generated by Palmerton, total and annual rates of deposition of selected metals, and their affect on the environment.

In the mid-late 1980s, the U.S. Environmental Protection Agency, Pennsylvania Department of Health Under Cooperative Agreement with the Agency for Toxic Substances and Disease Registry released a report on the Palmerton site. Among their findings, the investigation determined that historical smelting activities had defoliated mountain slopes and produced soil chemistries with anonymously high levels

of cadmium, lead, and zinc (Pennsylvania Department of Health, 1987). Other studies that focused on fugitive and stack emissions from the Palmerton facility during the period that primary zinc ores and concentrates were processed included those by Buchauer (1975), Gardner (1999), Jordan (1973), and the Water Environment Federation.

The metals analyzed in soil and dusts were primarily cadmium, copper, lead, and zinc. Literature research did not indicate that detailed soil analyses were performed for gallium, germanium, mercury, or other metals associated with zinc ores and concentrates, especially those consisting of zinc carbonate, sulfide, and oxidized sulfide minerals. Some mineralogical studies have also been performed. Scheinost (2002) found that soil samples were highly acidic and contained sphalerite and franklinite, likely from smelter emissions. Most of the franklinite probably originated from the processing of ores from New Jersey, but can also be produced from the oxidation of sphalerite during roasting in the presence of oxygen and iron.

Sulfur dioxide and heavy metal emissions were also generated on-site by coal-fired plants, but the amounts probably dropped significantly when the property converted to natural gas. Specific references to emissions from these sources were not stated in the literature. Release of cadmium from the production of zinc oxide using the American process was very low, most likely because of the use of oxide ores from New Jersey for its manufacture.

Sulfur Dioxide

The recovery of sulfur generated from roasting and sintering ores, concentrates, and supplemental sulfur-burning recovery at the facility changed over time. It depended on the efficiency of the sulfuric acid plant and presence of scrubbers, mist eliminators, waste water treatment, and other equipment. Total accountable sulfur recovery ranged over the operating life from about 88 to more than 95 percent. Approximately 95 percent of the sulfur could be accounted for during the period 1949-70, when scrubbers were used; higher amounts were probably captured with the installation of mist eliminators post 1970 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Despite the recovery, the sulfur dioxide that was released to the atmosphere from the roasting and sintering of ores and concentrates, plus the burning of supplemental sulfur, combined with water present in the atmosphere, usually fog or precipitation or both, to form sulfuric acid. The sulfuric acid reportedly contributed to the deforestation of Blue Mountain and Stoney Ridge, as well as sections of Palmerton and Aquashicola, Pa. (Palmerton Citizens for a Clean Environment, 2008) and contributed to the erosion of soils. It was estimated that from 1918 to 1962, the plant emitted between 3,300 and 3,600 pounds of sulfur dioxide per hour (Water Environment Federation, 2000). Oyler, 1997, reported the same emission rate, but as sulfur emissions (probably as an oversight), not sulfur dioxide, and estimated the time period to be 1918-70. Oyler, a remediation specialist, stated that the first scrubbers were installed in 1970 (Oyler, 1997); however,

he probably was referring to the mist eliminators that were installed about that time for suppressing the distribution of tail gas. Peabody scrubbers for cleaning roaster gases were installed at the plant many years prior to 1970 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). It has been suggested that emissions of dust, fumes and gas containing sulfur dioxide and heavy metals were generated by the acid sinter plant. The plant was commissioned in 1948 and operated for about 6 years without efficient collection controls until an electrostatic precipitator system was installed. The sinter plant was so named because of its location near the acid plant. Acid was not used in the sintering process. Additional sulfur dioxide emissions were also generated when a new roaster and associated acid plant went on-line in mid-1949 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

Sulfur dioxide emissions in 1970 were estimated to have dropped to 1,400 lbs per hour (Jordan, 1975). Jordan estimated that during 1970, the East Plant's operations were responsible for the source of 60 percent of the zinc oxide, 70 percent of the cadmium oxide and 100 percent of the sulfur dioxide emissions (Jordan, 1975, p. 80) which, although not specifically stated, was probably attributed to the roasting and sintering of sphalerite concentrate. This is the same value as Oyler reported, suggesting that he intended the estimates to represent sulfur dioxide, not sulfur. Smelting of ore ceased in 1980 (Oyler, 1993, 1997). Assuming the lower emission estimate of 3,300 pounds per hour for the years 1918-69, a total of up to 750,000 short tons of sulfur dioxide would have been emitted to the atmosphere from the facility during the 52-year period, plus an additional 68,000 short tons of sulfur dioxide from 1970-80 at 1,400 pounds per hour. Combining these two rough estimates based on published information, as much as 410,000 short tons of sulfur, equivalent to 820,000 short tons of sulfur dioxide may have been emitted to the atmosphere from 1903 through 1980.

The previous sulfur dioxide emission estimates appear high when considering the amount of sulfidic ore and concentrate treated at Palmerton as recorded in unpublished company data covering 62 years (approximately 5.5 million short tons) and estimates for 16 years (300,000 short tons), estimated sulfur content of sphalerite (32 percent), effectiveness of sulfur recovery (93 percent) in the acid plants over the period that primary sulfidic feed was treated, and other accountable amounts of captured sulfur, such as sulfur incorporated in zinc products, sulfur contained in waste residues, and concentrate loss during outdoor storage for a total of perhaps 2 percent. This leaves a balance of 5 percent as emissions. Although ores and concentrates from New Jersey, which comprised a large percentage of the feed treated at Palmerton, contained minor amounts of sulfide minerals, it was overwhelmingly non-sulfidic (Dunn, 1995).

Using these data and estimates, approximately 190,000 short tons of sulfur dioxide (about 93,000 short tons equivalents of sulfur) were potentially released to the atmosphere

from processing sulfidic ore and concentrates over the period 1903-80.

As mentioned earlier, sulfur burners were used at Palmerton to increase the amount of sulfur contained in roaster gases directed to the acid plant. Although not a significant contributor of sulfur dioxide-stack emissions when compared to the amount generated from sulfidic ores and concentrates, it was estimated that less than 10,000 short tons of sulfur dioxide were emitted to the atmosphere from sulfur burning. The estimate, expressed in one significant digit, was derived from industry contacts familiar with the actual operations of the plant.

Factors used to estimate the value included a 95 percent acid plant recovery, an atmospheric release of 5 percent, and a combined consumption of 5 short tons of sulfur per day more than 38 years from 1903-40 (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). Some small amounts of sulfur may have been contained in retort residues.

The two sources, ore and concentrate and sulfur-burning, contributed a combined total of approximately 200,000 short tons of sulfur dioxide as atmospheric emissions.

Production can be affected day-to-day by plant efficiency, ore and concentrate compositions, economic conditions, regulations, and other factors. For these reasons estimates should be considered with some caution.

Sulfurous emissions from coal used for mixing with ore or concentrate for calcining, sintering, manufacturing of producer gas, and generating electric power on site with coal-fired steam-driven generators are not included in any of the preceding estimates, nor are contributions to the atmosphere that may have resulted from treating secondary materials that contained sulfur.

Heavy Metals Emissions

The presence of anomalously high heavy metal content (cadmium, lead, and zinc) in soils in close proximity to the Palmerton smelter are attributed to the plant's emissions to the atmosphere. The metal content is in sufficient quantities and under certain conditions to be phytotoxic and inhibits the re-establishment of vegetation. Erosion on the mountain sides from the loss of vegetation also has stripped soils (Fargo, 1979) negatively affecting the process of natural re-vegetation. The metals emitted from the facility also may be responsible for elevated levels of cadmium and lead detected in the blood of children, illnesses in livestock (Palmerton Citizens for a Clean Environment, 2008), and high levels of cadmium and zinc in white-tailed deer (Sileo, 1985).

Metals such as arsenic and mercury were not addressed in the emission studies examined. Mercury was reportedly contained in zinc sulfide concentrates fed to the roaster and, in some cases at fairly high levels in material purchased from South America. Mercury recovery at Palmerton was practiced to an extent in order to avoid contaminating the sulfuric acid. Mercury was collected in the Cottrell mist precipitators

located after the scrubbers and before the acid converters and recovered in the wastewater. Statistical data and information pertaining to the effectiveness of the collection apparatus was not available (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

Amounts and Rates of Deposition

The emission estimates published by the USEPA and others researchers may be over- or under-estimated for some years, especially for cadmium and lead. Analyses of samples from feedstock processed at Palmerton for these elements and other materials were not always practiced. There were also analytical limitations. The determination of the amounts of cadmium and lead present in feed may have been below the detection limits of the analytical methods used and the state of the technology available at the time. The content was presumed to be at the detection limits (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008) or in some cases may not have been analyzed. For example, mercury was not addressed in the fugitive and stack emission studies examined. As discussed earlier, mercury was reportedly contained in zinc sulfide concentrates fed to the roaster, and in some cases, at fairly high levels in material purchased from New York and South America. Mercury recovery was practiced at Palmerton to the extent as to avoid contaminating the sulfuric acid. Mercury was collected in the Cottrell mist precipitators located after the scrubbers and before the acid converters. The mercury was recovered in the wastewater treatment plant, constructed in the 1940's. Statistical data and effectiveness of the mercury collection process were not available (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). The fate of the mercury contained in the ores and concentrates prior to the installation of the mist precipitators and waste water treatment is not known.

Buchauer estimated that from 1960 to about 1971, daily emissions to the atmosphere for the metals analyzed averaged between 6 and 9 metric tons of zinc, 70-90 kilograms of cadmium, and less than 90 kilograms each of copper and lead (Buchauer, 1973, p132). Applying these estimates as simple averages, approximately 2,700 metric tons of zinc and 29 metric tons of cadmium were deposited yearly during this period. A total of about 32,000 metric tons of zinc and 350 metric tons of cadmium would have been emitted during the period. Buchauer considered the East Plant as the source of 60 percent of the zinc oxide and at least 70 percent of the cadmium oxide emissions released to the atmosphere (Buchauer, 1973, p. 132). The East Plant is where most of Palmerton's roasting and sintering-related activities occurred. Buchauer did not address contributions to atmospheric emissions resulting from the burning of reductants during processing (charges for retorts and zinc oxide furnaces, and briquetting), producer gas manufacturing, and as fuel for electrical power and steam generation.

In 1969, sampling in the vicinity of the plant determined that deposition rates of dustfall ranged from 187 to 561

pounds of zinc per acre per year. The cadmium deposition rate probably was about 1 percent of that of zinc or about 1.9 to 5.6 lbs per acre per year (Jordan, 1975). Buchauer's estimate of cadmium deposition in 1969 was about 3 pounds per acre per year (Buchauer, 1973). Using these data, Buchauer estimated that approximately 12,000 pounds per acre of zinc and 160 pounds of cadmium per acre had been deposited in the uppermost layer of soil in close proximity to the East Plant since its startup (Buchauer, 1973) in 1911 to 1969.

In 1968, a technical study performed by employees of the Palmerton facility determined that an amount equal to approximately 3.5 percent of the zinc recovered in zinc oxide was lost through emissions to the atmosphere during the production of zinc oxide using the American Process. As with most plants at the time, a traveling grate was used in the process. Losses would have been somewhat higher using a stationary grate because the charge would require that it be manually raked into and out of the furnace. Losses occurred from the point of offloading feedstock through packaging. Combined, more than 70 percent of the losses originated from the furnace stacks and the bag room. During this period, roughly 1,300 short tons of zinc per annum escaped as emissions to the atmosphere during the production of zinc oxide from ore.

Jordan estimated that during 1970, the East Plant's operations were responsible for the source of 60 percent of the zinc oxide, 70 percent of the cadmium oxide and 100 percent of the sulfur dioxide emissions (Jordan, 1975, p. 80) and probably were generated by roasting and sintering activities.

Values as high as 4,500 ppm of zinc and 70 ppm of cadmium were found in the foliage of trees in close proximity to the smelting facility, suggesting uptake from soils and water was occurring (Buchauer, 1973). High levels of heavy metals have also been detected in wildlife (Sileo, 1985,) which also illustrates mobility of the metals. The ratio of zinc to cadmium in soils is lower near the East Plant than the West Plant. This finding also supports the hypothesis that the East Plant, where most of the roasting and sintering of sulfidic feed took place, was the primary source of cadmium (Buchauer, 1973). It would be expected that relatively high levels of lead would also be associated with the areas where high cadmium was detected.

Soil samples taken in the area of the smelter and reported by the USEPA ranged from 50,000-80,000 ppm zinc, 1,500-1,750 ppm for cadmium, and 200-6,400 ppm for lead and 2,000 ppm copper (Water Environment Federation, 2000, p. 169; Buchauer, 1973). The highest metal values were recorded in a soil sample containing a high percentage of partly decomposed leafy matter. The sample assayed 135,000 ppm zinc, 1,750 ppm cadmium, and 2,000 ppm lead (Buchauer, 1975, p. 132). Ambient soil concentrations for these metals in the area range from 10-300 ppm zinc, 0.1-7 ppm cadmium, and less than 50 ppm for lead (Water Environment Federation, 2000).

Variations in values of metals contained in soils could result from a number of factors which include distance from the plant, geography, operational activities at the facility,

particle size and shape, soil and wind-fall particle chemistry; and meteorological conditions, such as precipitation, and wind direction, duration, and intensity. Results of analyses may also be influenced by other factors including sampling method and sample type.

In 1986, the USEPA released a study that included fugitive and stack emission estimates of cadmium, copper, lead, and zinc to the atmosphere originating from the Palmerton facility (Cimorelli, 1986). The emission data published by the USEPA is separated into 5 sources and two types of emissions. The sources include (1) roasting and sintering; (2) horizontal retorts; (3) production of zinc oxide by the American process (direct process); (4) Waelz kilns used for calcining New Jersey ores; and (5) slab zinc production using vertical retorts. Emissions released from zinc oxide using the French process were not included as part of the estimates. The types of atmospheric emission were further categorized as having originated from fugitive or stack emissions.

Fugitive emissions are those materials, such as dust and fumes that are released to the air from sources other than from stacks or vents. They are often originate from equipment leaks, evaporative processes, and mechanical and windblown disturbances from activities such as preparing and loading charges to furnaces and retorts, movement of material, and plant ventilation. In the case of zinc smelters, most fugitive emissions were generated by mechanical activity in preparing charges and during sintering. Some of this material was recovered in and around the plant and reprocessed, if the economics were favorable or as a matter of safety and equipment operating efficiency or both.

Stack emissions can be from uncontrolled stacks and controlled stacks. Uncontrolled stack emissions generally are understood to be those emissions at facilities that do not use pollution control equipment.

Controlled stack emissions are those emissions for which some means were present to limit the release of material to the atmosphere through stack emissions. These would include baghouses, dust settling chambers, electrostatic precipitators, and scrubbers.

Although no evidence was found in the literature, the addition of coal as a reductant (bituminous or anthracitic coal) to the ore or the manufacture of producer gas, or both during the reduction of feed also were contributors to total sulfur dioxide emissions and some of the heavy metal emissions.

Variations in emission amounts and composition within time periods on an annual basis may have resulted from changes in the composition, type, proportions and amounts of ore, concentrate, and scrap feed; and amount, proportion and variety of product types; the evolution of technologies employed, including the introduction of technologies required by regulations to mitigate emissions and adherence to regulations; and changes in production levels.

Within the USEPA study are several tables showing emission estimates that were developed using data provided to the Agency by the NJZ (USEPA, 1987, p. 3-8). The data, presented in three time periods of 1900-49 (50 years), 1950-69

(20 years), and 1970–79 (10 years), are presented in tables 23-25 for the metals cadmium, lead, and zinc. According to the New Jersey Zinc Company, each time period represents years when production technology and plant were relatively constant. Although not stated in the USEPA study, the time periods coincide with a major expansion of plant capacity for the purpose of roasting and sintering ore and concentrate using established and newly installed vertical retorts in 1950. Although vertical retorts began operating as part of a phase-in plan in about 1929, it was not until 1950 that the permanent closure of the last remaining furnaces containing horizontal retorts occurred. From 1948–53, the sintering machines were not equipped to capture dust, fumes, and gas generated by the process. By one estimate, perhaps 240 short tons per year of lead and 180 short tons per year of cadmium or a total of 1,440 short tons of lead and 1,080 short tons of cadmium may have been emitted to the atmosphere during the 6-year period (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). A primary purpose of the sintering step was to reduce the cadmium and lead content of the calcine prior to entering the oxide furnaces or vertical retorts.

The introduction of additional scrubbers and other antipollution devices occurred in 1970. The switch to natural gas from coal as fuel for drying, briquetting and sintering; and the addition of new Waelz kilns furnaces occurred in the early 1960s. The modernization of the plant under more stringent antipollution regulations coupled with an increase of annual slab zinc capacity to over 120,000 short tons, and the increase in the amount of scrap treated at Palmerton are included in the third time period. The emissions reported to have been released to the atmosphere during the 10-years making up the third period (1970-79) in tables 23-25 appear disproportionately high because of a major plant expansion that resulted in higher production and an increase in share of primary feed from sulfide ores. Comparing cadmium and lead emissions for the three periods in tables 23 and 24, fugitive emissions of the two metals from production of zinc oxide using the American process were reported as zero in the first time period. This probably reflects the use of New Jersey ores as a major source of feedstock for the production of zinc oxide, which was low in cadmium and lead relative to other zinc ores and concentrates. The presence of the two metals in the other time periods suggest that ores and concentrate, or perhaps some scrap or other secondary material containing cadmium and lead were treated. A similar pattern is shown also for Waelzing. During the period 1950-69, fugitive cadmium and lead emissions from the Waelz furnaces, first installed in 1929, were reported as zero, strongly suggesting that the feed mostly was New Jersey ores, and perhaps secondary zinc material with little or no cadmium or lead. Unpublished company data suggest that the Waelz kilns were shut down or operated at reduced levels from 1956 through 1962, coinciding with the suspension of deliveries of feedstock from the temporarily closed Sterling Mine in New Jersey.

Emissions of cadmium and lead during the 1970–79 time period may represent the addition from new source(s)

or an increase in proportion of primary or secondary material containing the two metals, or both since New Jersey ores were known for their low deleterious metal content.

The stack emissions probably were from the kilns and sinter plant. A likely source of fugitive emissions would have been the Waelz oxide sinter plant, although it was not stated in the USEPA study.

Table 26 is a compilation of emission data reported in tables 23-25. It shows that for the 80-year period analyzed a total of 3,740 short tons of cadmium, 7,560 short tons of lead, and 286,000 short tons of zinc were released to the atmosphere by fugitive and stack sources at Palmerton. The zinc emission estimate is consistent with the estimates developed with the assistance of industry experts and other sites evaluated in this study

The total emission estimates for the 80 year period 1900–79, detailed in table 26, for cadmium and zinc were generated in roasting and sintering, which occurred mostly at the East Plant. It was in these steps that the metals, plus a large amount of the contained lead, were lost through volatilization and dust generated in the two-process steps. Sinter fumes analysis, performed while the sintering unit was operating, determined that the material contained 20 percent lead and 12-15 percent cadmium. Also, the sinter plant apparently was not equipped to collect the dust and fumes it generated from the period it initiated operation in 1948 until the early 1950s (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008) and likely was a major contributor of heavy metal emissions during that time period. The tabulated data published by the USEPA show that lead loss to the atmosphere was highest in the retorts, followed closely by roasting and sintering. Some of these losses may have resulted from volatilization because of lead's lower boiling point than zinc allowing it to fumes off before the zinc collectors were placed on the retorts. An alternative explanation offered by Arthur W. Larvey, a consulting chemical engineer with many years of experience supervising operations at Palmerton, is that the amount of lead emissions reported for the vertical retorts by the USEPA are misleading. Based on actual experience he believes that most of the lead loss assigned as emissions from the vertical retorts were actually accumulations in retorts that were physically removed when the retorts were shut down for maintenance and placed on the waste pile. This activity may explain relatively small areas containing anomalously high lead content in the waste pile.

Table 26 is a compilation of the estimated emissions for all years, annual averages (in parentheses), and annual atmospheric emissions of cadmium, lead, and zinc for three time periods for the Palmerton smelter (Adapted from U.S. Environmental Protection Agency, 1987, p. 3-8). The largest amount of fugitive and stack emissions was emitted for the first time period simply because it represents the greatest number of production years and the amount of zinc produced was relatively large.

Table 27 is a compilation of tables 23-25, but was created to illustrate the amounts of atmospheric emissions of

Table 23. Estimated atmospheric cadmium emissions from the Palmerton facility for three time periods, by process technology, and source of emission, (Adapted from U. S. Environmental Protection Agency, 1987, Appendix A-3).

[Values are expressed as short tons (st)]

Technology	1900–49 (st)	1950–69 (st)	1970–79 (st)	Totals 1900–79 (st)
Roasting and sintering	250 (fugitive) 250 (stack)	1,080 (fugitive) 120 (stack)	400 (fugitive) 100 (stack)	2,200
Primarily horizontal retorts	750 (fugitive)	Discontinued	Discontinued	750
American process (zinc oxide)	0 (fugitive) ¹	40 (fugitive)	50 (fugitive)	90
Waelz furnaces	Initiated production in 1929	0 (fugitive) ²	120 (fugitive) 80 (stack)	200
Vertical retorts	Not individually estimated by EPA ¹	100 (fugitive) 100 (stack)	150 (fugitive) 150 (stack)	500
TOTAL	1,250	1,440	1,050	3,740

¹The U.S. Environmental Protection Agency (EPA) did not include a separate estimate for zinc oxide using the American process or vertical retorts during this period. Presumably emissions from zinc oxide production were from use of New Jersey ores that were low in cadmium and lead and may have been volatilized during the sintering process. Vertical retorts were phased in towards the end of this time period and may not have been considered a significant portion of emissions over the evaluated time period. Further, it was assumed that emissions for the vertical retorts during this period are contained in the horizontal retorts estimates.

²Although the Waelz furnaces began operation in the early-mid 1950s, the EPA assigned “0” to this estimate, possibly because the material treated did not contain cadmium or the amount was considered negligible. The kilns were also shut down or on reduced productions schedules from 1958 through 1962.

Table 24. Estimated atmospheric lead emissions from the Palmerton facility for three time periods, by process technology, and source of emission, (Adapted from U. S. Environmental Protection Agency, 1987, Appendix A-3).

[Values are expressed as short tons (st)]

Technology	1900–49 (st)	1950–69 (st)	1970–79 (st)	Totals 1900–79 (st)
Roasting and sintering	500 (fugitive) 500 (stack)	180 (fugitive) 20 (stack)	800 (fugitive) 200 (stack)	2,200
Primarily horizontal retorts	2,500 (fugitive)	Discontinued	Discontinued	2,500
American process (zinc oxide)	0 (fugitive) ¹	40 (fugitive)	20 (fugitive)	60
Waelz furnaces	Initiated production in 1929	0 (fugitive) ² 0 (stack) ²	120 (fugitive) 80 (stack)	200
Vertical retorts	Not individually estimated by EPA	300 (fugitive) 300 (stack)	1,000 (fugitive) 1,000 (stack)	2,600
TOTAL	3,500	840	3,220	7,560

¹The U.S. Environmental Protection Agency (EPA) did not include a separate estimate for zinc oxide using the American process or vertical retorts during this period. Presumably emissions from zinc oxide production was from use of New Jersey ores that were low in cadmium and lead and may have been volatilized during the sintering process. Vertical retorts were phased in towards the end of this time period and may not have been considered a significant portion of emissions over the evaluated time period. Further, it was assumed that emissions for the vertical retorts during this period are contained in the horizontal retorts estimates.

²Although the Waelz furnaces began operation in early to mid-1950s, the EPA assigned “0” to this estimate, possibly because the material treated did not contain lead or the amount was considered negligible.

Table 25. Estimated atmospheric zinc emissions from the Palmerton facility three time periods, by process technology and source of emission (Adapted from U. S. Environmental Protection Agency, 1987, Appendix A, Table A-3).

[Values are expressed as short tons (st).]

Technology	1900–49 (st)	1950–69 (st)	1970–79 (st)	Totals for 1900–79 (st)
Roasting and sintering	20,000 (fugitive) 20,000 (stack)	27,000 (fugitive) 3,000 (stack)	22,400 (fugitive) 5,600 (stack)	98,000
Primarily horizontal retorts	50,000 (fugitive)	Discontinued	Discontinued	50,000
American process (zinc oxide production)	50,000 (fugitive)	20,000 (fugitive)	3,000 (fugitive)	73,000
Waelz furnaces	Initiated production in 1929	2,000 (fugitive) 2,000 (stack)	3,600 (fugitive) 2,400 (stack)	10,000
Vertical retorts	Not individually estimated by EPA ^{1,2}	22,000 (fugitive) 22,000 (stack)	5,500 (fugitive) 5,500 (stack)	55,000
Totals	140,000	98,000	48,000	286,000

¹Vertical retorts were phased in towards the end of this time period and may not have been considered a significant portion of emissions over the evaluated time period. Further, it was assumed that emissions for the vertical retorts during this period are contained in the horizontal retorts estimates.

²Although the Waelz furnaces began operation in 1965, the U.S. Environmental Protection Agency (EPA) assigned “0” to this estimate, possibly because contributions were considered negligible for the time period.

Table 26. Estimated total and annual average (in parentheses) atmospheric emissions of cadmium, lead, and zinc for four time periods and over the life of the Palmerton smelter facility analyzed. Does not include zinc oxide produced by the French process. (Adapted from U.S. Environmental Protection Agency, 1987, p. 3-8).

[Values are expressed as short tons and short tons per year (st/yr)]

Element	1900–49	1950–69	1970–79	1900–79
Cadmium	1,250 st (25 st/yr)	1,440 st (72 st/yr)	1,050 st (105 st/yr)	3,740 st (47 st/yr)
Lead	3,500 st (70 st/yr)	840 st (42 st/yr)	3,220 st (322 st/yr)	7,560 st (95 st/yr)
Zinc	140,000 st (2,800 st/yr)	98,000 st (4,900 st/yr)	48,000 st (4,800 st/yr)	286,000 st (3,575 st/yr)

Table 27. Estimated pounds of atmospheric emissions of cadmium, lead, and zinc per short ton of estimated zinc equivalents in slab zinc and American process zinc oxide produced at Palmerton, by time period. Does not include zinc oxide produced by the French process. (Adapted from U.S. Environmental Protection Agency, 1987, p. 3-8).

[Values are rounded to 2 significant digits.]

Element	1900–49	1950–69	1970–79	1900–79
Cadmium	0.64 lbs	1.2 lbs	1.6 lbs	0.98 lbs
Lead	1.8 lbs	0.70 lbs	5.0 lbs	2.0 lbs
Zinc	72 lbs	82 lbs	74 lbs	75 lbs

cadmium, lead, and zinc generated by fugitive and stack sources as a ratio to the production of units of zinc equivalents within each time period, and for the entire 90-year period reported in the tables. Comparing emissions estimates in this manner provides insights into the possible causal relations between occurrences and observed values over time. The two major factors affecting the values are types and amounts of feedstock and technologies used. Zinc oxide production using the French process was not included to avoid double-counting zinc already recovered as slab zinc and because there were low zinc emissions generated during its production.

Metal losses through fugitive and stack emissions during the period 1900–49 were reported to be on the order of 0.64 pounds of cadmium, 1.8 pounds of lead, and 72 lbs of zinc (3.6 percent) for every short ton of zinc equivalent recovered in product. Zinc losses through atmospheric emissions were approximately 3.6 percent of the total zinc equivalents contained in primary zinc products. Approximately 3.9 million short tons of zinc equivalents were produced during this period.

Based on an estimated production of 2.4 million short tons of zinc equivalents from 1950–69, the ratio of atmospheric emissions of cadmium, lead, and zinc from 1950–69 was approximately 1.2 pounds of cadmium, 0.7 pounds of lead, and 82 lbs (4.1 percent) of zinc per short ton of recovered zinc equivalents. An amount equal to approximately 4.1 percent of the zinc produced was emitted as fugitive and stack emissions.

Fugitive and stack emissions from 1970–79 were on the order of 1.6 pounds of cadmium, 5.0 pounds of lead, and 74 pounds of zinc (3.7 percent of total zinc equivalents) for every short ton of zinc equivalent recovered in product. These calculations are based on the production of approximately 1.3 million short tons of zinc equivalents during the 10-year period.

Cadmium, lead, and zinc emissions per short ton of produced zinc equivalent over the entire 90-year period were estimated at 0.98, 2.0, and 75 pounds (nearly 3.8 percent of total zinc equivalents), respectively. Approximately 7.6 million short tons of zinc equivalents were produced from 1900–79.

Comparing the three production periods defined by New Jersey Zinc, it is apparent that emissions of the metals change from time period to time period and their ratio to each other within time periods. The differences observed result from factors such as the types and amounts of feed and product, equipment employed and methods of treatment, and regulatory requirements, especially post-1970 with the introduction of the Clean Air Act.

Atmospheric emissions of cadmium increased over the period, probably reflecting the increased tonnages of sulfide ores and concentrates that required roasting and sintering before zinc metal could be recovered from retorts. The two processes were responsible for generating most of the operation's fugitive and stack emissions as the share of zinc produced at Palmerton from concentrate increased relative to that produced from oxide ores. During the period 1900–49 less

than 20 percent of the zinc recovered at Palmerton originated from sulfide ores and concentrates roasted at Palmerton while during the other two periods, zinc recovered from roasted sulfide ores and concentrates represented about 70 percent of the zinc produced. Much of the feed in the horizontal retorts and the impure oxide fed to the retorts from the Waelz kilns during the first period were derived from oxide and silicate ores mined in New Jersey that typically were low in cadmium and lead, while virtually all of the roasted ores and concentrates were fed to the vertical retorts and lithopone plant and contained varying amounts of cadmium, lead, and other metals. The other ores and concentrates delivered from New Jersey were used to produce zinc oxide and spiegeleisen. The increase in proportion of sulfidic feed coupled with the significant increase in production during World War II and continuing into the 1970s resulted in greater emissions per unit of zinc recovered. The amount of emissions generated during the period 1950–69 also are disproportionately larger because for the years 1948–53 a roaster and the acid sinter plant operated without emission collection devices. Using fumes composition data and estimates of tonnages of fumes produced from just the Acid Sinter Plant it was roughly calculated that annual emissions amounted to 180 short tons per year of cadmium, 240 short tons of lead, and 240 short tons of zinc during the 6-year period. Total emissions for those metals during that period would have amounted to about 1,100 short tons of cadmium and 1,400 short tons each of lead and zinc (Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008).

The increase in emissions in the time period including 1959–69 might have been even higher than the reported values if the horizontal retorts had not been fully replaced by vertical retorts.

When examining the average annual emissions for the third period represented in table 26, the cadmium, and especially the lead values are considerably higher than the other two periods.

The U.S. Bureau of Mines reported that Palmerton underwent a large modernization program in the early to mid-1970s which included improved mix houses, modifications of the roasting and acid plant, revisions to the material handling systems, and new dust control facilities. Specifically, some of the major improvements made in the 1970s to reduce air emissions included the addition of bag rooms to the vertical retort charge caps, zinc dust furnaces, Waelz plants, and sinter plants. Scrubbers also were added to clean emissions generated from the vertical retorts (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008). It has been also stated, however, that the Waelz sinter plant operated without a baghouse or the baghouse underperformed for part of this period (Robert Kuba, Horsehead Corporation, oral commun., 2008). According to the USEPA report, approximately 50 percent of the cadmium, 30 percent of the lead, and 60 percent of the zinc emitted from 1970–79 originated from the roaster and sinter plants. Reportedly, the other major sources for atmospheric emissions of the three metals during

this period were the vertical retorts, which the EPA stated were responsible for 62 percent of the atmospheric lead emissions, 30 percent of the cadmium emissions, and 23 percent of the zinc emissions.

It is difficult to reconcile why the cadmium, and especially the lead emission data, for the period 1970-79 disproportionately are high when compared to the previous time periods leading one to suspect the methodology used by the USEPA. Considering the large investments for emission controls in the early 1970s and newly emplaced regulatory requirements would suggest that releases on a unit of zinc production would have been considerably reduced. New and large sources of feed from company-owned mines became the predominant suppliers of concentrate in the early 1970s, such as the Gillman mine in Colorado, Friedensville, Pa.; and Austinville, Va., which contained relatively high amounts of lead and cadmium (USEPA, 2008), but it is unlikely that they would have resulted in emissions values so much higher than the previous time periods. Another change in concentrate feed in the late 1970s came about as much of the low lead concentrate was redirected to the Clarkesville, TN. smelter ((Robert Kuba, Horsehead Corporation, oral commun., 2008) beginning in late-1978, but again it unlikely that this would have affected the average for the time period to any large extent. The cadmium plant operated intermittently during the 1970s in response to poor market conditions. During the period the plant was shut downs the captured fumes were bagged and stored in anticipation of reactivation of the plant (Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008).

Based on comparisons with other zinc smelters that operated during the time period, historical zinc emission data appears reasonable. If the USEPA emission values are correct this suggests that: (1) newly installed pollution abatement equipment failed to lower emissions per unit of zinc produced for cadmium and lead to levels below the previous time periods; (2) the previous time periods were incorrectly calculated and were actually higher and/or; (3) the chemistry of the ore and concentrate treated at the Palmerton plant changed, perhaps to an extent that the pollution control equipment was inadequate.

Suspended Plant Emissions

A portion of the plant's emissions were large in size or heavy in weight, or both, causing them to settle in close proximity to the plant. Conversely, some of the cadmium, lead, and zinc material emitted into the atmosphere over the facility's life were considered to have been so small that they had a zero settling velocity. Except for occasional rain occurrences that may have contributed to deposition of this material in the Palmerton Valley, material was sufficiently small in size to have been wind-transported considerably further beyond the valley and dispersed over a wide geographic area (Alan Cimorelli, USEPA, oral commun., 2007). It was calculated (see table 28) that approximately 640 short tons (17 percent) of the total cadmium emissions; 1,040 short tons (14 percent) of the total lead emissions; and nearly 70,000 short tons (25 percent) of the total USEPA-reported zinc emissions could be placed in this size category.

Most of this material was emitted through stack emissions during sintering and production of zinc oxide using the American process (Cimorelli, 1986).

Plant Residues

During the facility's operation approximately thirty million short tons of solid residues, consisting mostly of retort residues, accumulated as a bank measuring 2.3 miles long and averaging 100 feet in depth. Zinc concentration in the pile has been reported to range from 2-10 percent (Shelov, 2001) and less than 1 percent to 20-25 percent (Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008). Values differ as a result of sampling methods and actual variations in values. To place the zinc content of the waste pile into perspective, currently mined primary-zinc ore bodies contain roughly between 3 and 11 percent zinc with additional values received from other metals, such as copper, lead, and silver. In the mid-late 1980's, the USEPA, Pennsylvania Department of Health (PDH) Under Cooperative Agreement with the Agency for Toxic Substances and Disease Registry released a report that the estimated 30,000,000 short ton pile of smelter waste contained 881,000 tons of zinc, 118,800 short tons of lead, and

Table 28. Estimated annual average (in parentheses), and annual Palmerton smelter for zero settling velocity atmospheric emissions of cadmium, lead, and zinc for three time periods (Adapted from U.S. Environmental Protection Agency, 1987).

[Values are expressed as short tons and short tons per year (st/yr)]

Element	1900-49	1950-69	1970-79	Total over life (annual average)
Cadmium	250 st (5 st/yr)	140 st (7 st/yr)	250 st (25 st/yr)	640 st (8 st/yr)
Lead	500 (10 st/yr)	40 (2 st/yr)	500 st (50 st/yr)	1,040 st (13 st/yr)
Zinc	45,000 st (900 st/yr)	13,000 st (650 st/yr)	12,000 st (1,200 st/yr)	70,000 st (875 st/yr)

8,250 short tons of cadmium (PDH, 1987). New Jersey Zinc estimated, based on a drilling program in 1981, that the residues contained 771,618 short tons of zinc in residues containing from 1.5 percent to 7 percent zinc (Shelov, 2001, table 2, p. 25). Based on an average 2006 zinc price of approximately \$3,400 per short ton of refined zinc, the gross in-place value of zinc residing in residues at the smelter site is nearly 3.0 billion dollars (U.S.). A combination of the costs associated with recovering the zinc, and actual and potential legal liabilities pertaining to the nature and location of the material, contributed to making the recovery of zinc commercially unviable in the year 2006 and in the near future.

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Austinville Furnace, Bertha Mineral Co., Austinville, Wythe County, Virginia

Introduction

The Austinville, Virginia zinc oxide plant was a relatively small plant that started operation in 1904 or 1905 (New Jersey Zinc (NJZ), written commun., 1945; Jolly, 1994; Higgins, 1905a) and possibly closed for a period beginning in 1915 or sometime soon afterward, since there is no mention of zinc production from the plant in published literature in subsequent years. It also is possible that the plant's small size did not justify inclusion in the literature. Internal New Jersey Zinc (NJZ) memoranda and discussions with industry specialists however, indicate that ore was roasted and impure zinc oxide was produced in the early to mid-1920s.

The facility was originally built for the purpose of producing zinc oxide from low-grade zinc ores and concentrated zinc-rich tailings that did not meet the high-ore grade specifications for zinc production at the Company's smelter at Pulaski, Virginia (Higgins, 1905a, p. 658; U.S. Geological Survey, 1912). The impure zinc oxide produced at Austinville was shipped to Pulaski, Va. as a portion of its feed for zinc metal production, and was also transported to the smelter at Palmerton, Pa. in the 1920s.

Map Number (fig. 1)

13

Location

The plant was located in the town of Austinville, Va. at latitude N36°51'04" (36.85111) and longitude W080°54'44" (-80.91222).

Alternate Names

Austinville zinc oxide plant
Bertha zinc oxide works

Years of Operation

The original plant located on the site was relatively small in size and its production was short-lived; operating from 1904 to about 1915 (Higgins, 1905a; U.S. Geological Survey, 1905;1912; internal NJZ documents). The actual year of the shut down was not stated in the literature. Data reported by NJZ data states that the plant started a new block of oxide furnaces in 1923 and a multiple-hearth wedge roaster in 1924, but technical details were not available (NJZ, written commun., 1945). Both of these facilities closed in 1925 (NJZ, written commun., 1945; NJZ internal production data).

Based on limited information it was estimated that a total of about 400 short tons of zinc were emitted to the atmosphere as a component of dust, fumes, and gas during the production of nearly 7,400 short tons of zinc metal equivalents contained in nearly 10,000 short tons of impure zinc oxide.

Owner

1902–1925 (est.)—Bertha Mineral Company, a subsidiary of New Jersey Zinc (Higgins, 1905a, p. 658; Foley, 2004).

Primary Product

High-lead zinc oxide.

Plant Feedstock and Sources

The zinc oxide plant received hand-sorted primarily low-grade zinc carbonate (smithsonite) and zinc silicate (hemimorphite) recovered from local mines and jigged tailings from the Austinville mill. The high-grade concentrates produced from the mill were sent to a company-owned zinc smelter at Pulaski, Va., and some undetermined amount was also shipped to the South Bethlehem, Pa. plant (Higgins 1905a; Higgins, 1905b). The concentrate was likely shipped to the NJZ Palmerton, Pa. plant following the closure of the South Bethlehem plant in 1911. The feedstock to the oxide furnaces at the Austinville oxide facility included ore and concentrated tailings. Grades of feedstock ranged from 15 to 20 percent zinc (Higgins, 1905a) with varying amounts of lead contained in the feed.

The feedstock for the roaster, which began operating in 1924, was composed of sphalerite ore and concentrate that were mined and beneficiated in the Austinville Mining District of Virginia. Concentrates were produced by flotation, gravity, or by combined methods. Most of the zinc charge to the oxide furnace during this period probably originated from the roaster.

Product

Zinc oxide assaying 70-80 percent zinc and 4 percent lead (Watson, 1907a) was reportedly produced at the facility in 1905. The assay of the product places the product in the high-leaded zinc oxide category (Hofman, 1922), which was also noted in Palmerton's historical production records (NJZ, internal company data). The zinc oxide was either used as a high-lead zinc oxide product for paint, or was shipped to the Pulaski, Virginia smelter for use as feed to the retorts in the production of zinc metal (Watson, 1905a; U.S. Geological Survey, 1912, p. 374).

From 1923 through 1925, products shipped from the Austinville plant to Palmerton, PA included impure zinc oxide and roaster products. The roasted material was used at the Palmerton smelter to produce low-lead zinc oxide

(Arthur W. Larvey, Consulting Chemical Engineer, written communication, 2008; NJZ internal company data). The impure zinc oxide produced at Austinville in the new furnaces was used for producing high-lead zinc oxide (NJZ internal company data).

Zinc Oxide Production

With the exception of one reference to a production of 348 short tons of impure zinc oxide over a period of approximately 6 months in 1905 (Ingalls, 1906), there were no additional plant capacity or production tonnages encountered in the researched published literature. In 1905, the facility was reported to have 12 zinc oxide furnaces, without mention of the amounts of feed, capacity, production, and furnace sizes (Higgins, 1905a; 1905b; Watson, 1907a). Given the number of furnaces, production may never have met expectations, the oxide furnaces were unusually small, or the data is incorrect.

Although the Pulaski smelter closed in 1910, the Austinville zinc oxide plant was reported to have been operating through at least 1914, although no statistics relating to capacity or production were published (Of, 1913; Roush, 1914; 1915). The facility was described as “small” in 1911 (U.S. Geological Survey, 1912) and was not referred to in any of the subsequent Mineral Resources of the United States published after 1914 (U.S. Geological Survey, 1914), suggesting that the plant’s production may not have been significant. A photograph of the oxide plant, taken about 1905, supports the written description of the small size of the plant (Watson, 1907b).

The paucity of the plant’s mention in the researched literature and discussions with historical experts (Allen Bishop, Geologist, Virginia Department of Mines and Energy, oral commun., 2008; Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008) also suggests that its production, even on a local level, was not significant and probably short lived. Finally, the Pulaski smelter, which closed down in 1910, relied on the Austinville plant’s impure zinc oxide product as a portion of its diverse sources of feedstock.

Using the broad assumption that annualizing the published 6-month production statistic of 348 short tons of impure zinc oxide was representative of the Pulaski facility’s output for the period 1904 through 1915, it was estimated that approximately 8,400 short tons of high-lead zinc oxide, containing about 6,300 short tons of zinc equivalents (75 percent zinc content) may have been produced.

In the early to mid-1920s, an experimental flotation plant, a multiple-hearth wedge roaster, and an additional oxide plant were constructed on the site by NJZ. Based on limited data, the oxide plant operated from 1923–25, and the roaster operated from 1924–25 (NJZ, written commun., 1945; NJZ internal data). The plants shipped roasted ores and concentrates, and impure zinc oxides containing lead to Palmerton (NJZ internal data); some of which was used for producing high-lead zinc oxide and lead oxide. No technical details or production records were available, but the roaster product probably

assayed about 55 percent zinc with 2–4 percent sulfur, and the high-lead zinc oxide product assayed about 75 percent zinc. It was assumed that approximately 1,500 short tons of high-lead zinc oxide containing 1,125 short tons of zinc was produced from 1923–25.

The total contained zinc production for both time periods was approximately 7,425 short tons.

Technology

The furnaces received hand sorted, low-grade ore and tailings concentrate that were recovered from settling tanks following jigging and other gravity methods. In 1905, there were reportedly 12 furnaces used to produce zinc oxide (Higgins, 1905b), but no technical data relating to their size and capacity were provided. The concentrate was mixed with anthracite or coal and shoveled onto a stationary grate furnace.

Zinc fumes were produced from the heated and reduced concentrates, which were later directed through a 600 foot-long, 3-foot diameter cast-iron flue that cooled and transported fumes from the furnace to the baghouse where the impure zinc oxide was recovered (Higgins, 1905b). Although not stated in the literature, the flue probably had several draw points that permitted the removal of precipitated impure zinc oxide and other zinc-rich residues. This material was either fed back to the furnace or possibly shipped to other plants for smelting into zinc metal.

In 1913, the oxide plant was remodeled, and in 1923, a new block of furnaces were constructed, but technical details were not available (NJZ, written commun., 1945). No information was available suggesting that the plant operated in the interim years.

In the year 1923, a multiple-hearth wedge roaster for the reduction of sphalerite ores and concentrates was constructed and initiated production in 1924 (NJZ, written commun., 1945).

Electricity was partly supplied by hydroelectric generation (Ingalls, 1906). Locally mined coal was used as a reductant and fuel source in the roaster and zinc oxide furnaces.

Emission Estimates

According to geochemical analyses performed by the U.S. Geological Survey, soils in the vicinity of the zinc mines and smelter (now a Virginia state park) at Austinville, Va. contained elevated levels of lead and zinc, which were related directly to mining and smelting activities in the area (Foley, 2004). A roaster also was operated in the area up until 1898. It was necessary to remove soils at or near the site because of their anomalously high level of the two metals. Sediment in a nearby river (probably the New River) also contains elevated levels of cadmium and zinc (Foley, 2004), but the area has a long history of lead and zinc mining and smelting. Up through 1905, virtually all of the ore mined was hemimorphite and smithsonite. Mining of lead and zinc sulfide ores began to

grow dramatically in 1913 (U.S. Geological Survey, 1914). It has not been determined that the anomalous metal values are attributable to the Austinville zinc oxide facility.

Given the lack of actual or reliable production data, or both, a rough estimate of atmospheric zinc emissions produced from 1904–15 and from 1923–25 was developed assuming that an amount equivalent to 6 percent of the zinc contained in recovered zinc oxide production. Using this method a total of nearly 450 short tons of zinc were possibly emitted to the atmosphere as a component of dust, fumes, and gas.

Given the impure nature of the zinc oxide, containing 4 percent lead, it is likely that lead, and possibly cadmium, were also components of atmospheric emissions. Fugitive and stack emissions to the atmosphere were generated during the unloading of feedstock (including crushing and grinding, when necessary; roasting of feedstock, charge preparation for the oxide furnaces, loading, stirring charges during furnacing, and emptying furnace grates; leaks in conduits and in the baghouse, and during packing of the oxide product.)

Without the presence of an acid plant to recover sulfur, settling chambers, baghouse, or other dust and sulfur recovery systems, it is likely that more than 95 percent of the sulfur contained in ores and concentrates reduced in the roaster during the short period it operated was emitted to the atmosphere. Data on the amount of material and its sulfur content treated in the roaster were insufficient for an estimate.

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Grasselli Chemical Company, Anmoore, Harrison County, West Virginia

Introduction

The Grasselli Chemical Company's zinc metal plant operated from 1904–27. The facility was located about 2 miles southeast of Clarksburg, W.Va., in a town later named Anmoore; and about 40 miles southwest of Morgantown, W.Va. The feed, originating from the Tri-State District, was first roasted at the Grasselli Company's roasters and sulfuric acid manufacturing facilities located in Indiana, Ohio, and possibly Pennsylvania and then railed to Clarksburg, W.Va. The plant produced zinc by reducing zinc ores and concentrates in furnaces with a maximum combined total of 5,760 zinc retorts. Approximately 16,000 short tons of zinc was emitted as a component in dust, fumes, and gas during the production of about 410,000 short tons of zinc over the period of 24 years that the plant operated.

Map Number (fig. 1)

14

Location

The plant was located in Anmoore, West Virginia at N39°15'25" (39.256846), W080°17'33" (80.292602)

Alternate Names

Grasselli Clarksburg
Grasselli Chemical Company

Years of Operation

1904–27 (Ingalls, 1906; U.S. Geological Survey, 1905; 1930; Asturian-American Migration Forum, 2008).

Owner/Operator

Grasselli Chemical Company (Hennen, 1912).

Sources and Types of Primary Zinc Feedstock

Feed for the zinc smelter at Clarksburg was supplied from company-owned roasting facilities located in Grasselli, Indiana; and Canton, Cleveland, Lockland, and Niles, Ohio (Roush, 1915; 1922; U.S. Geological Survey, 1910–1924). Some roasting of the ore and concentrates may have occurred in New Castle, Pa. (Roush, 1915), but could not be substantiated. Much of the ore and concentrate supplied to the

Company's roasters originated from Missouri and the Tri-State District (Kansas, Missouri, and Oklahoma) (Ingalls, 1908). See tables 3, 5, and 8 for examples of grade data. The Clarksburg smelter may also have received some feed in the form of hemimorphite and/or smithsonite from the Company's mines in Jefferson County, Tenn. before 1920 (Purdue, 1914; Roush, 1922).

Zinc Plant Capacity and Production Estimates

The maximum number of retorts that the smelter furnaces were able to accommodate was published for all of the years the plant operated in Mineral Resources of the United States, published by the U.S. Bureau of Mines and the U.S. Geological Survey at 5,760 (U.S. Geological Survey, 1908-28; U.S. Bureau of Mines, 1929). Testimony provided at the tariff hearing before the Committee of Ways and Means of the 60th U.S. Congress in 1908-09 stated that a new furnace with 576 retorts was added in 1907 or 1908 (Ingalls, 1908; Orr, 1910.). The operation reportedly reached full production level in its second year of operation (Ingalls, 1906). No statistical data referring to actual zinc metal production were discovered in the researched literature for any of the years the plant operated.

In 1921, the plant reportedly had a distillation design capacity of 51,100 short tons of roasted ore and calamine (hemimorphite or smithsonite) (Roush, 1922). Assuming that the average zinc content of ore and concentrate was 50 percent zinc, and zinc recovery was approximately 90 percent, nearly 23,000 short tons of zinc could have been potentially recovered on an annual basis at full capacity. At 85 percent capacity utilization, approximately 20,000 short tons of zinc could potentially have been produced. Running a plant at design capacity for any extended period usually results in expensive and time-consuming plant repairs. The average annual effective capacity estimate accounts for retort change out and replacement of broken retorts, furnace cleaning, rebuilds, and other routine maintenance procedures, and is a more realistic expectation of production at full capacity.

An alternative method to calculate the Clarksburg plant's effective capacity was based on estimated annual production and annual capacity of individual horizontal retorts. In the early 1900s, annual retort capacity in the zinc industry was approximately 3.5 short tons of zinc per retort in use, but increased to about 4.25 short tons per year by the early to mid-1920s. The increase in the average annual retort capacity reflected improvements in smelting technologies during the period and higher quality feed brought about through the use of concentrates produced using flotation methods. The average annual design capacity estimate of roughly 20,000 short tons of distilled zinc metal for the Clarksburg plant was developed by taking the average annual individual annual retort capacity estimates, multiplying by a zinc recovery factor of 90 percent and multiplying that result by the plant's capability to accommodate 5,760 horizontal retorts in its furnaces. The effective average annual zinc metal capacity of about 17,000 short tons/yr was calculated by multiplying the estimated design capacity

by a utilization factor of 85 percent. Using the average annual effective capacity, the Clarksburg plant was estimated to have produced up to 410,000 short tons of zinc metal over its 24-year operating life.

Unless published or available by analogy with other operations, the estimate does not include factors that could affect zinc production such as the availability, grade, and quality of feed, economic conditions, labor and technical problems, internal company decisions, and external occurrences. In the years the plant operated, capacity utilization at Clarksburg probably reflected to a large extent industrial activity in the United States. Production was probably low relative to its capacity during periods of economic recessions or depressions such as in 1914 and 1920. Conversely, capacity utilization was likely to be high during times of economic prosperity in the first years of the 20th century, during World War I, and the early to late-1920s leading up to the beginning of the Great Depression in 1929.

Technology

The Grasselli smelter used feedstock supplied by the Company's out-of-state offsite roasting facilities. Roasting decreased the feed's sulfur content from about 32 to about 2-3 percent or less. A small amount of the sulfur contained in the feedstock to the plant was retained in the retort residues and the balance was released as fugitive or stack emissions during several steps in the process of producing zinc metal.

The Clarksburg plant was equipped with 5,760 horizontal retorts distributed in 10 natural gas-fired Lanyon-Hegeler furnaces (Stone, 1915; Ingalls, 1920; Roush, 1922). Few technical details describing the plant's design are available, but the plant was probably similar to other zinc smelters operating horizontal retorts which treated a mixture of roasted ore, concentrate, and coal. Over the course of about 4-6 hours, zinc was volatilized and condensed onto iron condensers, as molten zinc. The molten zinc condensed and was collected every few hours and poured into molds. Each furnace had its own stack through which furnace gases were directed. Retorts were then replaced or emptied and cleaned and the process was repeated. It was estimated that zinc recovery at the Clarksburg, WV, plant ranged from 85-90 percent.

There is no mention in the literature concerning capture of dust and fumes using baghouses, scrubbers, settling chambers, or electrostatic precipitators at the facility.

Emissions

Emission estimates for the Clarksburg plant do not include emissions from roasting because the process was performed out-of-state. Loss of zinc at the roasters could have ranged from 1-2 percent (Wells and Fogg, 1920). Because of the paucity of plant design information, it was assumed that the sulfur was sufficiently reduced and the material sufficiently agglomerated, so that sintering was not required prior

to charging the retorts. Sintering machines rarely were used in plants using horizontal retorts but were commonly employed in plants employing vertical retorts. Sintering could have been a potentially significant contributor to emissions without dust- and fumes-capturing devices.

It was estimated that an amount of zinc equivalent to roughly 4 percent of the amount produced over the 24-year life of the operation, or nearly 16,000 short tons of zinc equivalents were released as fugitive and stacks emissions to the atmosphere in dust, fumes and gas. Some of this material may have been collected as accumulations in flues and in close proximity to the plant and recycled to the retorts, but the amount would have been relatively insignificant.

Assuming that the all of the nearly 900,000 short tons of prerduced material received and treated by the plant over its operating life contained an average of 2 percent sulfur, and possibly half was emitted during ore and concentrate storage, drying, preparation and retorting, up to 9,000 short tons of sulfur contained in dust, fumes, and gases were emitted to the atmosphere. The Clarksburg-Grasselli plant reportedly treated some smithsonite, which would have reduced the sulfur content of feed and resulting emissions (Purdue, 1914; Roush, 1922).

Most of the ores and concentrates that supplied the Grasselli plant originated from the Tri-State Mining District. The zinc sulfide ores extracted from the deposits in that area and the concentrates produced from the ores contained, in addition to zinc and sulfur, varying amounts of cadmium, copper, lead, mercury, and other metals contained in sulfide minerals. Following roasting, when cadmium and other metals probably were recovered, any remaining metals probably were contained in retort residues, flue accumulations, and zinc product. The balance was lost as fugitive and stack emissions in dust, fumes, and gas during unloading, storage, blending, charge preparation, and during the distillation of zinc in the retorts. See tables 3, 5, and 8 for assays of ore and concentrate samples from the Tri-State District. Assay data were insufficient to estimate the amount of these material released to the atmosphere.

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Clarksburg Zinc Company, Clarksburg, Harrison County, West Virginia

Introduction

The plant was located in North View, a small town now absorbed into Clarksburg, W. Va. The plant was constructed in 1907 and was located about 5.5 miles north of the Grasselli Chemical Company's zinc plant. The original intent for the plant was to produce zinc metal by smelting galvanizer's dross, skimmings, and other zinc-rich secondary material. The plant was designed to produce 7 short tons of zinc metal per day at design capacity. The plant expanded in 1911 under new ownership and treated zinc ore, concentrates, and secondary materials. The plant was idled during 1918 and was sold on June 12, 1920 [Asturina-American Migration Forum, 2008; Liddell, 1918] after producing a total of about 84,000 short tons of zinc during the approximately 12 years the plant operated. Approximately 3,500 short tons of zinc, plus sulfur, and heavy metals were emitted to the atmosphere as components in dust, fumes, and gas during this period.

Map Number (fig. 1)

15

Location

The plant site was located in North View which is in the northwestern section of Clarksburg, W. Va (Hennen, 1912; Asturina-American Migration Forum, 2008), Harrison County, WV at N39°17'15" (39.287504); W080°20'56" (-80.348815).

Years of Operation

The plant began producing in 1907 and closed in 1918 (Asturina-American Migration Forum, 2008).

Ownership

1907–08—James Latourette Company (Speir, 1907; Ingalls, 1908)

1909–11—Clarksburg Zinc Company (Asturina-American Migration Forum, 2008).

1911–16—Pearlman Company Incorporated (Weed, 1918).

1916–19—Pearlman Company Incorporated (A wholly owned subsidiary of the United Zinc Company (Asturina-American Migration Forum, 2008; New York Times, 1919; Roush, 1921).

1919–20—Pearlman Company, a subsidiary of the United Zinc Company, wholly owned by Charles Schwab

(New York Times, 1919). The owner apparently had no direct relation to the investment and stock trading company of the same name.

Primary Products

Zinc Metal

Feedstock

The United Zinc Company, the parent company of the Pearlman Company owned mines, roasters, and other smelters in the Tri-State District and in western states. The United Zinc Company also had a majority interest in the Kenefick Zinc Corporation and the Kenefick Electrical and Lead Mining Company that owned and operated the Airedale, Coyote, Electric, Media and other mines in the Joplin District in Missouri since early in the 20th century (Pulsifer, 1918). The United Zinc Company also operated a zinc smelter and distilling plant in Pueblo, CO (Engineering Mining Journal 1915b) and the Mineral State, Southern, and Thomas mines in Kansas during the time period the Clarksburg smelter operated (U.S. Geological Survey, 1917).

Considering the composition of roasted zinc concentrates produced from the zinc and lead-zinc operations previously mentioned, which for the most part were concentrated by gravity methods, it is likely that they contained, in addition to 1-3 percent sulfur, metals such as arsenic, cadmium, copper, and lead. Additional feedstock may have been purchased on contract.

The drosses and skimmings, which served as part of the plant's zinc feedstock in the first few years of its operation, and probably in later years, likely originated from steel and steel-galvanizing companies. Scrap zinc also could have been supplied from a number of other sources. The proportion of primary compared to secondary feedstock, if used at all, after the initial expansion of the plant is unknown.

As previously mentioned, ores and concentrates probably ranged from 50-55 percent zinc, dross assayed about 95 percent zinc, and skimmings contained 65-85 percent zinc.

Zinc Capacity and Production Estimates

In 1907, the plant was small and originally had a stated capacity of 7 short tons of zinc per day using feedstock from secondary sources (Ingalls 1908, U.S. Geological Survey, 1908; p. 663), most likely drosses, skimmings, and scrap. The plant operated for three months in 1907; its first year of production (U.S. Geological Survey, 1907), and likely continued to treat secondary materials as a portion of its feedstock in subsequent years, although not stated in the literature.

The plant was expanded in late-1911 or 1912 following its purchase by the Pearlman Company. In 1913, the plant's furnaces accommodated 2,736 horizontal retorts. From 1915

until 1918, the year the plant was idled, design capacity had been further expanded to permit the use of 3,648 retorts (Engineering Mining Journal, 1915a, Liddell, 1918; U.S. Geological Survey, 1915–1918). In 1918, it was reported that the annual design capacity of the horizontal retorts was 15,000 short tons of zinc metal (Weed, 1918) from feedstock, probably consisting of mostly zinc ore and concentrate, using 3,648 retorts. Annual design capacity per retort was about 4.1 short tons of zinc per retort, which was about average for the time period. The plant was also reported to have an annual refining design capacity of 7,500 short tons of zinc metal (Weed, 1920). Running a plant at design capacity for any extended period usually results in expensive and time-consuming plant repairs. The average annual effective capacity, about 85 percent of design capacity, accounts for retort cleaning and recharge, replacement of broken retorts, furnace cleaning and rebuilds; and other routine maintenance procedures. It is a more realistic expectation of production at full capacity. At 85 percent capacity utilization, approximately 13,000 short tons of zinc or 3.5 short tons of zinc per retort could be potentially produced annually and nearly 6,500 tons of zinc could be refined. Labor issues and other nontechnical occurrences and conditions, availability of feedstock, technical problems with equipment and other factors that can affect production, were not considered in the calculations. Favorable economic conditions for zinc producers in the United States prevailed during the years the plant operated, especially for the years leading up to and during World War I, so plant utilization probably was quite high, barring internal economic, labor, and technical problems. The plant was idled during the latter part of 1918, all of 1919, and sold in June 1920 (Roush, 1920, 1921; Asturina-American Migration Forum, 2008) during a period of national economic retreat following World War I. The United Zinc Company's newly opened plant at Moundsville, W. Va.; located about 50 miles north of Clarksburg probably accommodated the company's lost zinc capacity resulting from the closure of their Clarksburg smelter.

It was calculated that roughly 84,000 short tons of zinc metal were produced over the smelter's 12-year life based on published data, which included smelter and refinery design capacity data for some years from 1907 through 1918, the reported number of horizontal retorts installed at the plant for the years 1912–18, and an estimated 85 percent effective plant capacity. To avoid possible double-counting of the plant's historical zinc production the estimate does not include materials produced from the zinc refinery. Some portion, and possibly all of the refinery's production previously may have been retorted at the plant and then redistilled or liquated in order to recover a high-purity zinc product. Conversely, some secondary zinc also may have been fed directly to the refinery and was therefore not included in the capacity or production estimates.

Technology

The zinc feedstock originating from sulfide ores was preroasted at facilities outside of West Virginia and processed by conventional means using horizontal retorts in gas-fired furnaces as described in this study for other contemporary plants. Sintering of roasted feedstock was not mentioned in the literature. The zinc recovered in the condensers may have been upgraded by removing impurities at the facilities refinery.

The secondary material, which was treated exclusively in the early years of the plant did not require roasting, but like ore and concentrate, needed to be mixed with a reductant, such as coal. Secondary feedstock probably consisted of galvanizer's dross and skimmings. While ores and concentrates probably ranged from 50-55 percent zinc, dross assayed about 95 percent zinc and skimmings from 65-85 percent zinc. Drosses often contained other metals, such as cadmium and lead (Ingalls, 1903). The secondary feedstock could have been used as feedstock in the same furnaces as the ore and concentrate and recovered from the retorts using conventional methods of fuming and condensation. To make the product more valuable, the impure zinc product derived from primary and secondary feedstock could have been further treated. Refining could have consisted of redistilling in retorts or more likely liquated. Liquating zinc involved boiling the metals and maintaining a melt for a sufficient time to permit impurities to separate by their specific gravity before tapping.

The plant produced zinc dust from 1914 through at least 1917, but the amounts and the number of years that the product was manufactured were not reported (U.S. Geological Survey, 1917, 1919). Zinc dust was produced by vaporizing zinc and allowing it to condense in a carbon monoxide-rich atmosphere at temperatures below the melting point of zinc. This often was accomplished in a water-jacketed condenser.

Overall zinc recovery at the facility probably averaged between 85 and 90 percent. The site also was equipped with a retort manufacturing facility; also known as a pottery plant, that was equipped with the capacity to produce 500 baked clay retorts per day to replace broken and cracked retorts, which occurred quite frequently during the distillation process (Weed, 1918), and was a major source of zinc losses in the furnaces.

Estimates of Zinc and Sulfur Emissions to the Atmosphere

It was estimated that approximately 4 percent of the calculated zinc metal production or roughly 3,500 short tons of zinc equivalents were emitted to the atmosphere in dust, fumes, and gas over the 12-year period that the Clarksburg plant operated. The major sources of fugitive and stack emissions included the unloading, handling, blending, preparation and storage of feedstock, mixing feedstock with coal to prepare the charge for retorting, losses during retorting through fractured and failed retorts, escaping fumes from

condensers, and losses during removal, cleaning, and replacement of retorts. Some zinc might have been recovered from accumulations in flues and plant surfaces and recycled back to the retorts, but the amount was relatively insignificant.

It was assumed that all of the material received and treated by the plant contained was pre-roasted and contained about 2-4 percent sulfur. Upon retorting most of the sulfur would have been retained in the residue, and only a small portion emitted to the atmosphere. It was estimated that perhaps 1,000 short tons of sulfur in various species were emitted to the atmosphere during concentrate storage, drying, retort charging, and distillation. This estimate does not take into account the treatment of secondary zinc feedstock which probably contained little, if any, sulfur.

Emission estimates for materials other than zinc were not attempted because the amount of feedstock and assay values for materials contained in feedstock were not available. Considering that significant portions of the primary feedstock treated at the smelter originated from the Tri-State Mining District, it is likely that emissions contained metals such as arsenic, cadmium, copper, and lead. See tables 3, 5, and 8 for sample assays of ores and concentrates produced in the Tri-State District.

The materials, contained in secondary feedstock, other than zinc, probably included cadmium and lead, but at much lower levels per unit of zinc recovered than primary zinc concentrates. Estimates of emissions of these metals were not attempted.

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Moundsville Zinc Smelter, United Zinc Smelting Corporation, Marshall County, West Virginia

Introduction

The Moundsville plant was located in Moundsville, W. Va and produced zinc metal and sulfuric acid from 1918 until 1945. It was a larger, more efficient, and more vertically integrated plant than the one it replaced at Clarksburg, W. Va.; about 65 miles to the southeast.

Although annual design capacity and the number of installed horizontal retorts were published on an annual basis by the American Bureau of Metal Statistics, the U.S. Bureau of Mines, and the U.S. Geological Survey, only one production statistic was encountered in literature. The major activities performed at the facility included ore and concentrate offloading, feedstock storage and preparation; roasting and sintering; sulfuric acid production; zinc distillation; and possibly zinc refining. In addition to the ore and concentrate, some secondary material, probably in the form of dross, was treated at the plant.

It was estimated that about 9,000 short tons of zinc was emitted in dust, gas, and fumes as a component of fugitive and stack emissions during the 28-year total zinc production of approximately 183,000 short tons of zinc.

Map Number (fig. 1)

16

Location

The smelter site is located in the town of Moundsville, W. Va. [approximately 54 miles (87 km) southwest of Pittsburgh, PA] at N39°55'13"(39.920278); W080°44'36" (-80.743333).

Owners During Construction and Production

1916–19—United Zinc Smelting Corporation (U.S. Geological Survey, 1917; American Bureau of Metal Statistics, 1922)

1919–45—United Zinc Smelting Corporation, a wholly owned subsidiary of Charles M. Schwab (New York Times, 1919, U.S. Bureau of Mines, 1939).

Years of Operation

Ground was broken for construction of the primary treatment facility and a sulfuric acid plant in late-1916. The roasting of primary feedstock, and the manufacture of sulfuric acid were initiated in 1917 and the start of zinc production began in 1918 (U.S. Geological Survey, 1921, p. 868). The plant temporarily closed in 1938 as a result of increasing costs and

labor-related issues, but reopened the following year as prices increased for the metal as a result of escalating demand for zinc in the years leading up to World War II. (U.S. Bureau of Mines, 1939, p. 152). The plant permanently closed as a primary zinc producer in mid-1945 (American Bureau of Mining Statistics, 1948; Cotterill, 1950), at the close of World War II. The site was permanently shut down in 1957 after an undetermined period of recovering zinc oxide from residues (U.S. Bureau of Mines area report Vol III, 1959, p. 1192), perhaps generated from previous retorting activities, although no supporting information was available. Total zinc oxide production likely was quite low.

Primary Product

Zinc metal

Sources and Types of Feedstock

The plant was sited along the Ohio River near a major rail route that provided access to a number of domestic and foreign sources for primary feedstock, as well as dross and other secondary materials from steel-producing centers, such as Pittsburgh, Pa.

The origin of feedstock in the first several years of the operation is unclear, but it is likely that the plant assumed the void left by the closure of the company's Clarksburg plant by treating ores and concentrates from the Tri-State District. In 1915, sphalerite concentrates assayed up to 60 percent zinc (Rickard, 1922.; Weed, 1918 ; Lindgren, 1919). The United Zinc Company, the parent company of the Pearlman Company, owned mines, roasters, and other smelters in the Tri-State District and in western states. The United Zinc Company also had a majority interest in the Kenefick Zinc Corporation and the Kenefick Electrical and Lead Mining Company which owned and operated the Airedale, Coyote, Electric, Media and other mines in the Joplin District in Missouri since early in the 20th century (U.S. Geological Survey, 1914; Pulsifer, 1918). See tables 3, 5, and 8 for grade data. The United Zinc Company also had a zinc smelter and distilling plant in Pueblo, Colo. (Engineering Mining Journal, 1915b) and the Mineral State, Southern, and Thomas mines in Kansas during the time period the Clarksburg smelter operated (U.S. Geological Survey, 1917), which may have sent excess ore, concentrates, and calcine to Moundsville following Clarksburg's closure.

In the late-1930s and early-1940s the Moundsville facility received zinc concentrate from the Tri-State District, the Mineral Point District and other districts in Wisconsin, southern Illinois, southeastern Missouri, and other scattered mining districts in the Central States (U.S. Bureau of Mines 1941, p. 265). Uncalcined Mineral Point sphalerite concentrates assayed from 20 to 60 percent zinc percent zinc (U.S. Geological Survey, 1919; George, 1918; Uglow, 1914). These concentrates also contained varying amounts of cadmium, copper, and lead. An amount equal to about 20 percent of the amount

of the weight of sphalerite feed was supplemental sulfur (U.S. Bureau of Mines, 1923–33).

Information on the grades of ores and concentrates exclusive of the Tri—State District for the years 1921–28 are presented in table 4. Note that the lead content of concentrate decreases and zinc content increases over time illustrating, in part, the improvements in flotation technology. The increase in tonnage reflects to some extent the acceptance of flotation to separate ores containing lower grades and multiple products. Like the company's Clarksburg, W. Va., plant, the operation may have also treated secondary zinc sources, primarily zinc dross. Dross assayed about 95 percent zinc (Ingalls, 1903).

Plant Capacity and Production

The Moundsville plant relied on zinc metal and sulfuric acid to generate virtually all of its revenue. Essentially no production data related to the operation was encountered in the literature. Based on the number of reported standard-sized retorts installed at the Moundsville plant, its design capacity was relatively small American Bureau of Mining Statistics, 1918, 1920, especially in the later years of its operation, as plants employing horizontal retorts were either closed or replaced horizontal retorts as they transitioned to the use of more efficient vertical retorts.

Zinc Capacity Estimates

Virtually all of the zinc tonnage data relating to Moundsville referred to the plant's design capacity. The Moundsville smelter complex originally was planned to operate four furnaces housing a total of 6,912 horizontal retorts and an adjacent sulfuric acid plant (U.S. Geological Survey, 1921, p. 868). However, upon completion in late-1917, the facility was considerably smaller, possessing 1,728 horizontal retorts in perhaps 3 furnaces (Roush, 1921) and a sulfuric acid plant. In 1920, the facility underwent an expansion to where the total capacity of horizontal retorts was increased to 2,368 contained in four furnaces with a goal to double design capacity to 50 short tons of zinc per day (18,000 short tons annualized) and increase acid production from the existing design capacity of 120 short tons per day (Roush, 1922; American Bureau of Mining Statistics, 1922–48). Based on the actual increase in the number of installed retorts, however, it does not appear that the full expansion goals were actually achieved (EMJ, 1920, Roush, 1922, 895). The facility reportedly had a design capacity to accommodate 1,728 retorts from 1918–20 and 2,368 retorts for the years 1921 through late-1945, except for 1940, when only 1,216 retorts were reportedly available (Roush, 1921; American Bureau of Mining Statistics, 1922–46), possibly as a result of a furnace failure or limitations in restart following its shut down for one-half year in 1939.

From 1921–45, the plant had a reported daily design capacity to distill 59 short tons of feedstock in 2,368 retorts

(American Bureau of Mining Statistics, 1922–46). An annual design capacity of nearly 11,000 short tons of zinc metal, or 4.5 tons of zinc per retort per year, could have been achieved assuming that the feedstock was 55 percent zinc, zinc recovery was 90 percent, and all 2,368 retorts were used 365 day per year.

It was estimated the Moundsville plant could have produced approximately 269,000 short tons of zinc if it had operated at design capacity for the years 1918–45. The estimate was based on the number of installed or available retorts and an average of 4.25 short tons of distilled zinc per year. If the Moundsville plant had a zinc refinery, it was assumed that its entire purpose was to upgrade impure zinc metal recovered from the distillation of zinc in retorts. Design capacity in zinc smelters was rarely achieved for any length of time owing to controllable and unanticipated factors. Plants generally operated at approximately 85 percent utilization of design capacity at full production. Factors that impacted achieving full design capacity included technical factors such as feedstock availability and quality, retort batch change-outs, scheduled furnace rebuilds, and furnace and retort failures. To delay maintenance and repairs would sacrifice zinc recovery. Based on actual data on closures and the number of retorts at the facility, an estimated average zinc content in feedstock charges to the retorts of 55 percent, a zinc recovery of 90 percent, an estimated design capacity of 4.25 short tons of zinc per retort/year, and a plant utilization rate of 85 percent; the average annual effective zinc metal capacity would have been roughly 8,000 short tons for a total of 222,000 short tons of zinc over the operations' production life. Effective capacity probably is an overestimate of actual production. Factors such as unanticipated technical problems, reactions to market conditions, labor issues, and other nontechnical occurrences and conditions can affect production. For example, zinc production at Moundsville may have been comparatively low in the years immediately following World War I and in the early 1930s, because of the country's depressed national economic conditions. On the contrary, the plant's output of zinc likely was at its highest levels of production during certain periods of high zinc demand, such as during World War II when world zinc production reached a historical high. As a whole, U.S. zinc production in 1931 was operating at less than 50 percent of primary zinc smelting design capacity, and during World War II was operating at about 90 percent of design capacity (American Bureau of Mining Statistics, 1934; 1947).

Zinc Production Estimates

The only annual zinc tonnage production statistic encountered during the literature search for the Moundsville plant was 6,000 short tons for 1945 when the plant closed in mid-year (Cotterill, 1950). Historical annual production data for Moundsville may not have been made available because the company was held privately and was not required to publish operational or financial data, or the company considered the information proprietary, or both.

It was estimated that approximately 183,000 short tons of zinc were produced over the life of the Moundsville plant using the assumptions that: (1) zinc production averaged about 65 percent of effective capacity during the early 1920s and the period 1929–1937 when the U.S. economy was in a slow-down; (2) zinc production was at or near effective capacity during the mid-late 1920s when the U.S. economy prospered; and (3) production was at or near effective capacity during World War II when zinc demand for use in material was at an historical high.

Sulfuric Acid Capacity and Production

Sulfuric acid as a byproduct of smelting sulfidic zinc feedstock became an important byproduct as its use in industry increased. The burning of additional sulfur was practiced at most zinc smelters that had acid plants. From 1918–20, the sulfuric acid plant at Moundsville had a design capacity to produce 50 short tons of 60 degree, 98 percent-pure sulfuric acid per day (Weed, 1920) or about 18,000 short tons per year from roasted ore, concentrates, and supplemental sulfur. To produce this amount of acid, approximately 18 tons of sulfur contained in pre-roasted feedstock and supplemental sulfur were required, or optimally the equivalent of nearly dead roasting 55 short tons of ore, or concentrate containing 32 percent sulfur with 90 percent overall recovery to sulfuric acid or both. It is likely that sulfur content in feedstock varied at time thereby requiring different amounts of supplemental sulfur to produce the optimum sulfur dioxide atmosphere for acid making.

The sulfuric acid facility's design capacity in 1921 was reported as 100 short tons (DeWolf and Larison, 1921) and 120 short tons (Engineering Mining Journal, 1920) of acid per day with the addition of a new roaster. At the plant's roasting design capacity of about 33,000 short tons per year of material assuming a grade of 32 percent sulfur and a sulfur recovery of approximately 90 percent, nearly 30,000 short tons of 98 percent pure 60° B. sulfuric acid could have been potentially produced from primary feedstock on an annual basis (82 short tons per day). Using these assumptions, excess capacity in the acid plant was potentially available to produce an additional 20–30 percent from burning supplemental sulfur.

Approximately 400,000 short tons of sulfuric acid, plus an additional 20 percent or more from supplemental sulfur burning could have been potentially produced at the plant's effective annual zinc capacity (470,000 short tons at design capacity) over the life of the property using the ratios and roughly 350,000 short tons of sulfuric acid, plus an additional 20 percent or more from sulfur burning may have been produced applying the assumptions used for calculating the total zinc production of 183,000 short tons stated earlier. The amount of sulfur used could be affected by markets for acid.

Technology

No detailed descriptions and only a few specifications related to the technologies employed at the facility were encountered in the literature search. Published accounts described the initial facility as having one Hegeler roaster, two coal producer gas-fired furnaces containing a total of 1,728 horizontal retorts, and a sulfuric acid plant (Weed, 1920). The addition of a 14-hearth Hegeler roaster and two furnaces, brought the total number of horizontal retorts to 2,368 in four furnaces; and a doubling of the sulfuric acid making plant capacity in 1921 to 100–120 short tons of 60° Baume', 98 percent sulfuric acid per day (U.S. Geological Survey, 1920; U.S. Geological Survey, 1921; Fairlie, 1936; American Bureau of Mining Statistics, 1922). The plant apparently remained largely unchanged for the balance of its operating life.

Zinc from Primary Feedstock

The general process of producing zinc metal from sulfidic feedstock was a multi-step process. Sulfidic ore and concentrate were blended and roasted in order to reduce the ore to mostly zinc oxide. The roaster gases, containing sulfur dioxide were directed to the acid plant. It is likely that the smelting facility also had a sintering plant to further reduce the cadmium, lead, and sulfur content of the calcine produced in the roaster prior to distillation in the retorts. Considering the time period it is likely that the dust, fumes, and gases generated by the sintering process were not recovered for most of the operation's life, or possibly only partially recovered with residues fed back to the retorts. Calcined or sintered feedstock was mixed with anthracite or coal and placed in horizontal retorts contained in furnaces and zinc vapor produced as the zinc oxide and carbon were heated. Zinc precipitated as a liquid on a condenser attached to each retort from which it was tapped by a ladle and poured into a mold. The retort residues may have contained up to 7 percent zinc, but 2–4 percent was more common. Sulfur content, in the form of sulfate, was approximate 1–2 percent depending on the effectiveness of roasting and sintering.

Zinc from Secondary Feedstock

In reviewing literature it was unclear if the operation also treated secondary zinc sources, including zinc dross. Reference to a refinery was encountered once in the researched literature (New York Times, 1919). The Clarksburg facility, which treated secondary material, was replaced by Moundsville and may have continued relying on some of the same feedstock sources. Dross (a zinc-iron alloy collected from the bottom of galvanizing pots that assays about 95 percent zinc) and skimmings, (a zinc oxide-rich crust that forms at the top of a galvanizing bath and contains from 65–85 percent zinc), along with other secondary material may have been refined at Moundsville (Ingalls, 1903). If there was a refinery, feedstock

was either distilled separately in dedicated retorts or refined through liquation.

Sulfuric Acid

The sulfuric acid plant was the first part of the original facility to begin operating (1914, U.S. Geological Survey, 1916, p. 955; U.S. Bureau of Mines, 1935, p. 13) in order to produce a stockpile of feedstock for the distillation plant. In 1921, the plant had a reported design capacity of 50 short tons of 60 degree sulfuric acid per day (Weed, 1920). In 1921 or 1922, the sulfuric acid plant's design capacity was expanded with the addition of a new roaster to between 100 and 120 short tons of 60 degree acid per day (Engineering Mining Journal, 1920; De Wolf and Larison, 1921). The plant generated sulfur dioxide by roasting zinc sulfide and other sulfur bearing minerals while at the same time reducing the feedstock to a calcine for sintering or as a direct feed to the retorts in the zinc distillation plant. In order to meet market specifications for sulfuric acid, dust and other deleterious materials needed to be removed. During the early years of the plant's operation this was best accomplished with dust settling chambers placed between the roaster's flue and the sulfuric acid plant. Electrostatic precipitators or scrubbers, or both may have been added in later years, but this information was not available. It is not known if all of the emissions generated by roasting feedstock were directed to the sulfuric acid plant. Like other zinc smelters, supplemental sulfur was burned to upgrade the sulfur content of the gases directed to the acid plant, because the sulfur dioxide content of the atmosphere directed to the acid plant was too low for efficient production of high strength sulfuric acid. It is not known if the sulfur was burned in separate units connected to the acid plant or in the dust collection chambers.

Zinc and Sulfur Emissions

Lawsuits by members of the agricultural community in Moundsville beginning between 1911 and 1919 were based on similar claims as those at the Meadowbrook smelter, also in West Virginia, alleging that excessive dust and smoke were destroying crops and other vegetation (Asturina-American Migration Forum, 2008). Atmospheric zinc and sulfur emissions produced at Moundsville were estimated at full design capacity, effective capacity, and production. Estimates considered that most of the roaster residues suspended or contained in gases were captured in settling chambers prior to the acid plant, and that most of the zinc contained in atmospheric emissions were generated during offloading, mixing, storing, and drying feedstock, preparation of charges for retorts, and from dust, fumes, and gases produced during retorting. Some zinc might have been recovered from accumulations in flues and plant surfaces and recycled back to the retorts, but the amount would have been relatively insignificant.

Atmospheric emissions containing sulfur originated from the same sources described above for zinc, with additional losses during sulfuric acid production.

Zinc Emissions

Based on discussions with industry specialists and publications, it was estimated that an amount of zinc equivalent to 4 to 5 percent of the calculated amount of zinc produced at each of the three zinc output estimates were emitted to the atmosphere. Zinc emissions at Moundsville were released as zinc in its elemental form and as a component of compounds comprising dust, fumes, and gases over the 28-year period that the plant operated. For that reason, emissions are expressed as zinc equivalents. At the estimated design capacity, atmospheric emissions expressed at zinc equivalents would have been approximately 13,000 short tons; at 85 percent capacity utilization, emissions would have been approximately 11,000 short tons; and at the estimated historical production, roughly 9,000 short tons of zinc contained in compounds were emitted to the atmosphere in dust, fumes, and gas over the 28-year period that the plant operated.

Sulfur Emissions

Most of the fugitive and stack losses of sulfur and materials containing sulfur occurred during the unloading, blending, and storage of feedstock, roasting, acid making, and retorting. Supplemental sulfur burning for producing sulfuric acid also contributed in some part to the facility's sulfidic emissions.

Actual data pertaining to sulfur emissions and detailed operational data helpful in estimating emissions were not available. For these reasons, estimates of sulfur contained in emissions generated by the Moundsville plant should be considered with caution. The amount of sulfur recovered and emitted depended on the feedstock storage method, type of roasters employed, and their efficiency at removing sulfur from the feedstock, effectiveness of gas cleaning, the type of acid plant, and the methods employed to minimize tail gas and mist and the type of retorts used for distillation.

The assumptions used to estimate atmospheric fugitive and stack emissions included (1) sulfur content of concentrates treated by the roaster was 32 percent sulfur; (2) loss of sulfur to fugitive and stack emissions was roughly 5 percent of the total contained in feed, plus some additional losses from the burning of supplemental sulfur; (3) the emissions were generated during drying of concentrate, roasting, retorting, supplemental sulfur burning, and acid making; (4) ninety percent of the sulfur originally contained in feed and burned was recovered in sulfuric acid, and the balance contained in retort waste, losses through leaching, waste water, and other non-atmospheric losses; (5) the acid plant did not have mist eliminators or other tail gas treatment; and (6) sulfur-burning contributed to acid production and atmospheric emissions to a lesser degree than primary feedstock.

Using these factors it was estimated that approximately 6,000 short tons of sulfur equivalents, were emitted to the

atmosphere at estimated production, 7,000 short tons at estimated effective capacity, and 8,000 short tons at estimated design capacity. Releases would have been in the form of sulfides from storage and drying ore and concentrate, and sulfur dioxide and sulfur trioxide from the gases in the acid plant, and sulfuric acid mist.

Emissions of Other Materials

Emission estimates for materials other than zinc and sulfur were not attempted because the amount of feedstock and assay values for materials contained in feedstock were not available. Considering that a significant portion of the primary feedstock treated at the smelter originated from the Tri-State Mining District, it is likely that emissions contained metals such as arsenic, cadmium, copper, and lead. See tables 3, 5, and 8 for sample assays of ores and concentrates produced in the Tri-State District.

The materials, contained in secondary feedstock, other than zinc, also included cadmium and lead but at much lower levels per unit of zinc recovered than primary zinc concentrates. Estimates of emissions for these metals were not attempted.

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Bertha Zinc Works, Pulaski, Pulaski County, Virginia

Introduction

Before 1880, ores mined in the Austinville-Pulaski, Va. area were sent to a small smelter at Petersburg, Va. and to a smelter at Providence, R.I. Locally mined ores were redirected to the Bertha plant upon the smelter's completion in 1880 (Watson, 1907).

The Bertha Mineral Company, formerly called the Bertha Zinc Company, was formed in 1879 and initiated production of zinc the following year (Pulaski County, 2007). The facility was remodeled and enlarged in 1886 (U.S. Geological Survey, 1887, p. 155; Higgins, 1905b).

The owners of the Bertha Zinc Works brought skilled zinc smelter workers from Wales, United Kingdom, to Pulaski County, in southwestern Virginia to operate the facility. Early in the operating life of the plant, the purity of the zinc metal produced at the plant ranked with the best made anywhere in the world, because of its high purity and guaranteed specifications. Zinc ores were mostly hemimorphite and smithsonite that contained little or no lead. Shipments of zinc metal were exported to other countries, including Russia (U.S. Geological Survey, 1888, p. 155). Until at least 1907, it was the only zinc smelter in the southern U.S. and was Pulaski's largest industry when it closed in 1910.

According to analyses performed by the U.S. Geological Survey, soils in the immediate vicinity of the zinc mines and smelter (now a state park) at Austinville, about 25 miles to the south, had elevated lead and zinc contents which was related directly to the mining and smelter processes (Foley, 2004). It is not known if this particular operation contributed to the anomalously high metal values.

It was estimated that approximately 67,000 short tons of zinc were produced and approximately 3,500 short tons of zinc were released to the atmosphere as fugitive and stack emissions during the 31 years that the plant operated.

Map Number (fig. 1)

17

Location

The plant site was situated in Pulaski, Va. at N37°02'52" (37.047778); W080°46'47" (-80.779722)

Alternate Names

Bertha Zinc Works (Harrison, 1886)
Pulaski Smelter (Ingalls, 1902)

Owners

1879–1902—Bertha Zinc Company and Wythe Mineral Company (Jolly, 1994) succeeded by the Bertha Zinc Mining and Smelting Company, Bertha Zinc Company, and Bertha Zinc and Mineral Company (Ingalls, 1902; Tami Ramsey, Pulaski historian, oral communication, 2009).

1902–1911—New Jersey Zinc Company–Bertha Division (Stone, 1916).

1902–1911—Bertha Mineral Company, a subsidiary of the New Jersey Zinc Company (State of Virginia, 1910).

Years of Operation

The construction of the smelting facility was initiated in 1879 and the first zinc metal, measuring 400 pounds, was poured on February 19, 1880 (U.S. Geological Survey, 1911, p. 283; Pulaski County, 2007). The smelter operated from the year 1880 through the year 1910. The plant was idle for most of 1886 as a railroad was constructed through the property. The use of the railway eliminated a 16-mile haul of coal, ore, and supplies by mule wagon (U.S. Geological Survey, 1887, p. 155). The plant was closed in January, 1911 and dismantled the same year (U.S. Geological Survey, 1912, p. 286; Watson, 1907).

Primary Products

In the earlier years of the facility, three zinc products, based on zinc purity were trademarked according to their relative purity of zinc. Bertha Pure Spelter, Old Dominion, and Southern brands of zinc metal were produced. The Bertha Pure Spelter was guaranteed at 99.981 percent zinc, with the balance of the "slab," 0.019 percent iron. The "Old Dominion" zinc exceeded 99 percent zinc with 0.2-0.4 percent lead, and the "Southern" brand contained about 99 percent zinc with 0.8-1 percent lead (Higgins, 1905b; Watson, 1907). The amount of each product produced at the operation is not known. In the early 1900s, ore contained a higher lead content and the trade mark brand names were apparently no longer applied to the product of the smelter.

Sources and Types of Feedstock

The smelter's feed before the turn of the 20th century originated from the Delton and Bertha mines in the Austinville area. The Delton Mine produced approximately 8,000 short tons of hemimorphite and smithsonite concentrate that assayed 40 percent zinc, 0.5 percent lead, and 5 percent iron from the time they opened in 1902 (Watson, 1905) through 1906 (Watson, 1907). The Bertha mines also were a source of feedstock to the plant. The beneficiation plant at the mine site produced a hemimorphite and smithsonite concentrate that assayed 38.08 percent zinc (47.61 percent zinc oxide), 29.37 percent silicon dioxide, 9.23 percent oxides of iron and alumina, 4.54 percent

calcium carbonate, 2.07 percent magnesium, and a trace of lead (Higgins, 1905). The Bertha mines were worked for hemimorphite and smithsonite from 1879 until 1898 (Watson, 1907).

Sphalerite, galena, and pyrite were encountered in the mines around 1900 as the mines began to exploit the limits of the alteration zones. Assays of the sphalerite mined in the area determined that it was of high purity, reportedly consisting of approximately 62 to 67 percent zinc, 32-34 percent sulfur, plus iron, silica, and lime, although lower grade ores were also extracted from the mines. An ore sample collected from one of the active mine workings assayed 32 percent zinc, 4.02 percent lead, 9.09 percent calcium, 1.88 percent iron and the balance described as insolubles, plus traces of arsenic and copper (Watson, 1907). Sulfur content was not stated. Although some of these ores were treated at the smelter at Palmerton, Pa and probably other smelters, there was no information encountered in the literature describing shipments of the sulfide ores and concentrates to the Pulaski plant.

Feedstock delivered to the Pulaski smelter changed character between 1902 and 1905 when the Lead Mine Tract, in the Austinville area, was purchased and further developed by the Bertha Mineral Company. The ore assayed 28-30 percent zinc and 8-10 percent lead. A lead concentrate produced from the ore was processed on the Austinville site in a Scotch furnace and a zinc concentrate, consisting of mostly smithsonite and hemimorphite, was sent to the Pulaski smelter. Metal values in the zinc concentrate assayed 44 percent zinc, 1.5 percent lead, and 5 percent iron. Previously, most ore concentrate contained considerably less lead. Zinc dust recovered from the flues of local iron furnaces was also treated in retorts at Pulaski. Some shipments of willemite from the Franklin-Sterling Hill, N.J., Mining District and smithsonite from mines in Tennessee also were treated around 1905 (U.S. Geological Survey, 1906, p. 381).

In 1906, feed to the plants was described as willemite from New Jersey, local zinc carbonate and silicate ores, zinc-rich flue dust from local iron furnaces, and zinc skimmings from galvanizer plants. No sulfide ores reportedly were being treated at that time (Watson, 1905; 1907).

Although tonnage amounts were not reported, an impure zinc oxide which reportedly contained approximately 70-80 percent zinc and 3 percent lead was produced in the Company's furnaces in Austinville, (U.S. Geological Survey, 1912, p. 287; Watson, 1907). The material was used in the Pulaski smelter as supplemental feedstock to produce zinc metal from 1905 to 1910, when the Pulaski smelter closed (Higgins, 1905b). The zinc oxide was produced from hemimorphite and smithsonite mined in the Austinville District (Foley, 2004; Watson, 1907).

Zinc Plant Capacity and Production History

Data pertaining to capacity and production history at the Pulaski Smelter were scarce. In 1880, the first year of production, the plant operated 2 furnaces each containing 140 retorts.

The two furnaces were described as having an "average daily average capacity" of about 2 short tons of zinc (Boyd, 1881). In 1886, existing furnaces were remodeled and enlarged, and two new furnaces became operational, bringing the total to 4 furnaces (U.S. Geological Survey 1887, p. 155; Bertha Zinc Company, 1888). Six more furnaces were added in 1887, bringing the total number of installed furnaces to 10 resulting in a total annual capacity of 3,000 short tons of zinc (U.S. Geological Survey, 1888, p. 155). In 1888, annual zinc metal production capacity was stated in a company report as 3,700 short tons (Bertha Zinc and Mineral Company, 1888). In 1905, the facility was described by Higgins as having 10 furnaces, each with 140 retorts, and each furnace possessing the capacity to produce from 1,800 to 3,000 pounds of zinc every 24 hours, depending on the grade and type of feed (Higgins, 1905b). In 1905, Higgins also reported that the furnaces' average yield was 20,000 pounds of zinc every 24 hours or 1 short ton of zinc/furnace/day with recovery of the zinc in the charge estimated at 85-90 percent (Higgins, 1905b) for an annual capacity approaching 3,700 short tons of zinc metal per year. In 1906, production capacity ranged from 1,800 pounds to 3,000 pounds of metal per day per furnace, depending on the type and grade of material being treated (Watson, 1905, p. 144). The higher production amounts likely resulted when a higher proportion of zinc scrap, skimmings, or higher grade ores, or both, or concentrates were treated in the retorts and the lower estimates when lower grade material predominated. In 1907, the plant was described as possessing the capacity to produce 10 short tons of zinc every 24 hours (Watson, 1907) or about 3,650 short tons per year. It was assumed that the terms "average yield" and "capacity" used by Higgins and Watson in their description of the property, was equivalent to design capacity. Actual production, however, was usually lower as it is affected by availability of feed, economic conditions, labor and technical factors, internal company decisions, and external events.

For 1906-10, statistical data published by the U.S. Geological Survey (U.S. Geological Survey, 1908, p. 247; 1911; p. 208) listed zinc metal production for Virginia as 1,143 short tons in 1906; 771 short tons in 1907, 910 short tons in 1908, and 58 short tons in 1909. These statistics were attributed to the Pulaski smelter for this study because it was the only operating zinc smelter in the State during the time period. The amounts were well short of the production capacity of the plant. Tonnages probably decreased in the last few years of the plant's operation as the remaining reserves of oxide ore, a source of feed from Austinville, Va., became scarce, and increasing amounts of ore from New Jersey were sent to Palmerton, Pa., as its capacity was expanding.

Annual production estimates were developed for 1880-1905 because actual production data was not available. In 1880, when 2 furnaces were operating and the plant was undergoing trials it was estimated that zinc production totaled 500 short tons, or less. For 1881-85 it was estimated that the plant produced about 600 short tons of zinc each year based on two furnaces available 85 percent of the time with a

combined annual design capacity of 730 short tons. In 1886, production was estimated at 500 short tons although the plant had 4 furnaces because the plant was idled for about 7 months owing to construction of a railroad through the property (U.S. Geological Survey, 1887, p. 155). For the years 1887–1905, it was assumed that annual zinc production averaged 3,000 short tons of zinc per year, when plant design capacity was approximately 3,700 short tons using all ten furnaces. It was assumed that production in 1910, the last year of production, was 50 short tons of zinc following a published statistic for 1909 of 58 short tons.

Based on the combined estimates and published statistical data, the total zinc metal production over the life of the Pulaski smelter was estimated at 67,000 short tons.

Lead

Based on descriptions of the plant's zinc product, lead content increased in later years as the amount of lead contained in ore feedstock increased (U.S. Geological Survey, 1888, p. 155; Higgins, 1905a; Higgins, 1905a; p. 658; U.S. Geological Survey, 1912, p. 287). Lead was virtually absent in the early years of the smelter, but by the early 1900s the lead content in the ore feed generally varied from a trace amount to about 3 percent (Higgins, 1905b). The lead remained in retort residues; with the balance fumes during the distilling process, contained in blue powder, or contained in the plant's zinc product. Data were insufficient to determine how much lead was contained in each of these.

Technology

In the early 1900s, the plant had grown from the original 2 furnaces in 1880 to 10 smelting furnaces, a pottery plant for manufacturing horizontal retorts, and a roasting furnace which was installed to dry feed, not for reducing ore. Carbonate and sulfide ores may have been roasted at the facility because the facility was equipped with a roaster. Producer gas was generated by coal burning. Pulaski's Welsh-Belgian furnaces were arranged in five blocks, each containing 2 furnaces at the peak of the operation. Each furnace had 140 horizontally oriented retorts for a total of 1,400 retorts (Higgins 1905b). Welsh-Belgian furnaces were essentially the same as Belgian furnaces (Ingalls, 1903; p. 311). Ingalls estimated that 1,950–2,000 pounds of zinc metal per year were recovered from a furnace charge of 4.25 short tons of ore (consisting of approximately 38 percent zinc in hemimorphite) and 3 short tons of coal. Ingalls also estimated zinc recovery at 80 percent with additional zinc recovered as blue powder in the flues (Ingalls, 1903; p. 652). The retorts used in the furnaces had a relatively low failure rate (Watson, 1905; p. 145), but also were quite porous which permitted losses of metal by absorption and filtration through the material (Ingalls, 1903).

Higgins estimated that the charge to the furnaces was generally one third coal and coke and two third zinc ore

(Higgins, 1905b). Additional feed for zinc production in the early 1900s, and perhaps later, consisted of a mix of impure zinc oxide produced at the Bertha, Va., plant (70–80 percent zinc), willemite from N.J., and zinc flue-dust from local iron furnaces. Zinc skimmings purchased from galvanizers were treated in a separate set of retorts, but were first placed in a roaster in order to remove ammonia and chlorine. The ammonia and chlorine were introduced as a flux (zinc ammonium chloride) in order to prepare iron for galvanizing. The charges contained in the horizontal retorts were furnace for 24 hours, and zinc metal was tapped from the condensers every eight hours (Watson, 1907) and poured into moulds to produce slab zinc.

As previously mentioned a roaster was constructed on the site between 1900 and 1905 and was described as a "test" plant for the treatment of mixed of sulfide and carbonate ores and concentrates from Arkansas and Tennessee (Higgins, 1905b; Watson, 1905), however no production from the plant was reported. Figures 44–46 are photographs of a furnace containing horizontal retorts and the major facilities that comprised the plant at Pulaski during the early 1900s.

Energy Source and Types

In 1880, the Bertha Mineral Facilities Company built a narrow gauge steam railroad known as the Altoona Railroad from Pulaski to Altoona which was used to transport the anthracitic and bituminous coal from mines about 10 miles away. The fuels were used for reduction in the retorts (Ingalls, 1902) and for manufacturing producer gas. The furnaces were fueled by run-of-mine coal from the Merrimac Seam, about 75 miles distant (Ingalls, 1902; Pulaski County, 2007).

Zinc Emissions

No zinc emission data or soil testing related to the Pulaski smelter has been published. According to analyses performed by the U.S. Geological Survey, soils in the vicinity of the zinc mines and smelter (now a state park) at Austinville, about 25 miles to the south, had elevated lead and zinc contents which were related directly to historical mining and smelter activities (Foley, 2004). It is not known, however, if the anomalous metal values have been, or can be, attributed in part to this particular operation. It is apparent from figures 45 and 46 that the plant did produce emissions to the atmosphere when the photograph was taken.

During the period that the Pulaski Smelter operated, approximately 5 percent of the amount of zinc produced, or approximately 3,500 short tons of zinc may have been emitted to the atmosphere as a component of fugitive and stack emissions in the form of dust, fumes, and gas generated during the unloading and drying of feedstock, charge preparation, through fractures in and breakage of retorts, and migration through retort material and escape of during pre-heating and tapping, and during emptying and cleaning of retorts. Losses

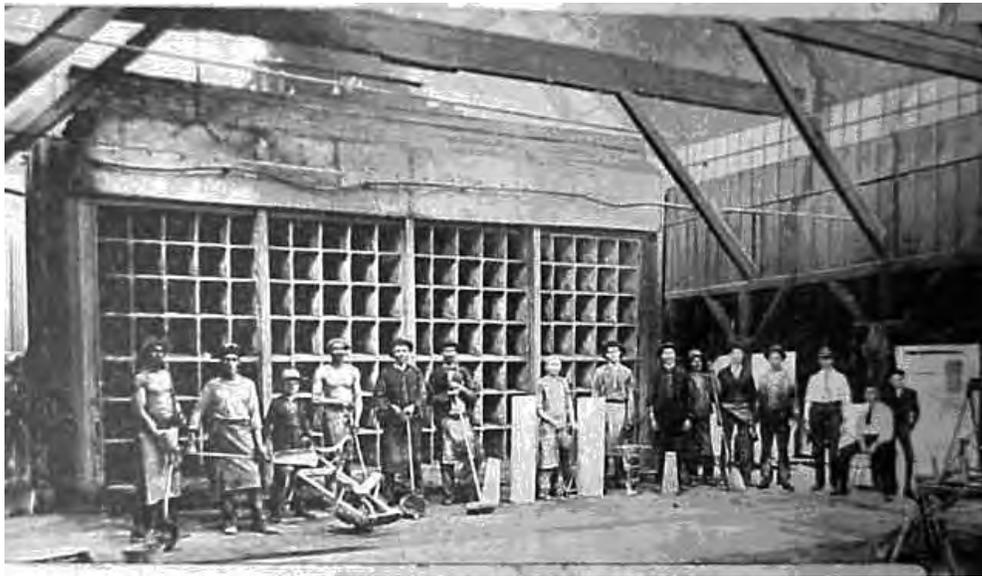


Figure 44. 1908 photograph of a horizontal retort furnace at the Bertha Zinc Works, in Pulaski, Virginia. Note the upright retorts (cylinders) and condensers (cones) in the foreground, the openings in the furnace accommodate seven rows of retorts, and the conduit leading to the stack at the top of the furnace for venting combustion gas. (Photograph provided courtesy of Tami Ramsey, Pulaski Historian, 2009.)

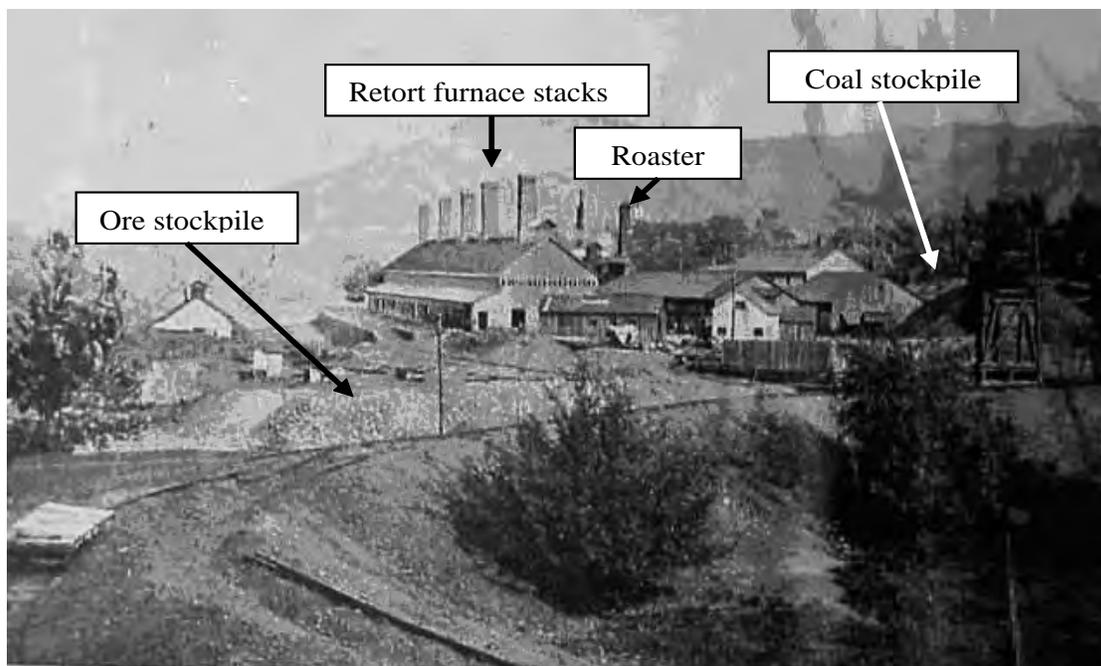


Figure 45. Photograph of the Bertha Zinc Works in Pulaski, Virginia taken in 1908. Note the retort furnace building with 5 stacks for the ten furnaces containing horizontal retorts, roaster, stockpiles of ore along the narrow-gauge rail tracks, and stockpile of coal on the right. The facility was also equipped with a small zinc refinery and a pottery plant for manufacturing retorts. (Modified from a photograph provided courtesy of Tami Ramsey, Pulaski Historian, 2009.)



Figure 46. Panoramic view of the Bertha Zinc Works in Pulaski, Virginia as it appeared in the year 1908. Despite the grainy nature of the photograph, the long furnace building and its furnace stacks, partly obscured by plant emissions, are visible. (Photograph provided courtesy of Tami Ramsey, Pulaski Historian, 2009.)

were less than some of the contemporary plants because ore was not roasted, retort breakage was relatively low, and intermediate zinc products, such as zinc oxide, skimmings, and other materials comprised part of the feedstock. Some portion of the accumulations of zinc-containing material also could have been recovered and fed to the plant when accumulations were sufficient to justify the activity.

Other Components of Atmospheric Emissions

Emissions to the atmosphere produced in the processes required to produce zinc metal would have included ammonia and chlorine released through the process of roasting dross and some lead generated during the last 8-10 years of the operation as the mix of feed changed from one of no- or low lead to sources of feedstock containing lead. Data were insufficient to develop an estimate of the amount of lead contained in the feedstock or emitted to the atmosphere during the processing of feedstock to product.

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Meadowbrook Zinc Smelter (Spelter Zinc Works), Harrison County, Spelter, West Virginia

Introduction

The Grasselli Chemical Company commenced operation of the Meadowbrook smelter, also frequently referred to the Spelter smelter or Spelter Zinc Works, in 1911. The plant produced zinc metal, zinc anodes and dust, and byproduct cadmium, lead and relatively minor amounts of base-metal alloys. By 1915, the plant was the largest capacity zinc metal smelter in the United States (Morrison, 1964).

The plant temporarily closed in 1971, but reopened in 1972, when ownership of the plant was conveyed to the Meadowbrook Corporation, an entity of T.L. Diamond in 1972. The plant treated secondary material exclusively from 1972 until the plant permanently shut down in 2001. The evaluation includes only the time period when primary zinc sources constituted the majority of the plant's feedstock. For that reason plant production and emissions were not estimated post-1971. Calcine and sinter constituted the majority of its primary zinc feedstock, and dross represented the majority of the plant's secondary-sourced feedstock.

Elevated levels of arsenic, cadmium, lead, and zinc contained in soils and groundwater in proximity to the plant have been attributed to atmospheric emissions generated by the Meadowbrook zinc plant (Sperduto and others 2003; Circuit Court of Harrison County, West Virginia, 2008). These elements were contained in primary zinc and secondary zinc feedstock purchased from domestic and foreign sources. In 2008, these findings and other evidence resulted in a jury verdict against DuPont, the defendant, in the amount of approximately 382 million dollars for the clean-up, medical monitoring of residents, and punitive damages. DuPont is planning to appeal the judgment (Smith, 2008). In 2001, the Meadowbrook zinc smelter site's remediation was being handled under an U.S. Environmental Protection Agency Superfund Removal Order with the State of West Virginia (U.S. Environmental Protection Agency, 2006). DuPont demolished factory buildings and capped the waste pile with plastic and top soil (Huber, 2008).

Based on available capacity, production, and technical data it was estimated that the operation produced approximately 2 million short tons of zinc products, mostly as slab and dust, over the facility's 61-year life. In the course of the plant's production it also was estimated that 60,000 to 80,000 short tons of zinc, plus other metals were emitted to the atmosphere as fugitive and stack emissions during the period the plant produced zinc primarily from primary zinc sources.

Map Number (fig. 1)

18

Alternate Names

Meadowbrook Plant—(Asturina-American Migration Forum, 2008; Morrison, 1964; U.S. Geological Survey, 1911, p. 284).

Spelter Zinc Works—(Asturina-American Migration Forum, 2008).

Spelter Plant (Asturina-American Migration Forum, 2008).

Location

The plant was located in Spelter, West Virginia along the banks of the West Fork River at N39°20'54" (39.348349); W080°18'59" (-80.316375) which is about 5.5 miles (nine km) north of Clarksburg, W. Va.

Years of Operation

1911–71 (Asturina-American Migration Forum, 2008, U.S. Geological Survey 1910, p. 284; 1911, p. 284; 375; U.S. Bureau of Mines, 1971, p. 1,258; Morrison, 1964; E.I. Dupont, unpublished date).

Owners/Operators

1910–28—Grasselli Chemical Company (Grasselli) (Morrison, 1964; Circuit Court of Harrison County, West Virginia, 2006).

1928–50—E. I. DuPont de Nemours and Co. (DuPont) (Morrison, 1964; Circuit Court of Harrison County, West Virginia, 2006). DuPont purchased the Grasselli Chemical Company in 1928 (Chemical Expansion: 1928 at http://heritage.dupont.com/touchpoints/tp_1928-3/overview.shtml).

1950–61—Meadowbrook Corporation, a subsidiary of the Matheson and Hegeler Zinc Company (Morrison, 1964; Circuit Court of Harrison County, West Virginia, 2006).

1961–72—Matthiessen and Hegeler Zinc Company, Inc., (M&H) - (Morrison, 1964; Circuit Court of Harrison County, West Virginia, 2006).

1972–2001—T.L. Diamond Company, Inc., (Asturina-American Migration Forum, 2008; Circuit Court of Harrison County, West Virginia, 2006; U.S. Bureau of Mines, 1971).

—**current**—E.I. DuPont de Nemours and Company (Circuit Court of Harrison County, West Virginia, 2006).

Products

The smelter's primary product, by weight and value, at the smelter was slab zinc (termed spelter in the early years of the operation), with lesser amounts of zinc anodes and battery plates, and zinc dust (1920s–71) and zinc powder (1930–71). Other product included cadmium anodes (1937–38), cadmium alloys of copper (1934–36), lead (1942–50), and zinc (1939–43), lead anodes (1942–50), sodium-lead alloys (1937 to at least 1958), and sodium zinc (1934 until at least 1958)

(Cotterill, 1950; Morrison, 1964; Circuit Court of Harrison County, West Virginia, 2006). Production of these products may have resumed or new products produced after 1964. For example, it is not known if a plan developed in the early 1960s to recover cadmium metal was actually placed in operation (Morrison, 1964).

Sources and Types of Primary and Secondary Feedstock

The Meadowbrook plant treated various types of feedstock from diverse sources over its production life. Although primary feedstock included nonsulfidic zinc carbonate ores, such as smithsonite, and minor amounts of hemimorphite, a zinc silicate ore, the largest tonnage of feedstock consisted of calcined and sintered sphaleritic ores and concentrates. These were used for the charges distilled in the horizontal and vertical retorts.

Secondary feedstock consisted for the most part of flue dust, cuttings and scrap, drosses, skimmings, and slab zinc. These materials were primarily used for producing zinc dust, while relatively minor amounts were also used as feedstock for producing slab zinc in the retorts.

Primary Zinc Feedstock

Comprehensive information on all of the sources, tonnages, types, chemistry of feed, and the years that material was received from suppliers by the Meadowbrook smelter were not published. Data was available for a limited number of years, mostly from company reports for the early to mid-1940s and from 1969 through early-1971. These data were adequate to provide some understanding of the amounts, nature, and origins of feedstock from primary sources.

Domestic Shipments of Ores and Concentrates

The U.S. Bureau of Mines and the U.S. Geological Survey reported that from the time the Meadowbrook smelter opened (1911) through the 1930s and at least through the 1940s the facility received "roasted concentrates" from Grasselli roasters (which produced byproduct sulfuric acid from the sulfur recovered from the company's roasters) located in Grasselli, Indiana; Canton, Cleveland, Lockland, and Niles, Ohio; and New Castle, Pennsylvania (U.S. Geological Survey, 1911, p. 286; 1914, p. 644; 1916; 1929; 1930-31; 1933; U.S. Bureau of Mines: 935; written commun., 941; Roush, 1916). In the 1940s, part of Meadowbrook's supply of calcine originated as sphalerite ores and concentrates from the Tri-State District and from Wisconsin, and southern Illinois (U.S. Bureau of Mines, 1941, p. 265). Roasting plants in Illinois and other states roasted the material prior to treatment at Meadowbrook. Roasted zinc sulfide concentrates generally contained less than 2 percent sulfur.

The Meadowbrook also received carbonate ores from the region. In 1944, the plant received three train cars of

smithsonite concentrates from the Granby mill in Mo. which originated from ore mined in southwestern Missouri (U.S. Bureau of Mines, 1946, p. 296), and may have represented part of a multi-year contract.

In 1942, the facility treated smithsonite ores or concentrates from the Austinville Mine, Va., and less than 1,000 short tons of smithsonite ore from the Little Wythe mine near Cripple Creek, also in Wythe County, Virginia (U.S. Bureau of Mines, 1942; Cotterill, 1950).

Several mines in Tennessee likely supplied the Meadowbrook smelter with ore and concentrates for many years, but statistical data are unavailable for all but a few years. The New Market Mine located in the Jefferson City Mining District of Tenn., owned by Grasselli, opened in 1937 (U.S. Bureau of Mines, 1939) and was a major supplier of feedstock to the plant in the 1940s. In the 1940s, the Meadowbrook smelter annually purchased about 20,000 short tons of smithsonite concentrate for at least several consecutive years containing about 10,000 short tons of recoverable zinc from the New Market Mine in Tenn.

During this period, the New Market mine was the largest single supplier of feed to the plant (Purdue, 1914). It is likely that mining operations in Tennessee played a role as a supplier of direct feed to the Meadowbrook smelter as early as 1911 since smithsonite and hemimorphite comprised a large portion of the Jefferson City Mining District's early production. Some of the mines were owned by Grasselli (Purdue, 1912) and produced direct-shipping ore as feedstock for the Meadowbrook plant. The Embree Iron Company operated the Embree mine at Bumpass Cove, TN (U.S. Bureau of Mines, 1945). The mine initiated production in the early 1900s and produced direct shipping ore and concentrate consisting of mostly smithsonite. Company reports show that the mine supplied the Meadowbrook plant with shipments of primary zinc ore that assayed about 40 percent zinc, with higher grades in concentrates produced by jigging. The Embree Iron Company supplied smithsonite to the Meadowbrook plant in 1941, and in 1942 approximately 1,000 short tons of smithsonite concentrate was purchased.

The Consolidated Copper Mines Co.'s Kimberly mine in NV, which opened in the early 1900s (U.S. Geological Survey, 1921), shipped a small amount of zinc concentrate in 1942 and 1943 containing at total of roughly 500 short tons of zinc (Internal Company report). It is not known if the ore was sphalerite and pre-roasted on site or offsite or was direct shipping zinc oxide, since in the early years of the operation both types of ores existed at Kimberly.

International Purchases of Ores and Concentrates

Global trade patterns of mineral concentrates during World War I and World War II were altered dramatically. Hostilities placed transoceanic shipments at high risk, and the structure of international relationships changed affecting trade contracts. During wartime some ores and concentrates that previously were sent to Asia or Europe were processed in the

United States. These patterns changed again following the end of the world conflicts.

No information relating to purchases of feedstock from other countries prior to 1941 was found in the literature, but it is likely that some was purchased. Partial information relating to purchases during and after World War II was discovered in company records. For example, ore and concentrate were purchased from the Atacocha and Huaron mines in Peru in the early through the mid-1940s. In 1942 and 1943, the Peruvian exports totaled approximately 1,500 short tons per month. Metal values for the minor metals varied from one shipment to another but were generally about 59 percent zinc, 32 percent sulfur, 1 percent lead, 0.36 percent cadmium, 0.07 percent arsenic, 5 ounces of silver per short ton, and some gold. The feedstock was roasted and perhaps sintered before treatment at Meadowbrook, possibly in Peru; but was more likely roasted at one of Grasselli's plants in the United States.

Zinc operations in Canada appear to have been a significant contributor of primary feedstock to the Meadowbrook plant from at least the early 1940s until the plant's closure in 1971. Most of the primary zinc feedstock from Canada was purchased in the form of calcine or sinter, or as concentrate and shipped to one of Grasselli's roaster plants in the United States for conversion to calcine or sinter or both prior to arrival at Meadowbrook.

In 1941, DuPont signed a contract to purchase zinc concentrates from the Lake Geneva Mining Company Ltd.'s zinc-lead operation at Lake Geneva, Ontario at the rate of about 650 short tons per month. The sphalerite concentrate assayed 58 percent zinc and was shipped to DuPont's New Castle Pa. plant for roasting prior to shipment to Meadowbrook.

In the early to mid-1940s feed was purchased from Noranda's Waite-Amulet mining operation, which operated from 1928–61 (Xstrata, 2007) and Normetal Mining Corporation's Normetal mine, which operated from 1938 to 1975 (Cigitore Resources Inc. 2007). Both mines were located near Quebec, Canada. Concentrates from the Normetal mine contained 52 percent zinc, 1.29 percent copper, 0.23 percent lead, 32.9 percent sulfur, 0.16 percent cadmium, 0.04 percent arsenic, and 0.005 percent fluorine. Approximately 6,000 short tons of concentrate per year was calcined and/or sintered prior to smelting at Meadowbrook.

Prior to calcining Waite-Amulet concentrate assayed about 55 percent zinc, 32 percent sulfur, 0.05–0.2 percent lead, 0.1 percent cadmium, 0.01–0.05 percent arsenic and 1 ounce per short ton silver. In the early-1940s, concentrate shipments ranged from 2,000–6,000 short tons annually.

In 1968, the Meadowbrook received roasted sulfide concentrate from Canada, but specific tonnages and mines and plants from where the material originated were not stated (Domestic U.S. Bureau of Mines, 1968, *Volume III* (1970), p. 800), but it was likely the same sources reported in 1969 and 1970.

In 1969 and 1970, the Meadowbrook received shipments of roughly 4,000 short tons of calcine per month from the Sherbrooke Metallurgical Company, (Sherbrooke) located

in Quebec, Canada. The calcine produced by Sherbrooke's roaster varied based on the mix of ores and concentrates the plant roasted, but generally assayed approximately 61 percent zinc, 1 percent sulfur, 0.15 percent cadmium, and 0.12 percent lead. The amounts and assays may not be representative of other years. The sphalerite ore and concentrate for the roaster originated from the Jamieson, Kidd Creek, and Willroy mines in Ontario and the Normetal, Mattagami, and Quemont mines in Quebec. Although data concerning feed from Sherbrooke were limited to 1969 and 1970, it is likely that a portion of Meadowbrook's feedstock also originated from the plant in other years.

Secondary Zinc Feedstock

Secondary feedstock was a minor component used in producing slab zinc in the retorts. Secondary materials included dross, flue dust collected at iron foundries, and to a much lesser extent scrap zinc, including shavings left over from manufacturing, and other materials. It is unlikely that the contribution of secondary sources to the plant's total annual zinc slab production ever exceeded 5 percent.

In the 1940s, several thousand tons a year of flue dust were treated at Meadowbrook. In 1943, shipments of flue dust totaling about 2,100 short tons were purchased from the Embree Iron Company in Tennessee that assayed approximately 26.77 percent zinc, 1.88 percent lead, and 7.18 percent iron at the rate of between 100 and 400 tons/month in trains (E.I. DuPont, unpublished data, July 27, 1943, August 11, 1943).

In 1957, dross (ranging from 85-95 percent zinc) represented the largest source of secondary feed to the plant for the manufacture of slab zinc. Approximately 700 short tons of zinc was contained in the material and represented about 2 percent of the zinc contained in the plant's total production and represented more than 80 percent of the total zinc contained in feed from secondary sources in that year used for slab zinc. In 1968, the Meadowbrook received some zinc dross from Canada, but tonnages and the plants from where the material originated were not stated. Zinc dross contains about 95 percent zinc and zinc skimmings from 65-85 percent zinc.

In 1930, 10 furnaces were constructed for the purpose of distilling zinc dross to produce zinc powder. Two more furnaces were added in 1948. Dross, a zinc-iron alloy collected from the bottom of galvanizing pots assayed about 95 percent zinc (Ingalls, 1903). Varying amounts of aluminum, cadmium, iron, and lead made up most of the remaining 5 percent (Rothwell, 1902; Ingalls, 1903). In later years, skimmings, a zinc oxide-rich crust that forms at the top of galvanizing baths, containing from 65-85 percent zinc, and other secondary zinc-based materials including scrap were likely also used, but as a relatively minor component.

Prime Western Grade slab zinc, although not a secondary zinc product, was also used in the process, but dross continued to dominate as the main feedstock (E.I. DuPont, unpublished data). Sources of dross included the domestic and to a lesser

degree the Canadian steel industry (*Domestic U.S. Bureau of Mines, 1968, Volume III* (1970), p. 800).

Only limited historical data on specific sources of slab zinc were available. In the early 1950s, slab was purchased from the National Matthiessen and Hegeler Zinc Company (M&H) of Illinois. M&H and the Virginia Zinc and Chemical Company, two long-term established companies, were the sole identified sources of slab zinc reported in internal company records for the years 1969 up to the plant's closure in 1971 (E.I. DuPont, unpublished data). In 1957, except for relatively small amounts of crucible residues (78 percent zinc) and retorts crusts (40 percent zinc), dross (95 percent zinc) represented nearly 95 percent of the feedstock for the company's zinc dust production of about 4,200 short tons. In 1969, approximately 5,000 tons of dross and 1,000 short tons of M&H slab zinc were consumed for the production of approximately 5,300 tons of zinc dust. Prime Western zinc from M&H generally assayed about 95 percent zinc, with the balance containing cadmium, iron, lead, and traces of other metals.

Capacity and Production History

Only a few references to actual zinc production and capacity statistics were discovered in published literature. However, published data by the U.S. Bureau of Mines and U.S. Geological Survey, primarily in *Mineral Resources of the United States* and *Mineral Yearbooks*, does refer to the number of installed horizontal retorts, vertical retorts, and some other details on the facility for many of the years the plant operated. Production estimates were made for those years using the published retort statistics coupled with estimated furnace capacities and capacity utilization. E.I. DuPont, unpublished data, internal-company documents reported specific operational details for some years or range of years. The reports contained data on annual and monthly production of slab zinc, zinc dust, and zinc anodes (Morrison, 1964; DuPont, unpublished data, monthly and annual reports).

Production estimates were adjusted for curtailed zinc production resulting from factors such as technical parameters, nationwide economic downturns (for example the early 1920s and the Great Depression), known labor disputes, and the partial year of production when the facility shut down at the end of the first quarter of 1971 (U.S. Bureau of Mines, 1971). Labor disputes at the smelter forced plant closure for 10 days in 1913, 75 days in 1919 and 87 days in 1920 (Morrison, 1964). About one-half year of plant production was lost in 1949 because of regional coal strikes (U.S. Bureau of Mines, 1949 p. 276). Taken together these data provided sufficient information to estimate historical zinc production for the years 1911-71. Estimates for other metals and alloys recovered at the facility were not made owing to the lack of statistical and technical data.

It is estimated that nearly 2 million short tons of zinc in slab, dust, and anode were produced over the life of the facility. In some years, zinc oxide and mixed-metal products containing zinc were produced, but capacity or production

data were not available. The gross production of these materials was not considered.

It was reported in a West Virginian court document that by the time the smelter closed down on July 3, 1971, that the total gross production amounted to "more than four billion pounds of slab zinc, 400 million pounds of zinc dust, 100 million pounds of anodes, and 50 million pounds of other alloys most of which contained zinc (In the Circuit Court of Harrison County, West Virginia, 2006). No data supporting the published estimates were provided. It is not known if the anode production was limited to zinc anodes or also included other anodes, some of which likely contained zinc. Also, a portion of the plant's zinc dust and anode production may have been generated from slab zinc poured at the plant. For purposes of comparison the combined reported gross production of slab, dust, and anodes was 2.25 million short tons reported to the court ((In the Circuit Court of Harrison County, West Virginia, 2006); about 12 percent higher than the USGS estimate of zinc production at the facility.

Zinc Production - Horizontal Retorts

No actual zinc production statistics were available for the period the plant operated horizontal retorts. Therefore, annual zinc production estimates were based on the reported number of installed retorts, average retort capacity of 4.7 short tons of zinc produced per annum, and an 85 percent utilization factor, a generally accepted industry standard for the time period. The relatively high retort capacity estimate reflects the high-quality feedstock used and advances in technology that took place during the 1920s. As mentioned earlier, adjustments in annual production were made to account for interruptions in production caused by labor strikes and during periods of national economic downturns. Total production of zinc for the years the horizontal retorts operated, from 1911 through 1930, was estimated at 610,000 short tons, an average of 30,500 short tons of slab zinc per year. The last building used to house the furnaces containing horizontal retorts was dismantled in 1941 (Morrison, 1964).

Zinc Production - Vertical Retorts

Production using vertical retorts at the Meadowbrook plant was initiated in 1931 following the shut down of furnaces using horizontal retorts in 1930. From 1931 through 1950, the facility produced slab zinc and other zinc products using 16 vertical retorts. In 1944, the plant had a reported design capacity of 22,000 short tons of slab zinc per year (Cotterill, 1950, p. 26), or approximately 1,400 short tons of zinc per retort annually. Assuming a utilization rate of about 90 percent (vertical retorts are generally more efficient than horizontal retorts); estimated annual production capacity was approximately 20,000 short tons per year—the same value as the production reported in 1945 (Cotterill, 1950, p. 26). About one-half year production was lost in 1949 because of regional coal strikes (U.S. Bureau of Mines, 1949, p. 1276).

A new vertical retort was added in 1951, followed by the construction and operation of another in 1952, which increased the total number of retorts to 18. A phased enlargement to increase plant capacity and efficiency of the vertical retorts started in 1959 and continued through 1964. From 1966 to 1970 the facility's annual slab zinc capacity was stated to be 48,000 short tons (McMahon and others, 1974, p. 57, table 14), but it is unclear if the estimate pertains to slab zinc or all zinc products. Considering 90 percent utilization efficiency, annual effective production capacity was estimated at 43,000 short tons per year for the same time period. This estimate compares favorably to the reported 1970 production of 41,000 st of slab zinc and dust by the USBM (U.S. Bureau of Mines, 1971, p. 1245). Internal company plant production records for 1970 state that approximately 41,250 short tons of zinc, made up of 34,000 short tons of slab zinc from vertical retorts, 6,400 short tons of zinc dust, and 850 short tons of zinc anode were produced. Production of slab zinc from vertical retorts for the years 1931 to early 1971, when the plant closed, was estimated at 1.1 million short tons; an annual average of 27,500 short tons.

Zinc Anodes and Zinc Dust

Zinc anodes and zinc dust also were produced at the Meadowbrook plant. Production estimates were derived primarily from a limited number of internal company annual and monthly operating reports. From 1927 through 1971, it was estimated that approximately 45,000 short tons of zinc was produced as zinc anodes. For the years 1930 through early 1971, when the plant was shut down, a total of approximately 210,000 tons of zinc dust may have been produced. Combined, approximately 255,000 short tons of zinc anodes and powder were produced, or 15 percent of the total amount of slab zinc produced over the life of the operation.

Technology

Only general information on the technologies employed at the Meadowbrook plant was available. The Meadowbrook plant did not employ an onsite roaster at any time in its production history. Instead, it relied mostly on nonsulfidic ores and concentrates, zinc calcine and sintered feedstock containing about 60 percent zinc previously processed to about 1-2 percent sulfur; and secondary zinc-based materials such as dross, scrap, and skimmings which generally contained more than 85 percent zinc with essentially no sulfur. Figure 47 is an aerial view of the Meadowbrook plant with the major facilities labeled taken in the 1950s while the plant was in operation, and after it had switched from employing horizontal to using vertical retorts to recover zinc. The emissions were most likely generated during the sintering process.

Slab Zinc

Slab zinc was the primary product at Meadowbrook over the 61-year life of the operation. Horizontal retorts were used for this purpose in the first 20 years of the operation and vertical retorts for the remaining 41 years. During this entire period, essentially all of the slab zinc was produced from primary zinc feedstock. Calcine was the major feedstock to the horizontal retorts and sintered calcine the major feed type to the vertical retorts.

Horizontal Retorts

The plant was constructed in 1910 and began operating in 1911 employing conventional horizontal retort technology for the purpose of producing spelter (slab zinc) as its primary product. The plant initially consisted of eight-externally-heated furnaces, each of which contained 570 horizontal fire-clay retorts that were probably about 5 feet in length with an outside diameter of about 12 inches. By 1915, the 20 furnaces at the Meadowbrook zinc smelter contained a total of 8,592 retorts and was the largest horizontal retort facility in the United States (Weed, 1916; Morrison, 1964).

Zinc was distilled from the charge by vaporization and then condensed onto iron pans or other collection devices as it exited the retort. The condensed-molten zinc was poured into large ladles, which were in turn poured into molds to form slab zinc or other zinc-metal products. The charge mix ratio in the retort probably was like most horizontal retorts, about 50:50 calcine and anthracite or coke. Most of the primary-zinc feedstock for the horizontal retorts consisted of ores and concentrates that were previously calcined at Grasselli-owned roasters in Illinois. Secondary feedstock were processed. From 1912-16 expansions of the horizontal retort furnaces continued. Zinc recoveries using horizontal retorts were likely in the range of 85 to 90 percent. The plant maintained an annual average of approximately 8,000 retorts over its operating life.

In the late-1920s, the company embarked on a modernization program which resulted in the complete replacement of the horizontal retort furnaces with more energy efficient and more productive vertical retort furnaces in 1931.

Coking and Sinter Plant

Although a large portion of the feedstock was purchased as sinter, a relatively small on-site coking plant and sinter machine was used for preparing purchased calcine (roast) and non-sulfidic fine-grained concentrates prior to entering the vertical retorts. Calcine and non-sulfidic concentrates averaged between 50 and 60 percent zinc. Zinc dross contained about 90-95 percent zinc, and flue dust contained an average of about 26 percent zinc. Other secondary and plant recycles probably comprised less than 5 percent of the total zinc contained in retort feedstock (Morrison, 1964).

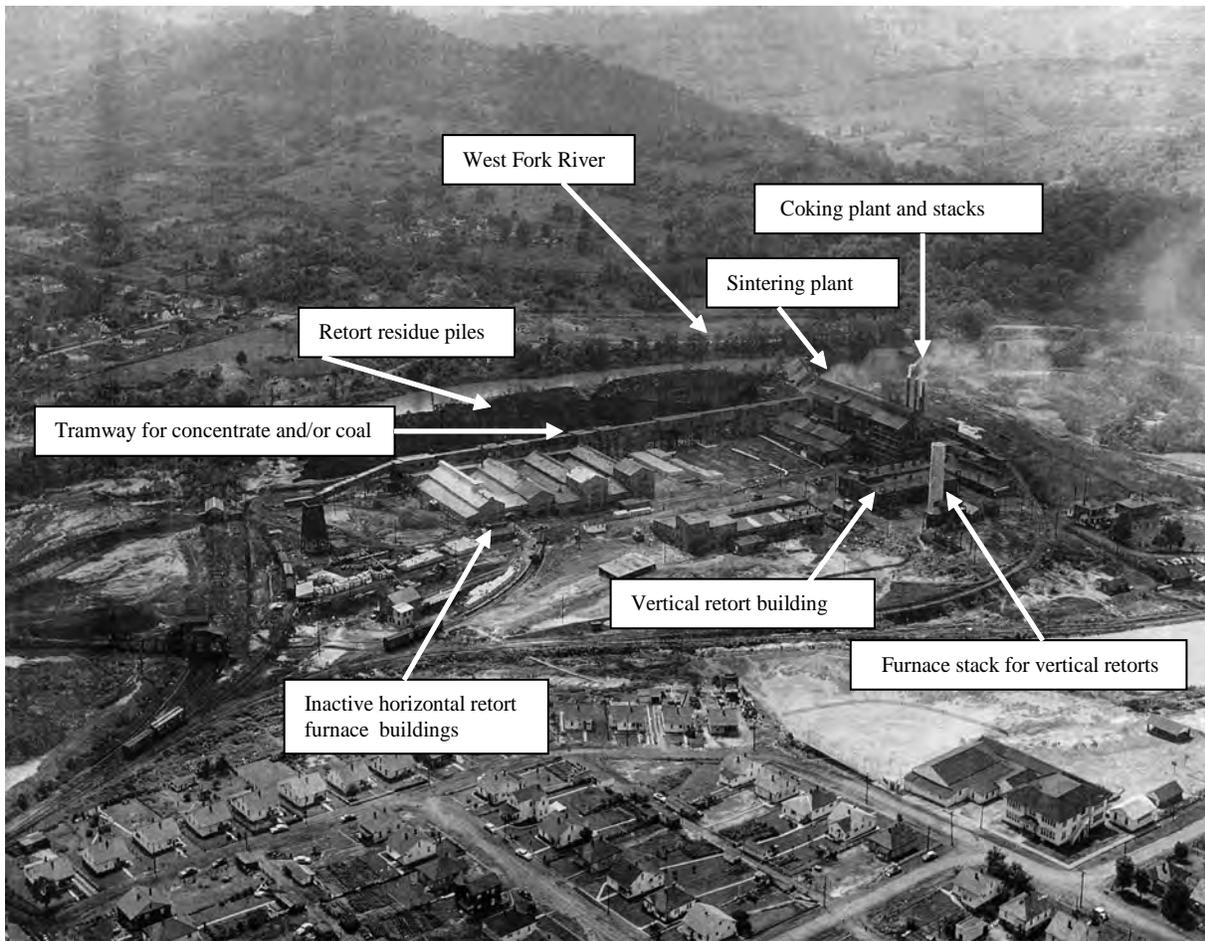


Figure 47. Photograph of the Meadowbrook Zinc Plant, also known as the Spelter Zinc Works, Spelter, West Virginia, looking in a northerly direction, circa 1955. The plant was operating when the photograph was taken. (Modified from a photograph provided courtesy of Mr. Ronald L. Gonzalez and Dr. Suronda Gonzalez, 2009.)

To produce a suitable feed for the vertical retorts it was first required that the calcine, plus other types of reduced or non-sulfidic feed, be combined with bituminous coal (a reductant), and clay and zinc sulfite which served as binders. The mixture was formed under pressure into briquettes. The resulting “green” briquette was then loaded onto a mechanical belt and passed through an autogenous coking plant from which a product was produced that could be fed to the vertical retorts. Using briquettes in the vertical retorts offered several advantages over calcine.

The sinter plant likely was small, because the company purchased sinter in addition to roast and concentrates that did not require reduction. These materials were likely combined with fine coal and heated in a Dwight-Lloyd sintering machine.

Using briquettes and sinter as feedstock in the vertical retorts offered several advantages over calcine. These included: (1) easier handling in the plant; (2) reduction in cadmium, lead, and sulfur content through volatilization during sintering resulting in a “cleaner” charge; (3) more efficient and thorough distribution of heat and carbon monoxide through the porous sinter and spaces between briquettes thereby liberating more zinc; and (4) provided conduits for more efficient evacuation of zinc fumes and gases throughout the charge. A major drawback of the sintering process was that the mechanical movement of briquettes along chain belts through the sintering machine and the conversion of the “green” briquettes to sinter by heating generated a large amount of dust and fumes. Without adequate dust control measures the sintering process could have been a major contributor of dust and fumes emissions containing heavy metals such as cadmium, lead, and zinc.

Specific information on emissions controls was unavailable. According to an internal company report, for some period until 1963, the dust produced by the sintering process may have been directed to a Peabody scrubber/cooler tower that captured some of the fumes and gases generated by the sinter plant and produced a filter cake or sludge. As mentioned earlier, DuPont did report that dusts captured by the Peabody Scrubber from the sinter plant containing cadmium and lead were placed on the waste pile. Although this shows that some dust collection was performed, the report does not address the amount collected, effectiveness, and time period that dust collection was practiced. In 1963, a 175 foot concrete-shelled smoke stack was constructed that reportedly eliminated the need for the fans and the Peabody cooler/scrubber tower (Morrison, 1964) for use at the sinter plant (see figure 48).

Vertical Retorts

Sixteen gas-fired vertical retorts began operating in 1931 when the company terminated the use of approximately 7,000 horizontal retorts contained in 20 furnaces (Morrison, 1964). The 16 original rectangular-shaped vertical retorts measured approximately 5 feet in width and later expanded to nearly six feet. They were about 1 foot in width. The height of the original furnaces was not available, but vertical retorts of

similar design during the same time period in Depew, Illinois and Palmerton, Pa. were approximately 30 feet tall. The vertical retorts employed the same principle used for distilling zinc in horizontal retorts. The zinc in the charge was vaporized in a reduced atmosphere and allowed to condense as molten metal. The manner of zinc condensation in the early use of the vertical retorts is unclear, but during 1953 and 1954 splash condensers, of New Jersey Zinc design were installed for all of the retorts (Morrison, 1964). Zinc was collected and poured into different shaped and sized molds depending upon the desired product.

During World War II 2 of the vertical retort furnaces were converted to produce zinc dust for a period of about 6 months to meet increased demand brought about by the War. An additional vertical retort was added in 1951 and another was added in 1952. A major expansion and modernization program was initiated in 1957 and completed in 1961 that resulted in larger retorts measuring 33 feet in height (U.S. Bureau of Mines 1957, p. 1292, Morrison, 1964).

The vertical retorts were more efficient than the horizontal type primarily because they allowed for continuous smelting. The process could continue uninterrupted, except for scheduled maintenance and repair. Sinter briquettes, which contained between 40 and 50 percent zinc, were loaded at the top of the retort as waste containing about 5 percent zinc was removed from the bottom. Much of preparation of the charge, briquetting, sintering and loading and unloading of the vertical retorts was accomplished mechanically. Horizontal retorts, on the other hand, needed to be loaded and emptied manually after the charge was exhausted, had relatively short operating lives caused by cracking or breaking, which resulted in losses of zinc in the plant or through furnace stacks, and had more downtime. Vertical retorts also were much less prone to large cracks and total failure than horizontal retorts, since the vertical retort were lined with refractory brick and the horizontal retorts were fired clay. The vertical retort linings frequently were sprayed with sealants to fill cracks that developed. A detailed discussion on the use of sintering and vertical retorting for zinc recovery using a New Jersey Zinc-designed plant has been published describing a process similar to that employed at the Meadowbrook plant (Fetterolf and others, 1970).

In the early 1960s, a stack measuring 175 feet high was constructed, probably to vent the coking-sintering plant, which enabled the elimination of Peabody coolers/scrubbers and fans (Morrison, 1964). Settling ponds were constructed during the same period to control coal dust and prevent contamination of the river. In 1964, a plant to recover cadmium was being considered, but whether the plant was actually built is not known (Morrison, 1964).

Meadowbrook conveyed the smelter to T.L Diamond in 1972, which operated the plant as a secondary smelter of zinc (Circuit Court of Harrison County, West Virginia, 2006).

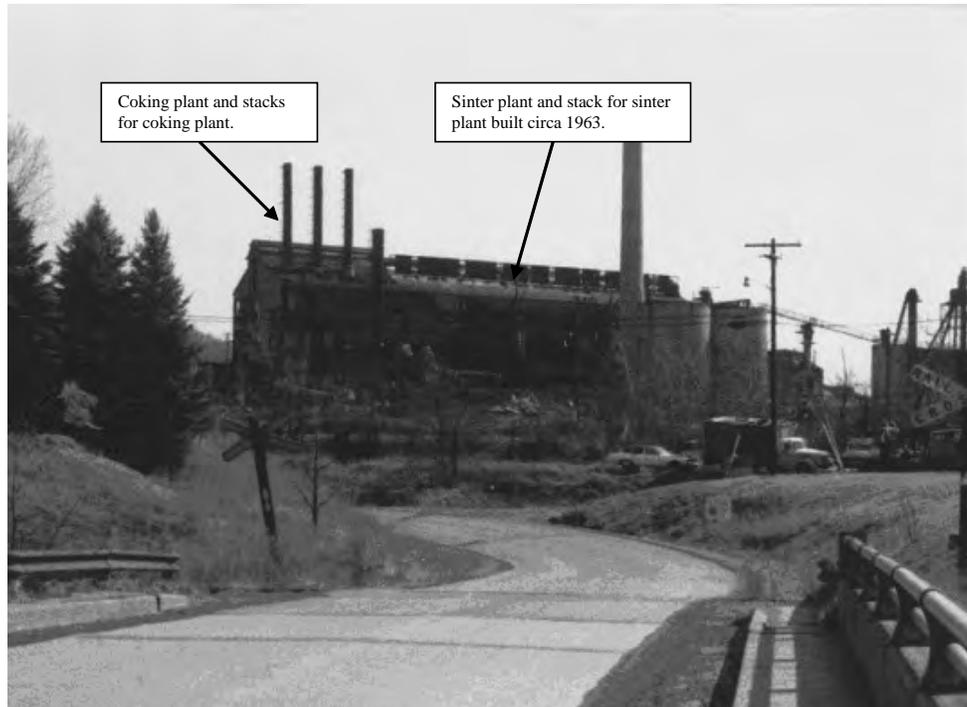


Figure 48. Photograph of the inactive Meadowbrook Zinc Plant, also known as the Spelter Zinc Works circa late-1980s. (Photograph provided courtesy of Mr. Ronald L. Gonzalez and Dr. Suronda Gonzalez, 2009.)

Zinc Dust Furnaces

A detailed technical description of the process used for zinc dust production at the Meadowbrook plant was not available however; the process was probably similar to that employed at the Palmerton facility (Robert Kuba, Horsehead Corporation, oral commun., 2008). The method employed to produce zinc dust of 300-mesh (approximately 0.05 mm) or smaller was based on passive fuming and condensation, whereas zinc powder was produced through aspiration of molten zinc and condensation. Zinc dust differs from zinc powder in that powder's particle size is considerably coarser at about 100 mesh (0.147 mm) (Banes, 1970; Internal company reports, 1958; Robert Kuba, Horsehead Corporation, oral commun., 2008).

The method to produce zinc dust entailed the use of externally heated furnaces in a closed system where feedstock was melted, boiled, and evaporated (Porter, 1991). The fumes condensed as fine particles in large vessels where they were collected and sized through sieves. Oxidation was avoided through careful temperature control in an inert atmosphere (Robert Kuba, Horsehead Corporation, oral communication, 2008). Ninety-five percent or more of the contained zinc was recovered in the process and the product assayed more than 99 percent zinc.

Zinc dust production started at Meadowbrook in 1930 using 10 small furnaces. Two vertical retorts were reconfigured to produce zinc dust during World War II which were returned to slab production when two additional furnaces for zinc dust production were placed online in 1948 (Morrison, 1964). The zinc dust plant relied on secondary feedstock, which consisted almost entirely of dross, containing about 95 percent zinc; and purchased zinc slab (Morrison, 1964; internal company reports). Minor amounts of coarse zinc dust which did not meet specifications, retort cleanings, skimmings, and other zinc-rich residues collected from the operation also were fed to the zinc dust furnaces. The zinc dust plant continued to produce until the entire Meadowbrook plant shut down in 1971.

Production of Other Metals

From 1930 until the late-1950s the facility produced small amounts of metals and alloys other than zinc metal. They included copper and cadmium alloys, lead anodes, zinc oxide and other zinc-based products (Morrison, 1964). Specific information on the processes used at Meadowbrook to recover the materials were not available, however zinc smelters that recovered metal-rich dust generated in their sintering

machines usually had onsite facilities to treat the material to recover cadmium, lead, zinc, and other metals or metal contained in compounds using a leach process. Some plants also were equipped with vertical refining facilities that used liquation to recover a lead and or cadmium-rich fraction.

Energy and Fuel Sources

The furnaces supplying heat to the furnaces containing the horizontal retorts were fired with natural gas from 1911–16. Coal-fired gas producers were installed in 1916, using coal from a nearby company-owned mine, and continued to supply gas until the horizontal furnaces were shut down in 1930 (Morrison, 1964).

The vertical retort furnaces were fired with producer gas generated by local coals from 1930, the year the retorts were first fired, through 1946. From 1947 through at least 1964, natural gas was used as fuel in the furnaces to heat the retorts (Morrison, 1964).

The facility generated its own electricity using local coal to fire steam boilers from 1911–30, and from 1933–46. The plant purchased electricity from the grid for the years 1930–33, and again from 1947 until at least 1964 (Morrison, 1964). It is likely that the plant continued to purchase electricity for the remaining years it operated.

The atmospheric emissions generated by the on-site electricity and gas-producing facilities were not considered in this study.

Atmospheric Emissions and Solid Waste

Evidence was presented in recent legal proceedings that during the years the plant operated it was responsible for releasing materials that were potentially harmful to the environment and human health (Circuit Court of Harrison County, West Virginia, 2006; Circuit Court of Harrison County, West Virginia, 2008). In 2008, The Circuit Court of Harrison County, West Virginia issued an order denying DuPont's and other defendants motion to appeal an award totaling nearly 400 million dollars consisting of attorney fees and other expenses, punitive awards, medical monitoring and remediation costs (Circuit Court of Harrison County, West Virginia, 2008; Smith 2008). The February 2008 court order, which has been appealed by DuPont to the West Virginia State Supreme Court (International Business Times, 2008), contained the Court's findings and information relating to atmospheric and solid waste emissions generated by zinc smelting activities at the site.

Further details and results of the extensive dust, soil, and smelter waste sampling and analyses in proximity to the plant site are illustrated and reported by Flowers, 2005 in a series of maps and tables available online (Levin and others, 2008).

Atmospheric Emissions

According to the court's document, as early as 1914, the community objected to the atmospheric pollution originating from the smelter (Circuit Court of Harrison County, West Virginia, 2008).

In 1919, Grasselli commissioned a study titled *Report of Investigations of Conditions Affecting the Growth of Plants and Animals in the Vicinity of the Meadowbrook Zinc Works of the Grasselli Chemical Company*, to evaluate the effects of the smelter's emissions on the surrounding community (Circuit Court of Harrison County, West Virginia, 2008). The company-sponsored study found that domestic livestock, plants, and soil in the area were negatively "impacted by the smelters emissions" within three miles of the plant in all directions and within 5 miles in a northeasterly direction. During this period, an expert witness reportedly found that arsenic was contained in the zinc dust deposited in the area and continued operation of the plant would negatively effect the environment over a greater area (Circuit Court of Harrison County, West Virginia, 2008). The 1919 study also determined that the dust generated by the smelter contained up to 2 percent lead, strongly suggesting that the feed to the smelter also contained lead during that time period (Flowers, 2005; Circuit Court of Harrison County, West Virginia, 2006; 2008), an observation also made by an analysis of dust captured in an onsite experimental baghouse in 1918 (Circuit Court of Harrison County, West Virginia, 2008). Figure 49 is a photograph of the plant during its first years of operation, circa 1915, when it employed horizontal retorts to produce zinc metal.

In the 1920s, a number of lawsuits were filed against Grasselli claiming that smoke and fumes generated by the Meadowbrook plant were harming crops and livestock. The litigation was apparently settled with selected property owners surrounding the facility (Circuit Court of West Virginia, 2006; Circuit Court of Harrison County, West Virginia, 2008). Lawsuits were based on similar claims as those at the Moundsville zinc smelter, also in West Virginia (Asturina-American Migration Forum, 2008).

As a part of a settlement between the parties, some of the litigators agreed to release Grasselli and its successors from any past, present, or future liability from the smelter (Circuit Court of Harrison County, West Virginia, 2006).

In 1927, the company apparently considered the installation of a Cottrell electrostatic precipitator, a device commonly used at smelters to capture particulates contained in process flows, such as gas emissions. Although the Meadowbrook's gaseous and particulate emissions were known to contain arsenic, cadmium, lead, and zinc, it was claimed in court documents that the company decided the overall economic benefits for installing the precipitator were not sufficiently compelling, and for that reason the device was not purchased (Circuit Court of Harrison County, West Virginia, 2008).

It is reported in the 2008 Findings of Fact in the Order Denying DuPont's Motion to Vacate or Reduce Punitive Damages Award Under *Garnes V. Fleming Landfill* contained



Figure 49. Photograph of the Meadowbrook zinc plant (Spelter Zinc Works) circa 1915 showing horizontal retort building and furnace stack. (Photograph provided courtesy of Mr. Ronald L. Gonzalez and Dr. Suronda Gonzalez, 2009.)

in the Circuit Court of Harrison County, West Virginia, that at least through the 1940s the plant operated without emission controls. As of 1950, the company was “spending \$8,200 per year for air pollution control,” an underfunded amount in the court’s opinion (Circuit Court of Harrison County, West Virginia, 2008). The replacement of horizontal retorts with more efficient vertical retorts in 1931 likely reduced escaping emissions per unit of zinc recovered in the retorts; however the sintering plant, could have been a major source of fugitive and stack emissions and offset a portion of the gains accomplished using the vertical retorts. The amount of dust and fumes produced during sintering would have been most dependent on the composition and tonnage of the material processed, and other factors such as the presence and adequacy of equipment to reduce emissions, condition, and type. Sintering of roast resulted in vaporizing most of the remaining cadmium and lead contained in the feed, plus some sulfur and zinc, and could, if not effectively controlled, contribute significantly to atmospheric emissions. Figure 47 shows the facility and atmospheric emission originating from the stack which vented the horizontal retort furnaces. Figure 49 shows the production of atmospheric emissions generated from what is believed to be the sintering plant and the coking plant when the plant was employing vertical retorts. Although values were not published, a study by Woodward-Clyde Diamond Group, a consulting company contracted by DuPont reported that the

soil adjacent to the smelter site contained elevated levels of arsenic, cadmium, and lead and those offsite residents potentially were exposed via inhalation, ingestion, and skin contact with residential soils (Circuit Court of Harrison County, West Virginia, 2008).

An extensive sampling and analyses of soil and dust in the area surrounding the smelter and materials collected from the waste piles was performed from 2003 through 2005 as reported by Flowers (2005). Results showed that some elements contained in the samples were above background levels and correlated with the composition of the chemistry of materials treated at the plant. Findings revealed anomalously high levels of arsenic, cadmium, lead, and zinc in surface soils that the investigator attributed to air emissions and fugitive dust originating from the smelter.

Abnormally high levels of metals contained in soil samples believed to be associated with the Meadowbrook smelter were detected among samples collected more than 17 km northeast of the smelter and 14 km southwest of the smelter site. The analysis of 917 soil samples taken in the vicinity averaged 12 ppm arsenic, 6 ppm cadmium, 137 ppm lead, and 1,126 ppm zinc. Overall, the great majority of samples contained metals that significantly exceeded normal background levels for the area (Flowers, 2005). Mercury content was not included in the analyses of waste or soils.

The results of soil sampling revealed that when the smelter is approached from any direction the arsenic, cadmium, lead, and zinc values increase, indicating a contaminant point source (Flowers, 2005). Variations in values of metals contained in soils could result from a number of factors that include distance from the plant, geography, operational activities at the facility, particle size and shape, particle chemistry, and meteorological conditions, such as precipitation and wind direction, and their duration, and intensity. Results of analyses may also be affected by other factors including sampling method and sample type.

The waste storage site contains approximately 2.5 million cubic yards of plant waste (Flowers, 2005). In 1984, the waste pile was measured and determined to range from 0.5 feet to more than 100 feet thick and covered 50 acres (Circuit Court of Harrison County, West Virginia, 2006), although another estimate placed the aerial extent of the waste pile at 112 acres (Smith, 2008). The waste pile was reported in court documents to have been a source of heavy metal contamination to soil and water by erosion and leaching, and to the atmosphere by dusts containing arsenic, cadmium, lead, and zinc over an extended period of time. The company was reportedly cited numerous times for violations of the Clean Air Act by State and Federal agencies (Circuit Court of Harrison County, West Virginia, 2006).

Samples taken from the Meadowbrook smelter’s waste pile, consisted primarily of spent retort charges and slag, some of which may have resulted from post-primary zinc feedstock. Assays of samples showed arsenic content averaged 272 ppm with levels recorded as high as 3,500 ppm; cadmium averaged 44 ppm and recorded as high as 1,400 ppm; the average

copper content was measured at 4,870 ppm and was recorded high as 71,000 ppm, lead averaged 2,798 ppm with measurements as high as 40,000 ppm, and zinc averaged 35,320 ppm with a maximum measurement of 238,000 ppm (Flowers, 2005).

DuPont also reported that spent retort charges and slag from retorts that were placed on the waste pile contained arsenic, cadmium, lead, iron and copper. An undetermined amount of dust captured (likely in the Peabody cooler/scrubber) during the sintering process that contained cadmium and lead were also present in the waste pile (Flowers, 2005), suggesting for a time, the company had some plant emission control during the preparation of feedstock to the vertical retorts.

In 2004, DuPont completed remediation of the site that included capping the waste, constructing erosion control systems, and installing monitors of soils, ground and surface waters. Figures 50 through 52 are photographs that were taken at the start and near completion of surface remediation of the site. By 2009, the surface of the site had been re-contoured and revegetated.

Sources of Atmospheric Emissions

Atmospheric emissions originating from the Meadowbrook consisted of fugitive and stack emissions. Fugitive emissions are those materials, such as dust and fumes that are released to the air from sources other than from stacks or vents. They are often because of equipment leaks, evaporative processes, and mechanical and windblown disturbances from activities such as preparing and loading charges to furnaces and retorts, movement of material, and plant ventilation. In the case of zinc smelters, most fugitive emissions were generated by mechanical activity in preparing charges and during sintering. Some of this material was recovered in and around the plant and reprocessed, if the economics were favorable or as a matter of safety and equipment operating efficiency or both.

Stack emissions can be from uncontrolled stacks and controlled stacks. Uncontrolled stack emissions generally are understood to be those emissions at facilities that do not use pollution control equipment. Controlled stack emissions are those emissions for which some means were present to limit the release of material to the atmosphere through stack emissions. These would include baghouses, dust settling chambers, electrostatic precipitators, and scrubbers. Little information relating to the presence or lack thereof of these types of emission-control equipment was discovered during research.

The major sources of fugitive atmospheric emissions at Meadowbrook included (1) dust from mixing and preparation of charges; (2) dust and fumes from sintering; and (3) "leakages" from horizontal and vertical retorting. Lesser sources of atmospheric emissions include the manufacture of zinc dust, wind-blown distribution of feedstock stored outdoors and waste material, and fumes dissipating from the waste pile. Examples of processes that generated stack emissions, controlled or uncontrolled depending on the process and time period, included sintering and external firing of retorts. Wind

blown material generated from stockpiles of unprotected feedstock and the accumulation of retort residues and other wastes were not considered in emission estimates. Onsite electrical generation and the manufacture of producer gas, sources of fugitive and stack emissions, also were not considered in this evaluation.

As described earlier, primary zinc feedstock from Canada, South America, and the United States contained materials considered deleterious to the value of zinc products and if released as emissions, potentially harmful to the environment and human health. These included, in addition to zinc, arsenic, cadmium, copper, fluorine, lead, mercury, and sulfur. Secondary feedstock treated at the facility included dross and scrap, and the treatment of flue dust also contained some of these elements, particularly cadmium and lead.

Estimated Total Atmospheric Zinc Emissions

It was necessary to consider a number of factors to estimate total atmospheric zinc emissions from Meadowbrook originating from fugitive and stack emissions. They included, but were not limited to, the types of technologies employed at the plant such as horizontal retorts from 1911 through 1929; the sintering plant used for a portion of the feedstock for the vertical retorts for the years they operated, 1930 through early 1971, and primary feedstock consisting of ore, calcine, and sinter; secondary feedstock such as dross, flue dust, and scrap; and Prime Western grade zinc slab that was purchased from other smelters. Using the aforementioned factors, data from operations using similar technologies, published data, and discussions with individuals familiar with the technical aspects of zinc production, it was estimated that an amount of zinc ranging from 3 to 5 percent or 60,000 to 100,000 short tons of the estimated total zinc production of nearly 2 million short tons were emitted to the atmosphere as fugitive and stack emissions. The high end of the estimate assumed that the emission controls on the sinter plant were absent or largely ineffective. Windblown material that originated from the plant's waste storage site or feedstock piles were not considered, nor were emissions produced during the manufacture of producer gas or generation of electricity.

The emission estimates are presented to one significant figure because production data and technical data were incomplete and broad assumptions were necessary. Variations in emission amounts and composition within time periods, even on an annual basis, may have resulted from changes in the composition, type, proportions and amounts of ore, concentrate, and scrap feedstock; amount, proportion and variety of product types and the evolution of technologies employed. One of the major unknown factors for estimating fugitive and stack emissions pertains to the amount and chemistry of feedstock supplied to the sintering machine and the dust control measures, if any, that were employed, and present, their effectiveness. Specific information on types and effectiveness of emissions controls was unavailable. According to an internal company report, for an unknown period up until 1963,

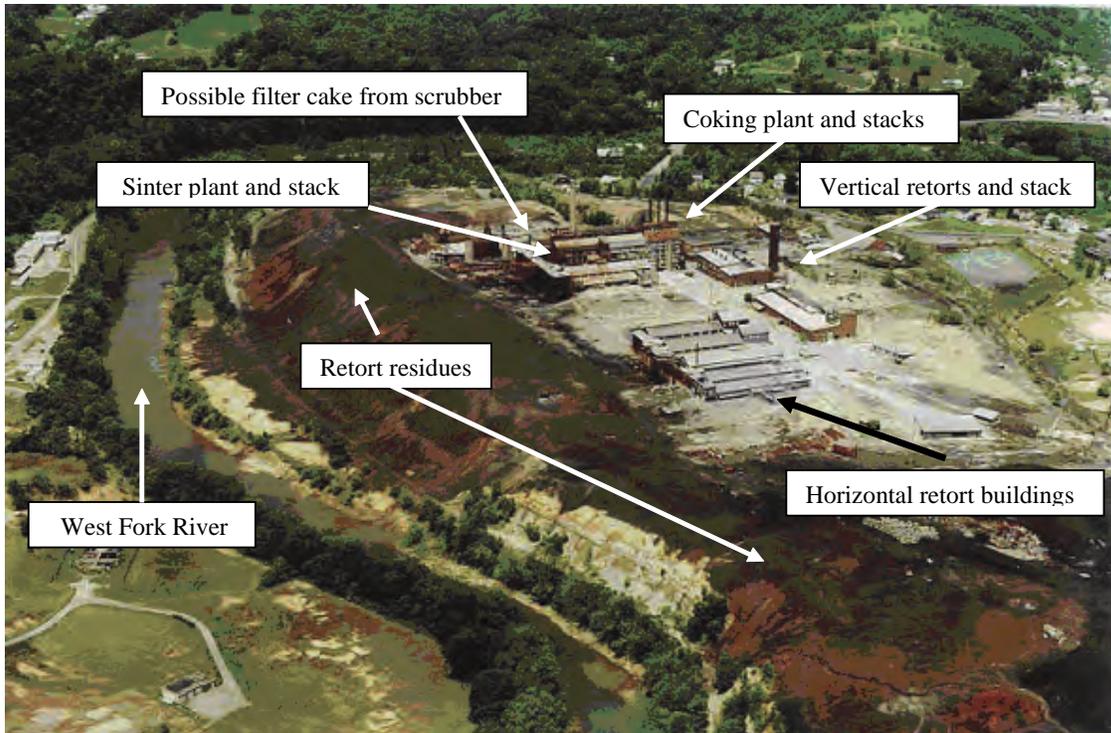


Figure 50. Photograph looking towards the northwest of the shut down Meadowbrook Zinc Plant also known as the Spelter Zinc Works as it appeared in 1998, prior to extensive surface reclamation efforts. (Modified from a photograph provided courtesy of E.I. du Pont de Nemours and Company, 2009.)

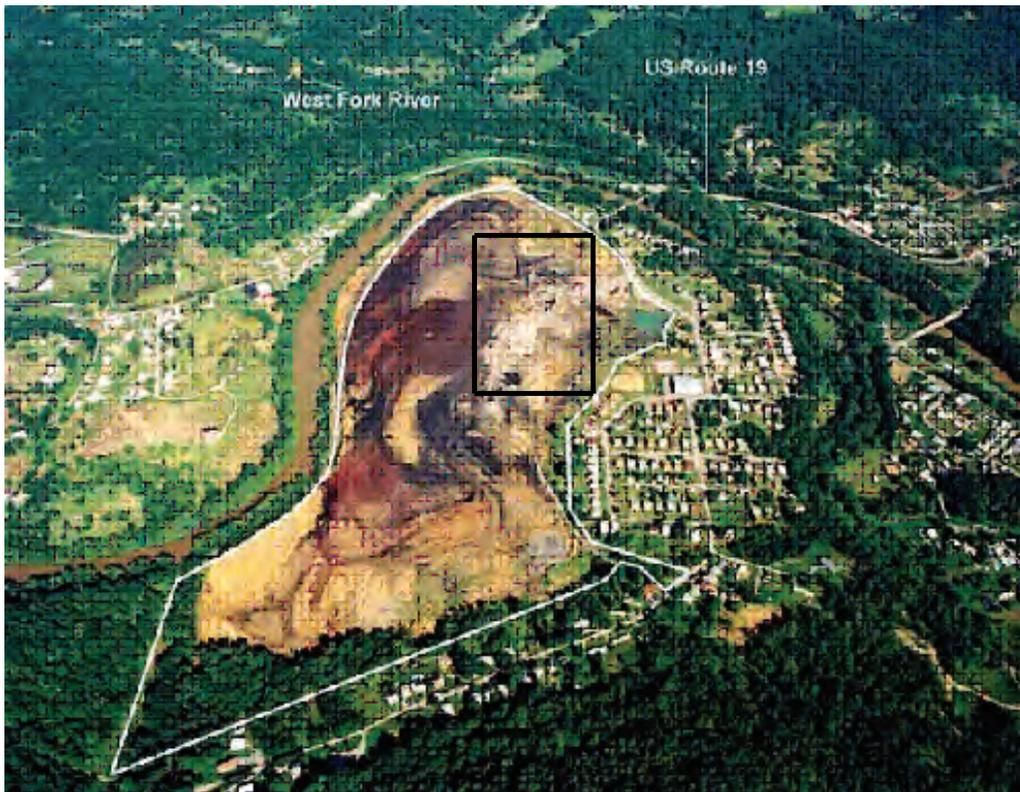


Figure 51. Photograph looking towards the northwest of the Meadowbrook Zinc Plant, also known as the Spelter Zinc Works site as it appeared in 2003, as extensive reclamation activities were underway. Most of the plant's pyrometallurgical activities were within the area bounded in black. (Modified from a photograph provided courtesy of E.I. du Pont de Nemours and Company, 2009.)



Figure 52. Aerial photograph looking northward of the site previously occupied by the Meadowbrook zinc smelter as it appeared in 2005 following surface remediation. Most of the plant's pyrometallurgical activities were within the area bounded in black. (Modified from a photograph provided courtesy of E.I. du Pont de Nemours and Company, 2009.)

the Meadowbrook did have a Peabody cooler/scrubber tower. It probably was used to capture some of the fumes and gases generated by the sinter plant (Robert Kuba, Horsehead Corporation, oral commun., 2008; Arthur W. Larvey, Consulting Chemical Engineer, written commun., 2008). This is however based on some conjecture because it is also possible that the scrubber/coolers were used for another part of the operation. In 1963, a 175 foot concrete-shelled smoke stack was constructed that eliminated the need for the fans and the Peabody tower cooler/scrubber (Morrison, 1964). The stack probably served to lift and remove emissions further from the immediate plant site at a lower annual cost than the cooler/scrubber.

As was the case at the Palmerton smelter, which employed a similar process during the same period, a portion of the plant's emissions were relatively large in size or heavy in weight, or both, causing them to settle in proximity to the

plant. Conversely, some of the material emitted into the atmosphere over the facility's life may have been sufficiently small in size that it had a near zero settling velocity and except for occasional rain events that may have contributed to deposition of this material in the valley, may have been wind-transported considerably further beyond the valley and dispersed over a wide geographic area (Alan Cimorelli, U.S. Environmental Protection Agency, oral commun., 2007).

Other Fugitive and Stack Emissions

The limited amount of data concerning the tonnage and chemistry of primary feedstock from Canada, South America and some parts of the United States treated at Meadowbrook and the analyses of dusts and residues suggests that metals such as arsenic, cadmium, copper, and lead were, as soil

surveys in the area confirm, emitted from the plant. The paucity of data prevented quantifying the amount. Other materials that have the potential to be environmentally harmful either reportedly contained in the primary feedstock or possibly contained by chemical affinity, included fluorine and mercury. No data relating to analyses for these elements the area were encountered in the literature.

Secondary feedstock, such as dross; and slab zinc that contained cadmium and lead may also have contributed to the plant's emissions, but to a lesser extent.

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United States Arsenal, District of Columbia

Introduction

The smelter initiated production in the mid-to-late 1830s. The smelter was built for the United States Department of Commerce by order of Congress. While small and short lived, historically it was important for producing brass by combining slab zinc (spelter) and copper for the manufacture of the first set of U.S. standardized brass weights and measures (Ingalls, 1908; Miller, 1941, p. 329). Up to this point in U.S. history, there were no Federal Government endorsed standards for weights or measure (Jolly, 1994, p. 16). The cost of producing zinc at the plant was reported to exceed the value of the metal that was recovered and was therefore not commercially viable (Kettell, 1875, Ingalls, 1908).

Map Number (fig. 1)

19

Name

United States Arsenal

Location

Greenleaf Point, Washington, D.C. – [(N38° 51'42" (N38.86167), (W077° 01'04"–77.01778)].

Owner/Operator

United States Customs Department, Government of the United States (Ingalls, 1908, Jolly, 1997).

Years of Operation

The year the plant was constructed, the year the plant initiated operation, and the number of years the plant operated are unclear. The plant appeared to have been constructed prior to 1834 (U.S. Congress, 1835, p. 334). Several different years, ranging from 1835 to 1838, were referred to as the year the plant opened (Jolly, 1994; Miller, 1941; Ingalls, 1908). No date was given to when the plant closed, but given its intended purpose and poor economics, it is likely it operated no more than a few years.

Production History

No statistical data or other data useful for estimating production data was encountered in the literature.

Feedstock

The original feedstock for the plant was derived from boulders in glacial drift containing zincite, a zinc oxide mineral, south of the town of Franklin Furnace, N.Y., hemimorphite, a zinc silicate mineral; and possibly copper ore, mined in Perkiomen, Pa., (Jolly, 1994, p. 65; Miller, 1924, p. 22; Miller, 1941, p. 329, Mindat.org, 2008; Stone, 1915). Copper was added for producing brass, an alloy of copper and zinc. Additional ore requirements were met from an open pit mine in the Franklin-Sterling Zinc District in N.J. (Stone, 1915) owned by a member of Congress (Ingalls, 1908). In 1872, zincite was mined once again in the Franklin, N.J. area for producing official weights of measure, but whether the ore was smelted in Washington, D.C. is not stated (Jolly, p. 65). It is unlikely that the same furnace was used.

Products

Zinc metal, brass, and possibly copper. The brass alloy was used to manufacture official weights of measure (Miller, 1941, p. 329, Stone, 1915).

Technology

A small Belgian furnace, containing horizontal retorts, was employed to reduce the zinc from direct-feed ore (Jolly, 1997). Coal was mixed with the zinc ore to form the retort charge. The nonsulfidic nature of the ore did not require roasting prior to distillation. Given the time period and nature of the ore feed, zinc recovery did not likely exceed 75 percent. Information regarding the actual size of the furnace, the number of retorts, and other technical details were not available.

Zinc Emission Estimate

Available data were insufficient to develop an estimate of atmospheric zinc emissions. Fugitive and stack emissions of zinc were probably on the order of 7-10 percent of the amount of zinc recovered. However, total emissions were likely low, given the short life of the plant, its small capacity, and the nature of the feedstock.

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