Water Requirements of the Aluminum Industry

By HOWARD L. CONKLIN

WATER REQUIREMENTS OF SELECTED INDUSTRIES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1330-C

A study of manufacturing processes with emphasis on present water uses and future water requirements

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1956

UNITED STATES DEPARTMENT OF THE INTERIOR

Fred A. Seaton, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 20 cents (Paper cover)

PREFACE

This report is one of a series describing the water requirements of selected industries that are of national importance. It was prepared at the request of and in consultation with the Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, Department of Commerce, and is designed to serve the dual purpose of providing basic information for national defense planning and at the same time rendering a valuable service to business and industry in their development of water resources for present and future use.

The officers of Aluminum Company of America, Kaiser Aluminum and Chemical Corp., and Reynolds Metals Co. gave the writer permission to visit their plants to determine the water requirements of each plant, the manner in which water is used, and all conditions peculiar to each plant that would account for the use of water in a manner that differs from the usual practice in the industry. Grateful acknowledgment is made to these officials and to the management of each plant visited for the courtesies and cooperation extended to the writer in the course of this investigation.

CONTENTS

ILLUSTRATIONS

TABLES

WATER REQUIREMENTS OF SELECTED INDUSTRIES

WATER REQUIREMENTS OF THE ALUMINUM INDUSTRY

By Howard L. Conklin

ABSTRACT

Aluminum is unique among metals in the way it is obtained from its ore. The first step is to produce alumina, a white powder that bears no resemblance to the bauxite from which it is derived or to the metallic aluminum to which it is reduced by electrolytic action in a second step. Each step requires a complete plant facility, and the plants may be adjacent or separated by as much as the width of the North American continent. Field investigations of every alumina plant and reduction works in the United States were undertaken to determine the industry's water use. Detailed studies were made of process and plant layout so that a water balance could be made for each plant to determine not only the gross water intake but also an approximation of the consumptive use of water.

Water requirements of alumina plants range from 0.28 to 1.10 gallons per pound of alumina; the average for the industry is 0.66 gallon. Water requirements of reduction works vary considerably more, ranging from 1.24 to 36.33 gallons per pound of aluminum, and average 14.62 gallons.

All alumina plants in the United States derive alumina from bauxite by the Bayer process or by the Combination process, a modification of the Bayer process. Although the chemical process for obtaining alumina from bauxite is essentially the same at all plants, different procedures are employed to cool the sodium aluminate solution before it enters the precipitating tanks and to concentrate it by evaporation of some of the water in the solution. Where this evaporation takes place in a cooling tower, water in the solution is lost to the atmosphere as water vapor and so is used consumptively. In other plants, the quantity of solution in the system is controlled by evaporation in a multiple-effect evaporator where practically all vapor distilled out of the solution is condensed to water that may be reused. The latter method is used in all recently constructed alumina plants, and some older plants are replacing cooling towers with multiple-effect evaporators.

All reduction works in the United States use the Hall process, but the variation in water requirements is even greater than the variation at alumina plants, and, further, the total daily water requirement for all reduction works is more than 9 times the total daily requirement of all alumina plants. Many reduction works use gas scrubbers, but some do not. As gas scrubbing is one of the principal water uses in reduction works, the manner in which wash water is used, cooled, and reused accounts in large measure for the variation in water requirements.

Although the supply of water for all plants but one was reported by the management to be ample for all plant needs, the economic factor of the cost of water differs considerably among plants. It is this factor that accounts in large measure for the widely divergent plant practices. Plant capacity alone has so little effect on plant water requirements that other conditions—such as plant operation based on the cost of water, plant location, and the need for conservation of water—mask any economy inherent in plant size.

INTRODUCTION

PURPOSE

This report, one of a series on the water requirements of important industries, presents a summary of basic data on water use in the production of primary aluminum from bauxite. This kind of information is presented to aid the planning of the over-all development of specific areas and the most effective use of our water resources. If defense mobilization should be necessary, the results of this survey would be especially helpful in locating new plants using large amounts of water so that they will be assured adequate water supplies of suitable quality and at the same time will not interfere with the requirements of other industries with which they must share the water.

SCOPE

Field investigations, which were carried out during the first half of 1952, included visits to every alumina plant and reduction works then in operation in the United States. Production of secondary aluminum by remelting aluminum scrap is not included in this investigation. Plants at which a water-use survey was made are shown in figure 19.

Detailed studies were made of process and equipment at every plant visited so that a water balance could be made to determine the gross water intake, the reuse of water, and a close approximation of the consumptive use of water.

Information was sought on the source of water, its adequacy, the need for treatment, the manner of disposal of waste water, and changes in process or plant practice that would indicate a trend in water use.

Subjects of primary interest throughout the investigation were: the quantity of water required for the operation of each plant; the chemical quality of water required; differences, from plant to plant, in operating practices; the extent to which those differences are explicable in terms of interplant variations in plant size, geographical location, and availability of water; and the effect these various conditions have on the quantity of water required by each plant and on the necessity to reuse water.

Because steam is essential to the production of alumina by chemical process from bauxite, boiler-feed makeup is included in the plant water balance as a process use of water.

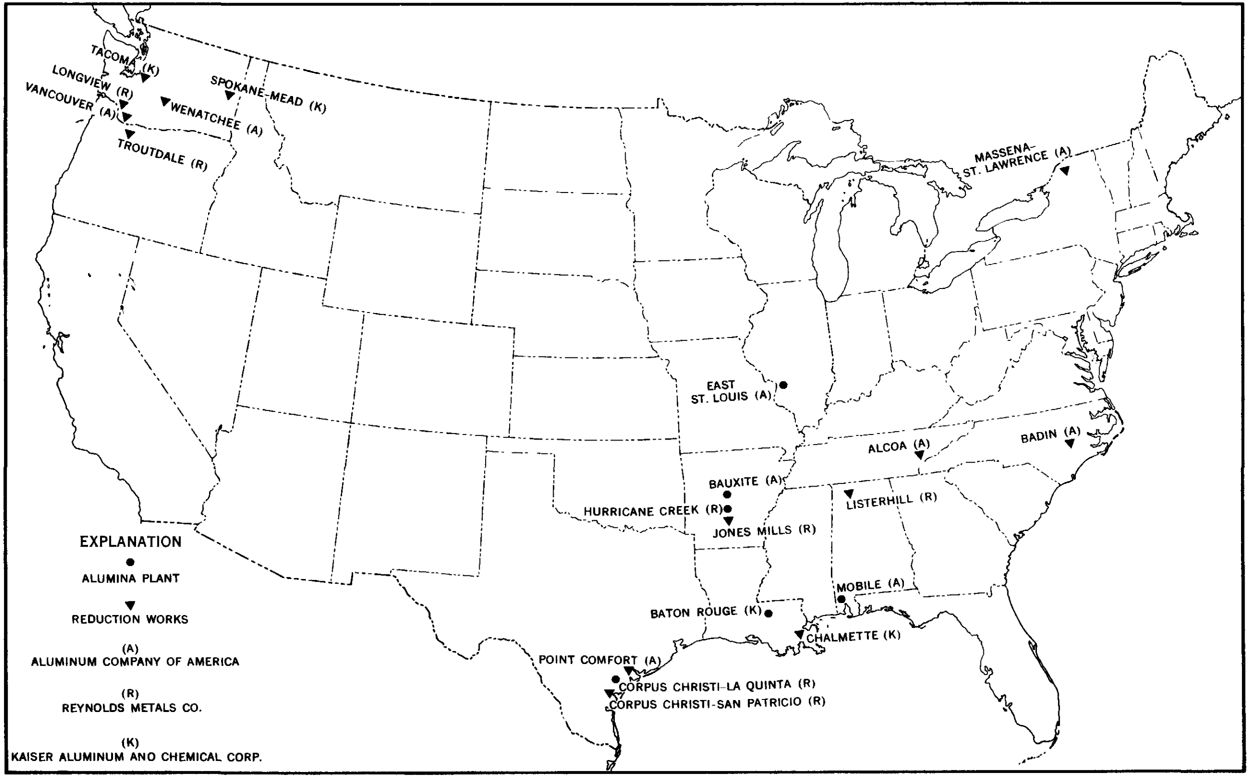

Figure 19. —Map showing location of plants surveyed for water requirements.

Reduction works present a more complicated situation in the consideration of the quantity of water required to produce electric power, which is essential for the process of electrolytic reduction of alumina to aluminum. Of the 14 reduction works in operation at the time this survey was made, 8 works purchased all the electric power required for potlines and other plant uses from federally owned power pools such as TVA and Bonneville; 2 operated company-owned hydroelectric generating plants and purchased supplemental power from privately owned utility companies; 2 generated all electric power at the plant, using internal-combustion engines as prime movers; 1 used internal-combustion engine generator sets for 2 potlines and purchased power for the other 3 potlines; and 1 plant operated 2 potlines by gas-diesel engine generator sets and 6 potlines from a steam turbogenerator plant. The condenser-cooling water required for the steam plant is estimated to amount to as much as 500 mgd (million gallons per day), approximately 16 times as much as all other water requirements of this reduction works.

In view of the fact that steam is not used in the electrolytic process and because 11 of the 14 works purchase power, part of which is produced by hydroelectric generators and part by standby steam powerplants, the purpose of this survey is best served by considering electric power used in reduction works as a purchased raw material. The water requirements for generating electric power by internal-combustion engines is insignificant. However, the quantity of condenser-cooling water required by the one reduction works at which electricity is generated by a steam powerplant distorts the water balance of that plant.

Water-use values in this report, therefore, do not include: the quantity of water required for the generation of electricity for the potlines, either in hydro or steam plants; the water requirements of plants not in operation at the time the survey was made; changes in process uses of water contemplated but not in operation at that time; and the quantity of water used for fabricating aluminum pigs, ingots, and billets into finished products such as castings, sheets, or extruded forms.

HISTORY AND GROWTH OF THE INDUSTRY

As little as 70 years ago aluminum was a rare and costly curiosity. In the span of one lifetime the aluminum industry has risen to fifth place, in tonnage produced, of all metal industries. Measured by volume rather than weight, aluminum production exceeds that of copper, lead, and zinc and is second only to iron.

The first sample of impure aluminum was extracted from clay in 1825 by Hans Christian Oersted, a Danish chemist. Frederick Wohler, a German chemist, succeeded in making metallic particles and in 1845 was the first to determine the physical and chemical properties of the metal.

The commercial history of aluminum dates from 1886 when two scientists, Charles Martin Hall in the United States and Paul L. T. Heroult in France, working independently, simultaneously developed essentially the same process of reducing alumina (aluminum oxide, Al_2O_3) to metallic aluminum (Al) by passing an electric current through alumina dissolved in cryolite. Two years later Karl Josef Bayer developed a chemical process for the production of refined alumina from bauxite. The processes of Bayer and Hall made possible the aluminum industry, the growth of which has been so spectacular.

From 1886 until 1910 growth of the new industry, in regard to tonnage produced, was slow. However, during that interval the price was reduced from 5 dollars per pound of ingot aluminum to 22 cents. In 1910, when the total United States output was only 20,000 tons, a period of phenomenal expansion began; total United States production increased to almost 1 million tons in 1952, a 47-fold increase of production. (See table 1.)

Table 1.—*Production of primary aluminum in the United States*

[Data for 1910-50 compiled by First Boston Corp. (1951), for 1951 by Office of Defense Mobilization (1952a), and for 1952 by Lutjen (1953)]

Year	*Thousand of metric tons*	*Year*	*Thousand of metric tons*
1910	20	1940	187
1915	50	1945	445
1920	75	1950	653
1925	77	1951	836
1930	139	1952	937
1935	75		

Peacetime uses for aluminum have enabled the aluminum industry to retain its tremendously expanded wartime volume of production. The utilization by industry of the total aluminum plant capacity has been brought about by new applications of the metal induced by a practically stable price.

USE OF ALUMINUM IN INDUSTRY

A conservative estimate indicates that there are today at least 4,000 end uses of aluminum. There are two general classifications of end products: wrought products, which develop from a change in shape of the metal by mechanical working of the billet; and castings, which utilize the molten metal of pigs or ingots.

Wrought products include sheet, extruded shapes, foil, rods and wire, and forgings made by hammering or by pressing the billet, which usually is cast in cylindrical form from remelted pigs.

Castings have become one of the largest outlets for aluminum. They are made by plaster, sand, and iron mold, and by die casting.

The year-by-year requirements of aluminum by the various industries fluctuate to such a degree that it is difficult to adjudge what is normal demand. Consider, for example, the aviation industry. In 1943 that industry was allocated approximately 90 percent of the total aluminum production in the United States (each B-29 required 25 tons of aluminum). In 1948, however, the aviation industry used only about 4 percent of the aluminum production. Owing to the rapidly expanded military program, nearly 9 percent of the 1949 production went into aircraft, and in 1951 it was approximately 25 percent.

The cumulative effect of expanding capacity, of broadening consumer acceptance, of development of new applications, and of an improving competitive position is becoming increasingly evident in sharp gains in peacetime consumption. All things considered, therefore, the aluminum industry confidently expects that production and consumption over the next 10 years will double, as it has during each decade in the past.

OCCURRENCE OF ALUMINOUS ORES

Of all the elements in the earth's crust the element aluminum (Al) is third in abundance, exceeded only by oxygen and silicon. It is the most abundant metallic element, constituting approximately one-twelfth of the earth's crust, whereas iron constitutes only about one-twentieth. Although aluminous ores are widespread, the element never has been found free in nature. Aluminum is found everywhere combined chemically with other elements in more than 100 combinations, generally in the form of an oxide. Alum, a double sulfate of aluminum, is the common styptic pencil. Rubies and sapphires are compounds of aluminum to which ferrous impurities give their beautiful and distinctive color.

Bauxite, an amorphous mixture of two hydrates, $Al_2O_3 \cdot H_2O$ and $Al_2O_3 \cdot 3H_2O$, is the ore used for all commercial aluminum produced in the United States. High-grade bauxite ore is found principally in Arkansas, where some deposits are high in aluminum-oxide content and low in impurities of silica and iron. Bauxite deposits of somewhat lower quality but economically usable are located in Georgia and Alabama. Domestic sources of high-grade bauxite are being depleted, and an increasing percentage of the total ore used in the United States is shipped from deposits in Surinam (Dutch Guiana), British Guiana, Jamaica, and Haiti. Samuel W. Anderson, formerly Deputy Administrator for Aluminum, Defense Production Administration, reported (1953) that the estimated quantity of high-grade bauxite in the United States is approximately 9 million tons, and that there are about 50 million tons of low-grade bauxite in the Arkansas area. Deposits in Surinam are estimated to contain approximately 50 million tons of bauxite, and the deposits in the islands of the Caribbean are estimated to total over 350 million tons.

Cryolite, sodium aluminum fluoride ($3NaF \cdot AlF_3$, formerly written Na_3AlF_6), is another aluminum compound required in the process used in the United States for producing alumina from bauxite. The only known commercial source of natural cryolite is one mine in Greenland. Synthetic cryolite is considered equally suitable as a solvent of alumina in the electrolytic reduction process, although it is claimed that natural cryolite has greater stability which makes starting a potline somewhat easier. Natural cryolite is concentrated to somewhat higher purity than synthetic cryolite, but the difference is small. Cryolite also is reclaimed from the old linings of pots, a process carried out at three reduction works.

A joint investigation by the Bureau of Mines and the Geological Survey (1948) indicates that domestic reserves of high-grade bauxite are very small; however, there are virtually unlimited quantities of low-grade sources of aluminum such as alunite, anorthosite, certain types of clays, and other aluminum silicates.

Utilization of low-grade bauxite with high silica content is made possible by the Combination process. This process is in operation at two alumina plants now in operation.

For many years the Bureau of Mines has conducted laboratory and pilot-plant research to find methods of recovering alumina from low-grade materials. The Government-owned demonstration plant at Laramie, Wyo., begun in World War II but never completed, was transferred by the Surplus Property Board to the Bureau of Mines to determine the equipment requirements, process techniques, and economics of producing alumina from anorthosite. This aluminum-bearing rock is found in enormous quantities in the Laramie Range, in Wyoming, and elsewhere in the United States.

THE METHODS OF PRODUCING PRIMARY ALUMINUM

There are two separate and distinct steps in the production of aluminum from ore. Aluminum differs from most other major metals in this respect as they are reduced directly from their ores. Each step, as shown in figure 20, requires a complete plant facility for the production of its end product. The requirements may be carried on in adjacent plants or they may be separated by as much as the width of the North American continent.

The first step is the production from bauxite of anhydrous aluminum oxide, a gritty white powder known as alumina (Al_2O_3). The second step is the production of aluminum from alumina by electrolytic reduction, the molten metal being cast into pigs or billets.

PRODUCING ALUMINA FROM BAUXITE

Many detailed discussions of the Bayer and other processes for the production of alumina are contained in the literature. The following brief descriptions constitute a résumé of the work on this subject (see the bibliography) but are not taken from any one source.

Several detailed descriptions of the various processes for refining alumina from bauxite and other source materials have been made by other governmental agencies, such as the report to the Office of Defense Mobilization by the U. S. Bureau of Mines (1953). A similar report on the reduction of alumina to primary, or virgin, aluminum was made to the same office by the U. S. Department of Commerce (1956).

In this report it is deemed necessary to discuss the various processes and the chemistry involved only sufficiently for the reader to be able to identify the equipment when reference is made to the use of water or its extraction from the liquor cycle. The Deville-Pechiney "dry" process is not used in the United States.

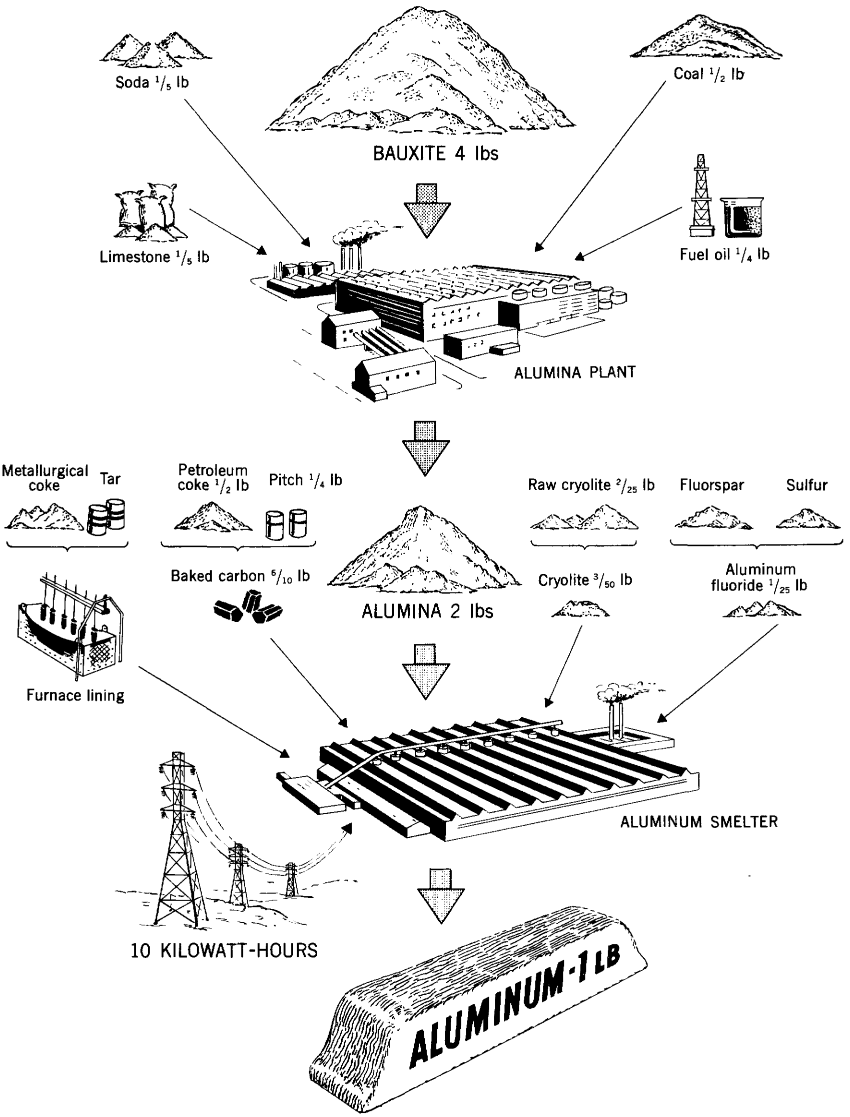

Figure 20.—Raw materials and processes required to produce 1 pound of aluminum ingot. (Copyrighted material reproduced with the permission of the First Boston Corp.)

BAYER PROCESS

Bauxite, finely ground in a ball mill, is fed from a weighing hopper into a mixer where it is thoroughly mixed with hot caustic soda solution from a previous cycle to which sufficient lime and sodium carbonate have been added to bring the solution to standard concentration. The thin muddy liquid, called slurry, is pumped into digester tanks, where it is heated by live steam at about 50 pounds per square inch pressure and agitated, causing the aluminum oxide in the bauxite to be dissolved or digested in the caustic solution as sodium aluminate. The insoluble residue of impurities is separated in open-top iron settling tanks where the sediment is drawn from the bottom and the relatively clear liquor is drawn off the top. In recently constructed plants the contents of the digester tank are passed through blowoff tanks and filter press to separate the insoluble residue known as red mud from the sodium aluminate solution. The red mud—containing iron oxide, aluminum oxide combined with silica as aluminum silicate, and other impurities in the bauxite—is an insoluble waste residue. It is transported to the red-mud lake by water pumped from the lake. Makeup water added to the red-mud lake to compensate for evaporation is an important water use at alumina plants. The clear sodium aluminate solution, dark brown in color but usually referred to as "green liquor" by plant personnel, is cooled and pumped to vertical precipitating tanks as tall as a six-story building, where it is seeded with alumina trihydrate from a previous cycle to accelerate precipitation. Alumina trihydrate, or aluminum hydroxide as some metallurgists prefer to designate it, is gradually formed by the hydrolysis of sodium aluminate in the presence of the crystalline seeds and settles to the bottom. The granular aluminum hydroxide crystals are drawn from the bottom of the precipitator. The crystals are classified and separated in thickeners, washed and filtered, and calcined at a temperature of approximately 2,000°F in long gas-fired rotary kilns where free water and chemically combined water of hydration are driven off, leaving pure anhydrous aluminum oxide, known as alumina.

The Bayer process flowsheet shown in figure 21 is obsolete in some particulars, such as the use of autoclaves and triple-effect evaporators. All recently constructed plants use digesters in which live steam is introduced into the liquor to raise its temperature, whereas the autoclave has a steam jacket to raise the temperature without increasing the volume of the liquor. Modern practice calls for the use of sextuple-effect evaporators to reduce the volume of liquor in the cycle rather than evaporating towers or the triple-effect evaporator shown in the flowsheet. The flowsheet is included as a historical item which may serve to show the various steps in the process.

COMBINATION PROCESS

The Combination process employs a sintering operation as a cyclic step in the Bayer process and is intended to recover some

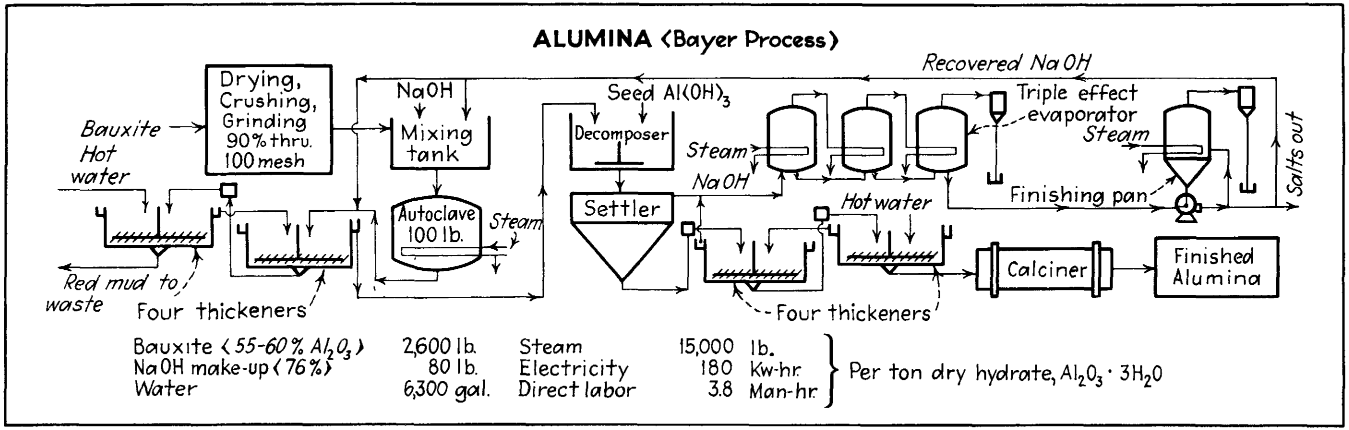

Figure 21. —Flowsheet for Bayer process. (Copyrighted material reproduced with the permission of McGraw-Hill Publishing Co., Inc.)

of the aluminum oxide lost as aluminum silicate with the red-mud residue. The flowsheet for this process is shown in figure 22.

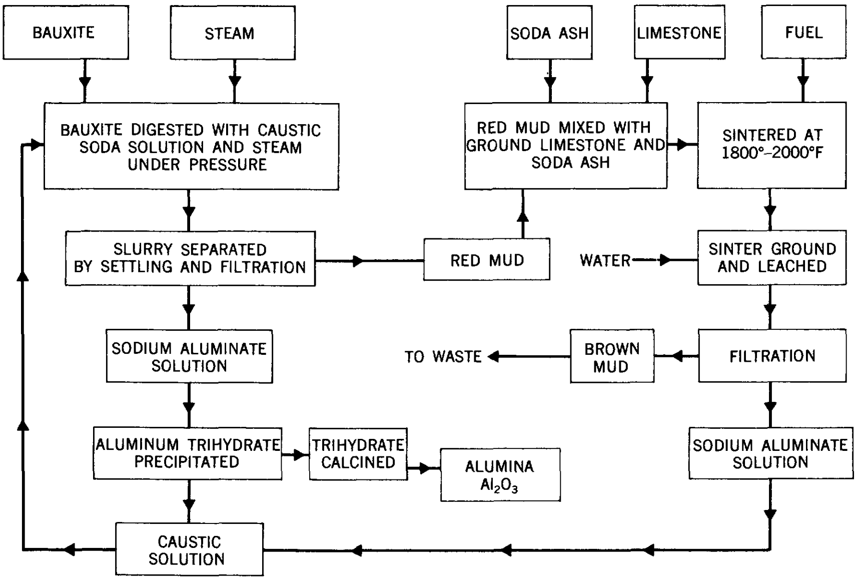

Figure 22.—Flowsheet for Combination process. (Copyrighted material reproduced with the permission of American Institute of Mining and Metallurgical Engineers, Inc.)

When high-grade bauxite, containing from 3 to 7 percent of silica, is used in the Bayer process, the amount of aluminum oxide converted to aluminum silicate that can be recovered is insignificant. However, the supply of high-grade ore in the United States is rapidly being depleted, and low-grade ores, with silica content as high as 15 percent, of necessity must be used. Since 1 pound of aluminum oxide and 1 pound of soda are lost in the red-mud residue for each pound of silica in the bauxite, the loss is appreciable when ores high in silica are used.

The Combination process has made practicable the utilization of the large reserves of ores not amenable to economic treatment by the Bayer process because of high silica content, but richer in alumina than clay or other available low-grade ores.

By making possible the utilization of low-grade ores, the Combination process has been of inestimable value in extending the Nation's commercial bauxite reserves and providing a source of supply of ore during a war emergency when foreign sources might be cut off to an even greater degree than was the case in World War II. An over-all recovery of as much as 94 percent of the alumina in high-grade bauxite has been achieved by the Combination process. Yields of 90 percent of the total alumina in low-grade ores having a high silica content are economically extracted by this process. Normal recovery by the Bayer process from high-grade bauxite is 80 to 85 percent, and the amount of alumina recovered when bauxites high in silica are treated is 70 percent or less.

PEDERSEN PROCESS

The Pedersen process is used advantageously with bauxite ores that contain a high percentage of iron as an impurity. In this process bauxite is smelted with limestone and coke in electric furnaces. The iron compounds are drawn off and poured as pig iron of high quality. The slag, containing the aluminum as calcium aluminate, is pulverized and treated with soda solution. As in the Bayer process, the aluminum is dissolved, forming a solution of sodium aluminate. The silica and other impurities form an insoluble mud. The solution of sodium aluminate is treated with flue gases from the smelting operation, causing aluminum hydrate "mud" to precipitate and settle to the bottom of the precipitating tank where it is drawn off, filtered, and calcined. The soda solution remaining in the tank is ready for reuse, without concentration by evaporation, for the treatment of new slag. The loss of soda is low. Alumina obtained by the Pedersen process has about the same purity as the product of the Bayer process and is as well suited for reduction in the electrolytic pots.

The Pedersen process is in use on a commercial scale in Norway, Sweden, and Russia in which countries the bauxite ores available contain a high iron content. It has been tried in the United States on an experimental scale in a pilot plant which yielded a good product, but the cost of production was too high to compete with the Bayer process using bauxite ores available to United States producers. It is expected that further development will result in lower costs of production.

PRODUCING ALUMINUM BY ELECTROLYTIC REDUCTION OF ALUMINA

HALL PROCESS

The American aluminum industry is founded on the process invented by Charles Martin Hall in 1886. It is a continuous electrolytic process in which alumina is dissolved in molten cryolite and then electrolyzed by direct current into its components, oxygen and aluminum. The oxygen ion migrates to and combines with the carbon anode to form carbon monoxide or carbon dioxide, thus liberating the aluminum at the cathode as pure molten metal. Approximately 2 pounds of dry alumina are required to make 1 pound of aluminum.

The electrolytic cell, or pot as it is usually called, in which this process is carried out, is a rectangular steel box lined with firebrick and carbon blocks or carbon casing in which is imbedded the cathode connection to the negative or return bus bar. The anode may be either a prebaked carbon block or a Soderberg self-baking electrode. A prebaked carbon block is about 12 to 14 inches square and 12 inches long and is made of a mixture of petroleum coke and coal-tar pitch. As many as 24 prebaked anodes are used in each pot, each connected by copper bar to the positive bus bar. The anodes are so arranged that they may be lowered into the pot as the carbon is consumed and withdrawn individually when replacement of the electrode is necessary. The carbon lining of the pot does not combine with the released oxygen from the alumina, but it does deteriorate and wear out, requiring replacement about every 2½ years.

Carbon thus becomes an important factor in aluminum production. About two-thirds of a pound of carbon in the form of petroleum coke and coal-tar pitch, is consumed for every pound of metallic aluminum produced.

The size of the pot varies. Some plants built during World War II have pots whose outside dimensions are approximately 12 by 15 by 3 feet high. Other plants use a pot that is 20 feet long and 8 feet wide. A pot of either size has a capacity of about 500 pounds of aluminum every 24 hours. The trend, however, is to larger units. This is revealed in comparing the 18,000-ton (per year) capacity potlines built during World War II with the 54,000-ton capacity of at least one potline now under construction (Lutjen, 1953).

A potline usually consists of approximately 100 electrolytic cells arranged in series. Direct current is used, and the voltage drop is approximately 6 volts per cell. The size of the cells determines the amperage that will be required at the bus bars of a potline. Current characteristics commonly used are 600 volts d-c at 60,000 amperes. Some recently built potlines, however, operate at 100,000 amperes. Approximately 10 kilowatt-hours of electric power is required to produce 1 pound of aluminum. An itemized tabulation of the total power requirements for electrolytic reduction of 1 pound of pig aluminum at a representative plant is as follows:

	Kilowatt-hours
General plant purposes	0.8
Conversion loss a-c to d-c	.4
Electrolysis	8.3
Total per pound of aluminum	9.5

Cryolite, either natural or synthetic, to which aluminum fluoride has been added, is maintained in molten state at a temperature of about 1,800°F by the flow of an electric current passing from the anode through the bath of cryolite to the cathode. Alumina is dropped onto the surface of the molten cryolite, and the crust of solidified cryolite is broken periodically. The alumina is quickly dissolved and electrolytically reduced to its components—oxygen, which combines with carbon of the anode to form carbon monoxide and carbon dioxide, and pure aluminum. The released aluminum remains in the molten state and settles to the bottom of the pot. Pure molten aluminum is siphoned from the pot into a ladle from which it is poured into pigs weighing up to 50 pounds or into billets weighing as much as 1,000 pounds or more.

SODERBERG PROCESS

This improvement of the Hall process avoids the frequent changes of prebaked anodes by the use of continuous electrodes. The Soderberg type of anode is continuously formed and baked in place in a consumable aluminum sleeve on top of the reduction cell as the anode functions.

Pots equipped with Soderberg electrodes can be completely enclosed for collecting gases from the reduction process. The gases are conducted by ducts and headers from the pots to gas scrubbers.

HEROULT PROCESS

At about the same time that Hall invented his process, a French metallurgist, Paul L. T. Heroult, made the same basic discovery. Heroult filed a patent application in France that antedated by several months the application filed by Hall with the U. S. Patent Office in July 1886. This interference was resolved when Hall proved that he had reduced his invention to practice in February 1886, thereby taking priority over Heroult's patent application.

METHODS USED IN THE UNITED STATES

All plants in the United States now engaged in the production of alumina on a commercial scale employ the Bayer process with the exception of two plants which use the Combination process.

One of the problems confronting the aluminum industry is to perfect processes for beneficiating clays and other domestic materials at a cost comparable with the Bayer treatment of high-grade bauxite for the production of pure aluminum oxide.

Various processes have been investigated at Government-owned pilot plants, including one using alunite and a lime-sinter process using clay. Costs of producing alumina by the process using alunite and the Pedersen process using high-iron bauxite are approximately 50 percent higher than by the Bayer process. Further development work at pilot plants is expected to result in lower production costs.

The Hall process for the production of aluminum by electrolytic reduction of alumina is used in all reduction works in the United States.

EFFECT OF VARIATIONS IN PLANT OPERATION ON WATER REQUIREMENTS

Although all alumina plants in the United States operate on the same basic process, it was recognized that local conditions caused wide variation between plants in the quantity of water used. Field investigations were undertaken to determine the manner in which each plant used water for plant and process requirements, the conditions peculiar to each plant that would account for the variation in water requirements, and all other pertinent water-use factors. For example, even though the chemical process for obtaining aluminum oxide from bauxite is essentially the same at all alumina plants, different procedures are employed to cool the sodium aluminate solution before it enters the precipitating tanks and to concentrate it by evaporation of some of the water in the solution. When this evaporation takes place in a cooling tower, water in the solution is lost to the atmosphere as water vapor and so is used consumptively. In other plants the quantity of solution in the system is controlled by evaporation in a multiple-effect evaporator where practically all of the vapor distilled out of the solution is condensed to water which may be reused. The latter method is used in all recently constructed alumina plants, and some of the older plants are replacing cooling towers with multiple-effect evaporators. This one variation of plant practice will make a significant difference in total water requirements of the plant, increasing the average daily water intake at one plant from 1.6 to 52.0 mgd but decreasing the consumptive use of water.

The variation in water requirements among reduction works is even greater than among alumina plants. As gas scrubbers are one of the principal water users in reduction works, this variation is largely accounted for by whether or not gas scrubbers are used and, if so, whether the wash water is reused. Of the 14 reduction works visited in the course of this water-use investigation, all but 3 works use gas scrubbers to wash the fumes before they are released to the atmosphere. Ducts convey the gases from the reduction pots of the gas scrubbers where the gases are washed by sprays of water which absorb fluorine gas. This gas, if passed to the atmosphere, constitutes a nuisance because of its toxic effect on vegetation. At some works where prebaked electrodes are made, fumes from the carbon plant also are scrubbed. When wash water is reused it must be cooled, and the method employed to cool it makes a considerable difference in the quantity of water lost to the atmosphere by evaporation. Several reduction works, having an abundance of low-cost water available, find it more economical not to reuse water from the gas scrubbers. The quantity of water used per pound of aluminum produced at such works is high, and the percentage of the total water intake used for gas scrubbing also is high. At one reduction works where the water from the gas scrubbers is not reused, approximately 95 percent of the total intake of 30.9 mgd is used for gas scrubbing.

The total water intake for each reduction works, its production of alumina or pig aluminum, and the quantity of water required per unit of product are facts readily obtainable. The objective of this report encompasses the broader purpose of determining the unit quantities of water used under present conditions for each process and plant use and the minimum requirements under adverse conditions.

As the manner in which each plant is operated is dictated in some degree by conditions over which the management has no control, there is included a summary of the observations that were made at each plant. This summary is intended to show not only how water is used but also facts pertaining to why such practice is followed.

FACTORS AFFECTING LOCATION OF PLANTS

ALUMINA PLANTS

The quantity of raw materials required by the aluminum industry is enormous. Production of alumina in 1952 was approximately

2 million tons, and the unit quantity of materials needed to produce a similar unit of aluminum is shown graphically in figure 20.

The two most important elements of cost in the production of alumina and its delivery to the smelter are bauxite and transportation. Taken together they account for 30 to 40 percent of net mill costs of primary aluminum and approximately 20 percent of its selling price.

Prior to the first great expansion of the industry resulting from World War II, most of the alumina produced was derived from domestic bauxite. As the chief domestic high-grade ore deposits are in Arkansas, it was logical to locate the alumina plants near the source of supply of the principal raw material.

In recent years more and more bauxite is being imported, principally from the Guianas and the West Indies. Alumina plants built to utilize ores from these sources are located on deepwater channels where ore carriers can dock alongside the plants.

REDUCTION WORKS

The largest cost item involved in the smeltering of aluminum is electric power. The power consumption in 1952 for the production of aluminum was more than 13 billion kilowatt-hours. Low-cost production is dependent upon low-cost electricity. As it takes approximately 10 kilowatt-hours of electric power to produce 1 pound of aluminum in the electrolytic cell, a variation in power cost of as much as 0.1 mill per kilowatt-hour has a significant effect upon production costs. With power costs at the remarkably low average of approximately 2 mills per kilowatt-hour, the percentage of net plant costs per pound of aluminum for power is from 16 to 21 percent.

When the aluminum industry began its first great emergency expansion program to meet World War II needs, most of the new reduction works were built near the great hydroelectric powerplants in the Pacific Northwest. Plants so located, constituting about 30 percent of the total United States plant capacity, are the reduction works at Troutdale, Oreg., and at Tacoma, Spokane, Vancouver, Wenatchee, and Longview, all in Washington. However, power shortages and higher freight rates on alumina and pig aluminum have reduced the advantage of low-cost electric power.

So urgent was the need for rapidly expanded production of aluminum that cost of production became a secondary consideration.

Some reduction works were located by necessity near existing sources of electric power even though the cost of that power was greater than the industry could afford to pay under normal conditions of competition. Such high-cost producers became unprofitable when the wartime needs of the military decreased. Some of them were dismantled and are not included in this report. Others, such as the plants at Massena, N. Y., and Badin, N. C., were retained as marginal operators and were put back in operation to ease the shortage while new plants were being constructed to meet the industry's second great emergency expansion program, which started in 1951.

The more recently built plants have been located in the Gulf of Mexico area, nearer to the source of supply of alumina. There the electric power required to operate the potlines, whether purchased from a utility company or produced at the plant, is generated principally by natural gas used as fuel burned either in a steam powerplant or in internal-combustion engines. The most recent plant, at Rockdale, Tex., will use power developed by steam turbogenerators in a plant in which charred lignite is the fuel.

Expansion of the industry is likely to occur either in areas unattractive to general industrial development, such as Alaska, or in areas likely to have reliable long-term cheap power through the use of natural gas, lignite, and coal.

FINDINGS OF THE SURVEY

SOURCES OF WATER

Water for the plants surveyed is obtained from both surface-water and ground-water sources and is supplied to the plants by both municipal and company-owned waterworks. Brackish water is used in two reduction works, principally for fume scouring. Several plants obtain water from more than one source.

A summary of the sources of water for 6 alumina plants and 14 reduction works is shown in table 2. The quantity of water and the percent of total intake from the various sources used at alumina plants and reduction works are shown in tables 3 and 4, respectively.

Table 2.—*Sources of water, alumina plants and reduction works, 1952*

[Compiled from data obtained at the plants]

Source	Number of plants	
	Alumina plants	Reduction works
Surface water only	4	7
Ground water only	1	4
Surface and ground water	1	1
Ground water and brackish surface water	0	2
Total	6	14

Table 3.—*Quantity and percent of water from various sources used at alumina plants, 1952*

Source	Thousands of gallons	Percent of total intake
Surface water	[1]8,326	70.5
Ground water	3,475	29.5
Brackish	0	0
Total	11,801	100.0

[1]An additional 50.4 mgd is planned to be used for barometric condenser-cooling water.

Table 4.—*Quantity and percent of water from various sources used at reduction works, 1952*

Source	Thousands of gallons	Percent of total intake
Surface water	[1]65,685	62.8
Ground water	35,842	34.4
Brackish	2,996	2.8
Total	104,523	100.0

[1]An additional 500 mgd is used for condenser-cooling water at thermoelectric generating plants.

EFFECT OF SIZE OF PLANT ON WATER REQUIREMENTS

The six alumina plants fall into two general sizes; those having a capacity of approximately 2 million pounds per day and those having approximately double that capacity. Each of the three smaller plants used more water per pound of alumina produced than did any of the three larger plants. Furthermore, there was considerable uniformity in the water requirements of the three smaller plants. The one that had the highest unit water requirement used about one-third more water per pound of alumina than did the small plant that had the lowest unit requirement. The variation in unit water needs in the group consisting of the three larger plants was far greater than that in the smaller plants; the highest unit water requirement was $2\frac{1}{2}$ times the lowest.

The largest use of water at alumina plants is for makeup water to the red-mud lake to compensate for losses due to evaporation. If the capacity of a given plant were doubled and the areal extent of the red-mud lake were not increased, it follows that the surface evaporation would remain approximately the same as it formerly was and the unit loss from this cause for the enlarged plant would be less per pound of product. This assumption is borne out in general by the data obtained in the course of the survey, but the wide variation in unit water use between plants of similar size indicates that other factors have a greater effect on the water requirements for a given plant. For example, the annual quantity of precipitation added to the red-mud lake varies by plant location and has a significant effect on the quantity of water added to the lake as makeup.

The 14 reduction works visited do not have even this slight degree of conformity of economy based upon plant capacity. There is not sufficient uniformity in capacity of the individual plants to permit grouping them by size. Neither is there any apparent relationship between plant size and unit water requirements. The plant that has the lowest water requirements per pound of pig aluminum is next to the smallest in plant capacity. The second-best plant in water economy is next to the largest of all reduction works, having a capacity more than three times that of the plant having the highest water economy. The plant having the smallest daily production uses more than 13 times as much water per pound of aluminum as does the second smallest.

It is concluded, therefore, that plant capacity, in itself, has so little effect on plant water requirements that other conditions—such as plant operation based on cost of water, plant location, and need for conservation of water—mask any economy inherent in plant size.

PLANT USES OF WATER

Although the chemical process is essentially the same in all alumina plants located in the United States, the manner in which various plants are operated differs sufficiently to make direct comparisons difficult. For example, in some plants water from the distribution mains is added to the cycle as hydrate wash water and is charged as such in the plant water balance. At other plants, the condensate from the evaporators is used for hydrate wash, and water for this purpose does not appear in the water balance as a charge against water intake. At others, wash water is taken from the red-mud lake, and the water thus used is charged as lake makeup.

Table 5 shows how the total daily plant intake of water is charged to the various plant and process uses at alumina plants. The water intake is tabulated in gallons per day and in percent of total plant intake for the industry.

Table 5.— *Uses of water in alumina plants, in gallons per day and percent of total intake, 1952*

[Compiled from data obtained at the plants]

Use	Thousands of gallons per day	Percent of total intake
Sanitary and washhouse	984	8.4
Cooling water	3,591	30.4
Hydrate wash	550	4.7
Red-mud lake makeup	6,676	56.5
Total	11,801	100.0

Water requirements of the electrolytic process used in reduction works are entirely different from the water uses at alumina plants. Table 6 shows the quantity of water used per day for various purposes at reduction works and the percentage of the total water intake charged to each water use.

Table 6.—*Uses of water in reduction works, in gallons per day and percent of total intake, 1952*

[Compiled from data obtained at the plants]

Use	Thousands of gallons per day	Percent of total intake
Engine cooling	1,168	1.1
Air-compressor cooling	714	.7
Sanitary and plant	8,682	8.3
Boiler-feed makeup	416	.4
Electrode plant	1,420	1.4
Rectifier and transformer	13,524	13.0
Gas scrubber	78,599	75.1
Direct-chill billet casting	1,357	1.3
Total	104,523	100.0

Several reduction works are equipped to cast aluminum in billets and pigs by the rotary-cast method. Both of these processes use water consumptively for quenching by direct chill. The production of the industry, as shown in this report, is stated in terms of production of pig aluminum even though some of that tonnage is cast in billets. The additional water used when billets are cast by the direct-chill method is included in the water balance of the plants so equipped.

The unit quantity of water required for cooling transformers and rectifiers ranges from zero to 9.28 gallons per pound of pig aluminum. The plants that use no cooling water for this purpose generate electric power by internal-combustion engines at 600 volts d-c for direct connection to the bus bars of the potlines. Even when high-voltage a-c electric current is purchased, the quantity of water used for conversion or rectification to d-c current ranges from 0.72 gallon to 9.28 gallons per pound of aluminum. At the plant having the lowest unit water use, the cooling water from the rectifiers is recirculated in a closed system through air-cooled heat-transfer units. Water must be conserved at this plant, and the low water requirement for rectifier cooling justifies the first cost and maintenance of the equipment necessary to effect this saving of water. The plant having the highest unit use of water for current rectification is so located that there is no economy in plant operation to be gained through recirculation of cooling water.

The quantity of water required by the sprays in gas scrubbers is the largest water use at reduction works, accounting for 75 percent of the total water intake of all such works. Three of the older reduction works are not equipped with gas scrubbers; all recently built plants are so equipped to eliminate or considerably lessen air pollution. At one plant, where water is available in abundance, as much as 95 percent of the total plant intake is used for gas scrubbing; this amounts to 28.50 gallons of water per pound of aluminum. At the other extreme is a plant that uses purchased water for gas scrubbing. By the use of cooling ponds, makeup water for gas scrubbing is only 3 percent of plant intake, equivalent to 0.04 gallon of water per pound of product. The variation in use of water between these two plants, both accomplishing the same degree of protection against air pollution but differing in the need to conserve water, is about 700 to 1. It is such wide variations in the quantity of water used for similar purposes at different plants, but operating under different economic compulsion to save water, that makes it difficult to state categorically the quantity of water required in the necessary processes for the production of aluminum.

As indicated by the foregoing observations, the total water requirements of alumina plants and of reduction works differ greatly. Despite the fact that the process in alumina plants is a chemical one in which an enormous quantity of liquid recirculates through the various stages of the Bayer process, the total daily water requirements of all such plants is only about one-ninth of the total required by all reduction works; 11.8 mgd as compared to 104 mgd.

The percentage of the total daily water intake of all alumina plants and of all reduction works that is used for various plant and process requirements is shown in figure 23.

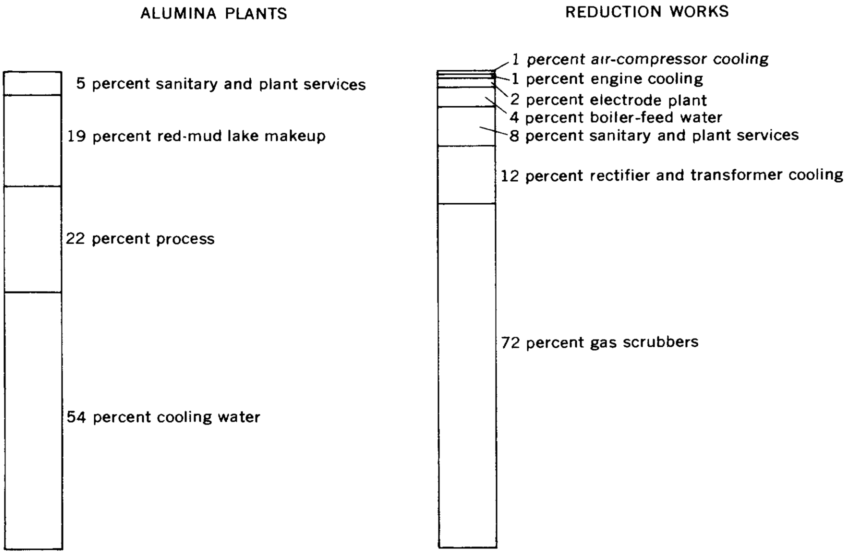

Figure 23.—Percentage of total water intake for various plant uses.

CONSUMPTIVE USE OF WATER

With but one exception all alumina plants and reduction works were reported by the plant managements to have an adequate supply of water for plant and process needs. Only one plant is handicapped by a source of water that is seasonally deficient for the plant water requirements. This plant obtains all its water directly from a stream, the flow rate of which at times is less than the water requirements of the plant. As the water of the creek cannot be impounded, the plant has been designed with an exceptionally large brown-mud lake which is depleted at times of low flow and refilled when the flow of the stream is in excess of plant requirements.

Although the supply of water for all other plants is ample for all plant needs, the economic factor of the cost of water differs considerably between plants. It is this factor that accounts in large measure for the widely divergent plant practices in the use of water.

For example, consider two previously discussed alumina plants, both of which buy all water for plant requirements from municipal waterworks. Because the cost of this water is higher than the average cost of water pumped by company-owned plants from surface-water sources or from wells, the management of each of these plants makes complete utilization of the water intake by reuse. No water is discharged from either of these plants as a liquid, and the entire plant intake is used as makeup to compensate for water lost to the atmosphere as water vapor. Thus the water requirement for the above-mentioned plants is reduced to an absolute minimum, and the entire plant water intake is used consumptively. On the other hand, another plant obtains its water for process use from wells on the property at low pumping cost and will pump cooling water from a river for the barometric condenser to be used with the sextuplet-effect evaporator now being constructed. It is more economical for this plant merely to use the cooling water once and discharge it to the river than it would be to reuse the water by means of a spray pond or cooling tower and furnish only enough to make up for the water consumptively used.

Production costs similarly dictate the degree of utilization of water used in reduction works. Low-cost water is obtained at five reduction works either directly from a river or from wells hydraulically connected to the river. At all these works water is used but once. At one works, water is available in abundance, but it is relatively costly owing to the required water treatment. Because of this fact, it is desirable to reuse water in the interests of decreasing plant costs. Two works use water furnished by a municipal source; the supply for both works is ample, but the cost is high. At both works utilization of water is carried out to such a degree that practically all the water taken into the distribution mains leaves it as water vapor.

Of six alumina plants in operation, three use the entire plant water intake consumptively. It would seem, therefore, that when conditions require it, the water requirement for an alumina plant can be reduced to the quantity of water used consumptively.

No reduction works achieve 100 percent consumptive use, although one reported only 2 percent of the total water intake was discharged as waste water. Two plants reported about 80 percent consumptive use of water.

When the supply of water is inadequate, economy of water must of necessity be practiced. When the cost of utilizing water one time is higher than the cost of reusing it, the highly competitive status of the aluminum industry can be depended on to bring about a greater degree of reuse in order to lower production costs.

QUALITY OF WATER

The necessity of furnishing pure water for the health protection of employees is the same for alumina plants and aluminum reduction works as obtains in manufacturing plants in general. Water used for plant purposes such as drinking, washhouses, sanitary fixtures, cafeterias, and kitchens is chlorinated at all but 2 of the 20 plants covered by this report. The source of supply of water for these two plants is ground water pumped from deep wells. Periodic examinations of water samples for bacteria are made, which to date have indicated no need for chlorination. Water is furnished to some plants from municipal waterworks and is treated for domestic use before entering the distribution mains. Other plants have their own sources of supply, pumping water from wells or rivers. The entire plant intake from such sources is chlorinated at the pumps. Additional treatment, consisting of coagulation and filtration, is given to the water at all plants where river water is used for process.

Water of good quality for process use is a prerequisite for alumina plants because impurities introduced by process water entering the liquor cycle as hydrate wash tend to accumulate in the caustic soda solution and to impair its function. The water, pumped from deep wells, which is used at one alumina plant requires no treatment other than chlorination for bacteria control and control of algae growth in the mains. Cooling water used at this plant is obtained from a river adjacent to the plant. Ground water, pumped from eight company-owned wells located on the plant site, is used for process at another alumina plant. As this water has a total hardness of 16.7 grains per gallon, that portion of process water which enters the liquor cycle is softened by cation exchange. The remaining four alumina plants all use river water, and in three of these plants all plant intake water has been chlorinated, coagulated, and filtered prior to delivery to the plant. At the fourth plant, which obtains its water from a stream, the only water treated is that used for such plant uses as drinking, washhouses, and sanitary lines. Process water is not treated. The explanation of this departure from normal procedure lies in the fact that this plant uses the Combination method, and the brown-mud lake is exceptionally large to provide storage when the flow of the stream is deficient. Its 200 acres of surface permits the brown-mud lake to act effectively as a cooling pond. At this plant, and others similarly equipped with sextuplet-effect evaporators, most of the process water is used as cooling water. Condensate from the evaporators is used as hydrate wash and, as such, enters the liquor cycle free from objectionable impurities in solution. The increasing use of multiple-effect evaporators in the liquor cycle, therefore, in addition to improving over-all efficiency, has the important advantage of enabling alumina plants to utilize water of inferior chemical quality without as complete treatment as would be required were that water introduced directly into the liquor cycle as hydrate wash.

The quality of water for some plant uses at aluminum reduction works is of great importance, but the quantity of water required for those uses is a relatively small percent of the total plant intake. The quality of water used as boiler-feed makeup is important, and because reduction works, unlike alumina plants, do not have condensate water as a byproduct of process, all boiler-feed makeup water is given such treatment as is necessary. At one plant, brackish water is evaporated, and the condensate is used for boiler-feed water. The principal use of water at reduction works is for wash water at the gas scrubbers, and for this the quality of the water used is unimportant. Brackish water is satisfactorily used at one plant in the gas scrubbers. The relative unimportance, quantitatively, of the quality of water required for aluminum reduction works is shown in figure 23. The average amount of water used for gas scrubbers is 72 percent of the total water intake. Thus it is seen that reduction works can be so designed that even brackish water can be used for a major portion of its total water intake. Water of high quality, required for boiler feed, averaged only 4 percent of total plant intake.

TREATMENT OF WATER

Table 7 indicates the frequency of occurrence of various kinds of water treatment given to all or part of the plant intake.

Table 7.—*Kinds of water treatment*

	Alumina plants (6)	Reduction works (14)
Chlorination	6	12
Coagulation	5	7
Filtration	5	7
pH adjustment	3	5
Softening	1	5

Water used for drinking and sanitary purposes at all six alumina plants is chlorinated. Five of these plants obtain water for all purposes from surface-water sources, either municipal waterworks or company-owned pumping plants. All these plants treat further all or part of the water intake by coagulation and filtration. Three plants find it necessary to condition the water further by pH adjustment. Only one alumina plant obtains its supply of water entirely from ground-water sources. At that plant the water pumped from wells located at the plant site is chlorinated before entering the distribution mains.

Of the 14 aluminum reduction works visited, all but 2 chlorinate all or part of the plant water intake, and these 2 exceptions obtain their entire supply from ground-water sources. The water at all seven plants that use surface water requires further treatment by coagulation and filtration either at the municipal waterworks or at company-owned pumping plants. The electrolytic process at reduction works does not provide condensate from evaporators as does the chemical process of extracting aluminum oxide from bauxite, so that boiler-feed water is a matter of concern to the management even though the quantity for this use is an extremely small percent of total plant intake. Ten reduction works, of the total of fourteen, treat boiler-feed water further either by pH adjustment or by zeolite softening.

TREATMENT AND DISPOSAL OF WASTE WATER

The problem of disposing of sanitary sewage at alumina plants and reduction works is the same as that which confronts the management of any other kind of industrial plant or the adjacent municipalities. Disposition of sanitary waste water at three alumina plants is made to the red-mud lake, either treated or raw, in order to effect economy of water. Because aluminum reduction works have no such opportunity to reuse sanitary waste water, all 14 works discharge the waste from sanitary sewers into a river or the sea; sewage is given the Imhoff treatment in all but three.

The disposition of waste process water at alumina plants presents no problem. Although the supply of water is adequate, its cost at three such plants is high, so that it is desirable in these plants to return all waste process water to the red-mud lake. Because the supply of water at one alumina plant is inadequate at times, the supply available is supplemented by returning all waste water to the brown-mud lake. At the other two alumina plants, waste process water is dumped, untreated, into the river.

Waste process water is recirculated at five reduction works. The quantity of water used at these works for all plant uses other than sanitary service reflects the quantity lost to the atmosphere as water vapor. The remaining nine reduction works discharge waste process water into a stream or bay.

Tables 8 and 9 summarize how sanitary sewage and plant process water is disposed of at alumina plants and reduction works, respectively, and indicate whether the waste water is treated.

Table 8.— *Treatment and disposal of waste water at alumina plants*

Method of disposal	Frequency of occurrence	
	Sanitary sewage	Process water
Red-mud lake, treated	1	0
Red-mud lake, untreated	2	4
Stream, treated	1	0
Stream, untreated	1	2
Bay, untreated	1	0
Number of plants	6	6

Table 9.— *Treatment and disposal of waste water at reduction works*

Method of disposal	Frequency of occurrence	
	Sanitary sewage	Process water
Stream, treated	8	1
Stream, untreated	3	7
Bay, treated	2	1
Bay, untreated	0	0
Septic tank	1	0
Recirculated	0	5
Number of plants	14	14

POLLUTION FROM PROCESS WASTE

There is no pollution problem involved in disposing of waste process water at alumina plants. The principal use for water which leaves the plant in liquid form is for cooling purposes and as such is not contaminated. Water added to the caustic soda solution in the chemical process used at such plants is removed from the solution either directly as water vapor as in the case of cooling towers or as condensate from evaporator and aftercondenser.

Pollution is more serious at reduction works. Fumes given off by the electrolytic action in the cells contain fluorine which destroys vegetation for a considerable distance from the plant and is harmful to cattle grazing in the affected area. All the reduction works constructed in recent years have overcome this nuisance by scrubbing the flue gases. Particles of aluminum oxide and carbon are removed, in some instances by mechanical separators, and the gases are scrubbed with a water spray which removes fluorine by absorption and the particles too fine to be removed by mechanical means.

At those plants where the waste water from the gas scrubbers is discharged directly into a river the acid formed by the absorbed gases, principally fluorides, undoubtedly would cause stream pollution were the flow of the stream not sufficient to render them harmless by dilution. To avoid stream pollution from this source two plants discharge the waste water from the gas scrubbers to settling ponds where lime is added to neutralize the acids. The sludge resulting from precipitation is removed and safely disposed of by burying.

SUMMARY OF PLANT WATER-USE DATA

The following water-use data were obtained from the water balances of the individual plants as reported by the plant managements. The water-use data are based on operating conditions obtaining at the time the plants were visited in 1952.

Important changes in plant operation were being made at several alumina plants and reduction works. These changes will affect the water-use data at those plants and the averages for the industry.

ALUMINA PLANTS

A summary of the water-use data of 6 alumina plants indicates that the industry was using approximately 11.8 mgd in order to produce 17.9 million pounds of alumina per day.

The unit water use ranged from 0.28 gallon to 1.10 gallons of water per pound of alumina. The average over the industry was 0.66 gallon per pound of alumina.

A sextuplet-effect evaporator was under construction at one alumina plant, the last stage of which will consist of a barometric condenser taking condensing water from a river and returning it to the river on a once-through-to-waste cycle. The maximum quantity of water that will be required for this operation is estimated to be 50.4 mgd.

This single modification of plant operation will increase the total quantity of water used by the industry for the production of alumina from 11.8 to 62.2 mgd. The range of unit water use between plants will be increased from 0.28–1.10 gallons of water per pound of alumina to 0.28–26.00 gallons per pound. The average for the industry also will be greatly changed when this evaporator is put in operation, increasing the average unit water use from 0.66 gallon to 3.48 gallons per pound of alumina.

Table 10 is a summary of water-use data of alumina plants, as operated at the time the survey was made and as they are expected to be after the barometric condenser has been put in operation.

Table 10.—*Summary of water-use data for alumina plants, 1952*

[Compiled from data obtained at the plants]

Alumina plants	Present use	After plant changes
Daily water intake, thousands of gallons	11,801	62,201
Daily plant output, thousands of pounds	17,936	17,936
Unit water use, gallons per pound:		
Minimum	.28	.28
Maximum	1.10	26.00
Industry average	.66	3.48

REDUCTION WORKS

A compilation of water-use data from 14 reduction works shows that the total water intake was approximately 104.5 mgd to produce 7.1 million pounds of pig aluminum per day.

The unit water use varied even more between reduction works than it did between alumina plants, ranging from 1.24 to 36.33 gallons of water per pound of aluminum. The average for the industry was 14.62 gallons per pound.

The proposed installation of additional gas scrubbers at one plant will nearly double its total water intake, adding approximately 10 mgd to the present plant intake.

A summary of water-use data for reduction works is given in table 11. This table, as does the preceding one, shows daily intake and average unit water use for the industry under operating conditions found when the plants were surveyed and as they are expected to be after plant changes in the use of water are effected.

Table 11.—*Summary of water-use data for reduction works, 1952*

[Compiled from data obtained at the plants]

Reduction works	Present use	After plant changes
Daily water intake, thousands of gallons	104,523	[1]114,523
Daily plant output, thousands of pounds	7,148	7,148
Unit water use, gallons per pound:		
Minimum	1.24	1.24
Maximum	36.33	36.33
Industry average	14.62	16.05

[1]500 mgd of condenser cooling water for thermoelectric power generation is not included.

These several examples illustrate the profound effect major changes in plant operation have on total water intake and unit water use, not only of the plants involved but on water requirements for the industry. Any comparison of water-use data, therefore, must take into account the dates of the comparative data, the plant practices obtaining at those times, and the water uses included.

WATER USE PER UNIT OF PRODUCT

The average for all alumina plants in the United States of the quantity of water required for all plant and process uses for the chemical production of 1 pound of alumina from bauxite, as determined when the plants were surveyed in 1952, was 0.66 gallon.

On the same basis the average quantity of water required for the production of 1 pound of aluminum from alumina by electrolytic reduction was 14.62 gallons.

However, if the information sought is the average quantity of water required to produce 1 pound of aluminum from bauxite, not only must the water requirements for alumina production be taken into consideration but also the fact that approximately 2 pounds of alumina are needed to produce 1 pound of pig aluminum, making a total water requirement of 15.94 gallons.

Average water use, in gallons, to produce 2 pounds of alumina	1.32
Average water use, in gallons, for reduction to 1 pound of aluminum	14.62
Total average water use, in gallons, per pound of pig aluminum from bauxite	15.94

CONCLUSIONS

When economic conditions demand it, the water requirements of plants engaged in the production of virgin aluminum from bauxite can be reduced to an exceedingly low quantity per unit of product. The gross plant intake, however, assumes significant volume because of the large production capacity of these plants.

Alumina plants and aluminum reduction works are designed and built as a complete unit. When unforeseen circumstances require rapid expansion of plant capacity such as occurred during World War II and again more recently, any increase in the size of existing plants was made in large increments, frequently doubling their capacity. Plant growth in the aluminum industry is not achieved by small additions here and there to take care of constantly increasing demand for product. The water requirements of the completed plant therefore can be designed for a known production by a known process with which the management is familiar from experience.

The range of the quantity of water required at alumina plants, from a minimum of 0. 28 gallon of water per pound of alumina to a maximum of 1. 10 gallons, is considerable but not nearly as great as that at aluminum reduction works at which the gallons of water per pound of pig aluminum range from 1. 24 to 36. 33. As the size of the plant has a relatively minor effect upon the unit water use, other local conditions must of necessity be the principal controlling factors.

Meteorologic phenomena—such as local precipitation, air temperature, relative humidity, and wind—have some effect on plant water intake. The following observations illustrate the effect of climatic conditions on total plant water requirements of two plants. All the water used by each of them is purchased from a municipal supply. Both plants are operated in such a manner that water is used to the best economic advantage; the first plant uses consumptively 92. 5 percent of the total water intake, the second approximates 100 percent consumptive use. Despite the fact that both plants are operated to use water most economically, the unit water requirement varies in the extreme. The first plant uses 0. 28 gallon of water per pound of alumina, the lowest unit water use of all alumina plants; the other has a total unit water use of 1. 10 gallons, which is the highest of all. This disparity is attributed largely to different rates of evaporation from the red-mud lakes and partly to differences in replenishment of the red-mud lakes by precipitation. The annual precipitation (U. S. Weather Bureau, 1953a), in the area of the first plant is 67. 21

inches; that at the second plant, subjected to a strong, steady breeze, is estimated to be 25.44 inches (1953b).

The aluminum industry is highly competitive, not only between major producers within the industry but also with the older metallic industries (such as steel and copper). Aluminum plants are operated at a high degree of efficiency, and the management is alert to effect economy of operation. It can be taken for granted that production cost is a major factor in determining the plant water requirement. At plant locations where the supply of water is abundant, pumping costs are low, and the quality of water is such that little if any treatment is required, it may be cheaper to use water once and waste it rather than to pump the waste water to some distant part of the plant for reuse. At most of these plants the water available would be lost to the sea if not utilized. A study of their water balance shows that they are among the plants having a high unit water use.

Variations in the manner in which details of a basic process are carried out account in part for the range in unit water use between plants. It is basic in the Bayer process that the quantity of the caustic soda liquor in the cycle be held constant. For that reason water added to the liquor as hydrate wash water must be compensated for by the removal of an equal amount of water at some point in the cycle. This is accomplished by evaporation. At one alumina plant, for example, the spent liquor now is passed through cooling towers where it is concentrated by evaporation, the water vapor passing into the atmosphere. The majority of alumina plants achieve this end by sextuplet-effect evaporators, the final stage of which is a barometric condenser. An evaporator of this kind is being erected at the above-mentioned plant to take advantage of its higher efficiency as compared to evaporation effected in a cooling tower. Cooling water for the condenser will be taken from a nearby river and returned to it unchanged except for a slight rise in temperature. It is estimated that as much as 35,000 gpm will be required when the temperature of the river water is 90°F, the highest temperature on record. This one change in plant procedure will increase the average water intake of this plant approximately twentyfold and will triple the total quantity of water used by all alumina plants. It should be borne in mind that, were the large volume of river water not available, this plant probably would follow the practice of reusing the cooling water by recirculating it, thereby reducing the quantity of water utilized but increasing the quantity used consumptively.

Reduction works also differ in details of plant operation even though all reduction works employ the Hall process. Water used to scrub the gases rising from the rows of electrolytic cells constitutes a principal water use. This nuisance-abating improvement was used in all but 3 of the 14 plants in operation at the time this water-use survey was made. The increasingly insistent demand for elimination of fluorine from the gases given off to the atmosphere will tend to further the use of gas scrubbers, thereby increasing the gross plant intake of water by the industry and the unit quantity of water required per pound of pig aluminum produced.

SELECTED REFERENCES

Anderson, Samuel W., 1953, Aluminum industry expands for war and peace: Jour. Metals, v. 5, no. 3, p. 388–394.
Bray, J. L., 1947, Nonferrous production metallurgy: 587 p., 2d ed., New York, John Wiley & Sons, Inc.
Budgen, N. F., 1947, Aluminum and its alloys: 369 p., 2d ed. London, Pitman & Sons, Ltd.
Carr, C. C., 1952, Alcoa, an American enterprise: 292 p., New York, Rinehart.
Chemical and Metallurgical Engineering, 1947, Chemical Engineering flowsheets: 4th ed., p. 7.
Chemical Engineering, 1951, Lignite process hits the mark: v. 58, no. 9, p. 219.
Civil Engineering, 1953, Aluminum industry sets production record in 1952: v. 23, no. 2, p. 71.
Defense Production Administration, 1951, Bureau of Mines plans to run alumina plant: Defense Production Record, v. 1, no. 31, p. 2.
Edwards, J. D., 1945, Combination process for alumina, *in* Metals technology, v. 12, no. 5: Am. Inst. Min. and Metall. Eng., Tech. Pub. 1833.
Edwards, J. D., Frary, F. C., and Jefferies, Jay, 1930, The aluminum industry: 870 p., v. 1, 2, 1st ed., New York, McGraw-Hill Book Co., Inc.
Electrical World, 1953, Aluminum industry sets output record in 1952: v. 139, no. 4, p. 264.
Encyclopedia of Chemical Technology, 1947, Aluminum: v. 1, p. 602, New York, The Interscience Encyclopedia, Inc.
Engle, N. H., Gregory, H. E., and Mosse, Robert, 1945, Aluminum, an industrial marketing appraisal: 494 p., Chicago, Inland Press.
First Boston Corp., 1951, Aluminum, the industry and the four North American producers: New York, 79 p.
Fortune, 1951, The great aluminum farce: v. 43, no. 6, p. 93, Time Inc.
Frary, F. C., 1949, The light metal picture: Metal Progress, v. 56, no. 2, p. 204.
Kaiser Aluminum and Chemical Corp., 1951, Brochure on company's aluminum activities, Oakland, Calif., 48 p.
Lutjen, G. P., 1953, Aluminum: Eng. and Min. Jour., v. 154, no. 2, p. 88–89.
Metal Progress, 1950, Alcoa's new plant at Point Comfort, Texas: v. 58, no. 1, p. 56–59.
National Association of Manufacturers and The Conservation Foundation, 1950, Water in industry: New York, 51 p.
Office of Defense Mobilization, 1952a, Aluminum expansion will double 1950 production: The Battle for production, Fourth quart. rept. to the President, p. 15.
——1952b, Aluminum capacity will rise by over 400,000 tons in 1952: Strength for the long run, Fifth quart. rept. to the President, p. 17.
Reynolds Metals Co., 1950, The A-B-C's of Aluminum: 96 p., Louisville, Ky.
U. S. Bureau of Mines, 1953, Materials survey: Bauxite; rept. prepared in cooperation with U. S. Geological Survey, for the Office of Defense Mobilization, 305 p.
U. S. Bureau of Mines and U. S. Geological Survey, 1948, Mineral resources of the United States: Washington, D. C., Public Affairs Press.
U. S. Dept. of Commerce, 1956, Business and Defense Services Admin., Aluminum and Magnesium Div., Materials survey on aluminum (in press).
U. S. Surplus Property Board, 1945, Aluminum plants and facilities: 131 p., rept. to Congress.
U. S. War Assets Administration, 1947, Aluminum plants and facilities: 51 p., First supp. rept. to Congress.
U. S. Weather Bureau, 1953a, Climatological data, v. 58, no. 13.
——1953b, Climatological data, v. 59, no. 13.
Weldon, J. D. C., 1953, Special study of the aluminum industry: Mag. of Wall Street, v. 91, no. 10, p. 530.
Western Metals, 1953, Alcoa operates western reduction plant: v. 1, no. 10, p. 24.

INDEX

☆ U. S. GOVERNMENT PRINTING OFFICE: 1956 O—395701