Water Requirements of the Petroleum Refining Industry

By LOUIS E. OTTS, JR.

WATER REQUIREMENTS OF SELECTED INDUSTRIES

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WATER REQUIREMENTS OF THE PETROLEUM REFINING INDUSTRY

By Louis E. Otts, Jr.[1]

ABSTRACT

About 3,500 million gallons of water was withdrawn daily in 1955 for use by petroleum refineries in the United States. This was about 3 percent of the estimated daily withdrawal of industrial water in the United States in 1955.

An average of 468 gallons of water was required to refine a barrel of crude oil, and the median was 95 gallons of water per barrel of crude charge; withdrawals ranged from 6.5 to 3,240 gallons per barrel.

Ninety-one percent of the water requirements of the petroleum refineries surveyed was for cooling. One-third of the refineries reused their cooling water from 10 to more than 50 times. Only 17 refineries used once-through cooling systems. Refineries with recirculating cooling systems circulated about twice as much cooling water but needed about 25 times less makeup; however, they consumed about 24 times more water per barrel of charge than refineries using once-through cooling systems.

The average noncracking refinery used about 375 gallons of water per barrel of crude, which is less than the 471-gallon average of refineries with cracking facilities. Refineries are composed of various processing units, and the water requirements of such units varied; median makeup needs ranged from about 125 gallons per barrel for polymerization and alkylation units to 15.5 gallons per barrel for distillation units.

Refinery-owned sources of water supplied 95 percent of the makeup-water requirements. Surface-water sources provided 86 percent of the makeup-water demand. Less than 1 percent of the makeup water was obtained from reprocessed municipal sewage.

INTRODUCTION

PURPOSE AND SCOPE

This report presents the results of a survey of water used in the manufacture of petroleum products from crude oil and is one of a series describing the water requirements of selected industries that are of

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national importance. The report is designed to serve the dual purpose of providing basic information for national defense planning and of providing assistance to business and industry. This information will be helpful in planning the location of new refineries and the expansion of existing ones. A knowledge of the water requirements of industry is needed for planning the most effective use of the water resources of specific areas.

A field survey of 1955 refinery operations was made in the summer and fall of 1956; data for 1955 were collected so that information for an entire year would be available. Sixty-one, or 21 percent, of the refineries operating in 1955 were visited. They processed 30 percent of the crude oil refined in the country during 1955. Refineries were selected to give a wide range in size, geographic location, and processes used. (See fig 42.) The refineries surveyed included no natural-gasoline plants, and no attempt was made to obtain information on the water requirements of the other divisions of the oil industry—namely, exploration for and production of crude oil, transportation of crude oil or refinery products, and marketing of petroleum products.

Information was obtained on the source of water, the adequacy of the supply, the quality and treatment of the water, and the disposal of waste. Data on the amounts of gross and makeup water required, the amount reused, the amount used consumptively, and the amount of effluent were obtained for the complete refineries and for their component units. Information was obtained on use of water for cooling, boiler feed, processing and sanitary. Information on the crude charge and production of the refineries was also obtained in order to compute unit water use.

Early in 1951, J. K. Searcy (written communication) of the U.S. Geological Survey obtained information on the water intake of 63 petroleum refineries and 29 natural gasoline plants in the United States, but he did not obtain details on the use of water within the refineries. Information for 48 of the petroleum refineries were incorporated in this report where applicable.

The literature was carefully reviewed to obtain information on the water requirements of the industry and to obtain an understanding of the water-supply problems of the industry. Special acknowledgment is given to the officials and management of the petroleum refineries who permitted the author to visit their refineries and who supplied information on water use at their refineries. The author is indebted to his colleague, O. D. Mussey, who made the survey of the petroleum refineries in western Pennsylvania.

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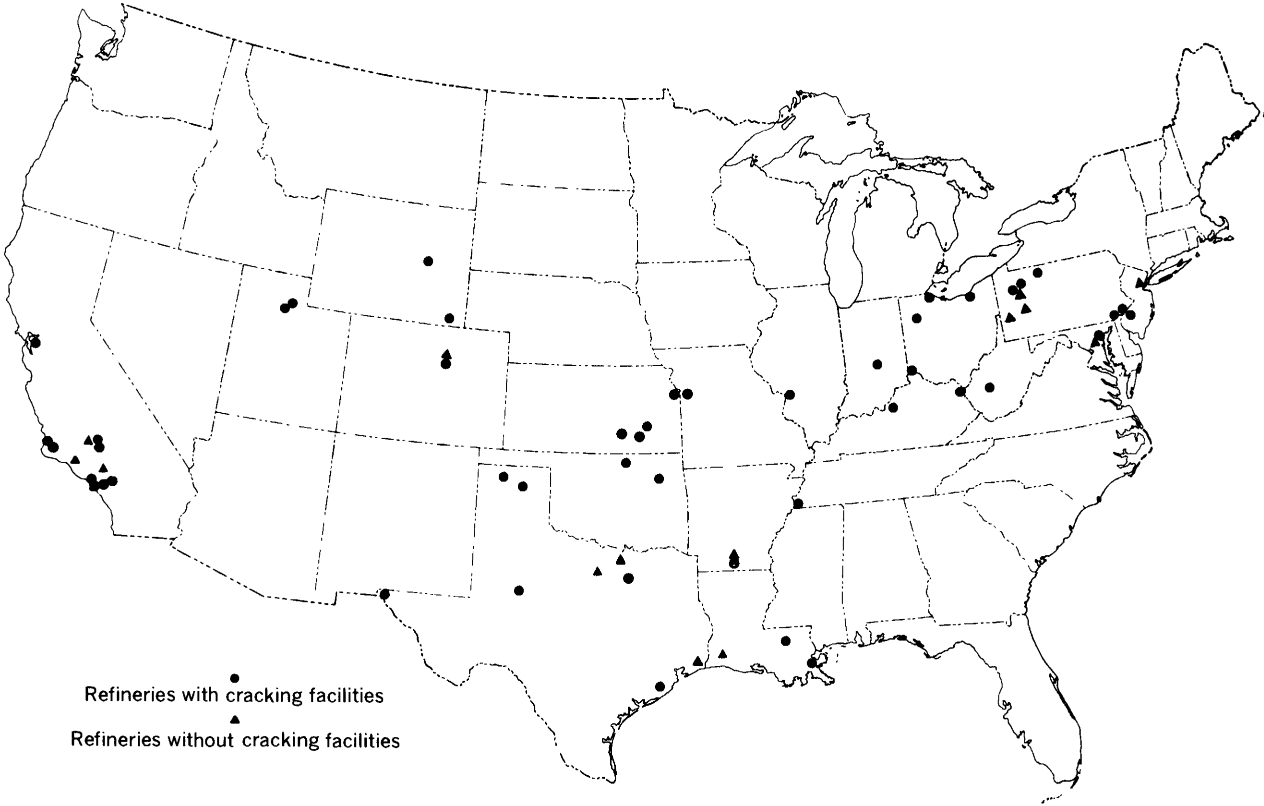

FIGURE 42.—Location of refineries surveyed, 1956.

HOW WATER IS USED

The major use of water in a petroleum refinery is for cooling. Relatively small quantities of water are used for boiler feed, processing, sanitary services, fire protection, and miscellaneous purposes. Simonsen (1952) noted that a typical 50,000-barrels-per-day refinery generates more than 1,000 million Btu. per hr and that about 50 percent of this heat is removed by water. Allowing for other water uses and assuming a 30°F temperature rise in the cooling water, he estimated the refinery would require about 40,000 gpm (gallons per minute) to remove this amount of heat. This quantity of water would have supplied the domestic requirements of the city of Toledo, Ohio, in 1952.

In petroleum refining, vapors are reduced to liquids in condensers, and coolers are used to lower the temperature of liquid products to permit safe handling. Water is the normal cooling medium used in these units; however, refineries save both heat and water by cooling high-temperature products with raw charging stocks and other cooler liquid streams.

Water requirements of early refineries were small, and the uses of water were as simple as the refining process. Water was needed only for cooling and for generating sufficient steam for the pumps. In contrast, both the modern refining process and the use of water are varied and complicated. The quantity and the quality of water required by the entire refinery and in individual operations are affected by the type of refinery process. The principal processes used are distillation, cracking, polymerization, alkylation, and treating and finishing. Detailed descriptions of petroleum refining and refining equipment can be found in the literature.

A skimming or topping refinery separates crude oil by distillation into gasoline, kerosene, fuel oil, gas oil, and reduced crude. Atmospheric distillation is generally the first step in refining crude oil. The crude oil is generally warmed by heat exchange with a fluid to be cooled. The use of the crude oil as a cooling medium reduces the amount of cooling water required. The hot oil partially vaporizes as it enters the fractionating tower. The lightest vapors are drawn off at the top of the tower and are condensed as gasoline; other fractions are drawn from the tower as side streams. Water-cooled heat exchangers condense overhead streams and cool tower side streams.

The reduced crude from atmospheric distillation may be further processed by vacuum distillation, by steam distillation, or by a combination of both to provide lubricating oil fractions or asphalt base stocks. The heavier fractions of the crude oil may be fractionated without danger of decomposition or cracking in these units, as the oil is distilled at temperatures lower than those in atmospheric units.

A vacuum distillation unit consists of a pipe still and a distillation tower operated at a reduced pressure that is maintained by the use of a barometric condenser and steam jets or vacuum pumps. This equipment requires both water and steam. Because the separations obtained in distillation towers are not perfect, the undesirable fractions in side streams are vaporized and are removed by steam stripping in short auxiliary towers known as stripping columns. Steam is also used for pumping and heating.

In the manufacture of lubricants, the lubricating-oil base stock is prepared by vacuum distillation or by propane deasphalting. The base stock is then dewaxed by chilling and cold filtering or pressing, or by solvent dewaxing. Water is used for making brine solutions in refrigeration units of lubricating-oil plants. Steam is used for cleaning filter clays, pumping, and heating.

Cracking is the breaking down of large molecules into smaller molecules. Cracking is an important process, because it not only gives an increase in the gasoline yield to 70 to 85 percent of the charge but also improves the quality of the yield. About 50 percent of the gasoline produced in this country is obtained by cracking. Cracking processes may be thermal or catalytic, and thermal cracking may be either liquid phase or vapor phase. Thermal cracking units operate at temperatures ranging from 800° to 1200°F and at pressures ranging from 600 to 1,000 pounds per square inch. Catalytic cracking units utilize a catalyst to hasten the change in molecular structure of the material being cracked and operate at temperatures and pressures generally lower than those of thermal cracking units.

Polymerization could be considered to be the reverse of cracking, as it is a process that combines two or more molecules to form a larger molecule. The process is used largely to change the byproduct petroleum gases that are produced in cracking into high-grade motor fuel and aviation fuel. Polymerization can be a thermal or a catalytic process, but thermal polymerization is not used extensively today.

In the alkylation process, complex saturated molecules are formed by the combination of a saturated and an unsaturated molecule. Alkylation can be a thermal, a thermal-catalytic, or a catalytic process, but most commercial applications are catalytic. Alkylate is the product of the process and is the principal component of many high-octane motor fuels and aviation gasolines.

Cracking, polymerization, and alkylation units use water for cooling and for other heat transfer operations. They use steam for regenerating catalysts, pumping, and heating.

Products must be treated to improve color, odor, or stability or to remove sulfur, gums, or other corrosive substances before the product is marketable. Caustic treating, acid treating, clay treating, oxidation sweetening, copper sweetening, and solvent extraction are some of the methods used to remove or alter the impurities in light distillates. Water is used for caustic and acid solutions and for product washing. Lubricating oils are treated with acids, by contact with or percolation through clay, or by solvent extraction methods. Both steam and water are used to recover solvents and to clean filter clays in lubricant treating operations.

Brines associated with many crude oils should be removed before the oils are distilled to prevent serious corrosion of refining equipment. Brines are generally removed from crude oils by scrubbing with water.

A refinery is composed of a combination of several unit processes, but no two refineries will use exactly the same process. A diagrammatic flowsheet of a refinery is shown plate 3. It is not a flowsheet of any specific refinery, nor is it a recommended refinery design. It merely illustrates how several of the more important processes may be utilized by a refinery to provide the products desired. The designation of the type of a refinery will be determined by the combinations of processes used.

The manner in which cooling water is used varies with local conditions. Generally water will be used once in areas where it is plentiful and cheap. On the other hand, where water is in short supply and its cost is high, makeup water requirements are kept to a minimum by reusing the cooling water many times. One type of reuse system uses water as a coolant for operations with low-temperature demands and then reuses the warmed water to satisfy cooling requirements of higher temperature operations. In the recirculating type of cooling system, water absorbs heat as it flows through condensers and coolers. The heat acquired by the water is removed by evaporative cooling in cooling towers, spray or cooling ponds, or evaporative condensers, and the cooled water is reused. Most refineries use once-through cooling for some operations and several types of water reuse for other operations.

The conventional recirculating cooling system in a modern petroleum refinery uses cooling towers to transfer the heat absorbed by the water to the atmosphere. The rate at which water is pumped into the cooling tower is known as the gross circulating rate. Evaporation and windage losses occur as water passes through the cooling tower, and some water is drained from the system to prevent excessive mineral concentrations. The water remaining is returned to the cooling system to be reused and is known as recirculated water. A quantity of water equivalent to the evaporation and windage losses and to the withdrawal for mineral concentration control is added to the recirculated water to maintain the gross circulating rate. This replacement is known as makeup water.

The second largest use of water in a refinery is makeup for boiler feed. The chief uses of steam are for stripping, steam distillation, and vacuum distillation. The steam comes in contact with the products in these operations, and generally the steam condensate is so highly contaminated that it cannot be reused for boiler feed or for other purposes. Steam is also used for process heating, for pumping, and, in some refineries, for generating electric power. The condensate from the condensers and traps of these systems is usually reused as boiler-feed water or as makeup for other water needs.

Smaller amounts of water are generally needed for process operations, sanitary and plant services, fire protection, and other uses. The water requirements during a fire will be large, but the average requirements for fire protection during a year will be negligible. Some refineries use separate fire-protection systems, whereas others use water from the cooling or other water systems of the refinery to fight fires. The latter method is less desirable, as the increased water needs during a fire must be entirely or partially offset by a decrease in water uses in the refining process. Some refineries also require water for company housing, and refineries with dock facilities may supply the water needs of oil tankers.

Water is used both consumptively and nonconsumptively by the petroleum refining industry. Consumptive use is water that is discharged to the atmosphere or that is incorporated in the products of the process (Am. Water Works Assoc. Task Group, 1953). Evaporation and windage losses in a cooling tower and the discharge of process steam into the atmosphere are examples of consumptive use. The discharge of once-through cooling water, cooling-tower blowdown, and discharge to waste of the condensate from a steam trap or examples of effluents and not of consumptive uses. The sum of consumptive uses and effluents equals the makeup water.

Makeup water may be new or reused. Water that is used for the first time is new makeup water, whereas water that was used in one process or operation and is being reused in another as makeup is known as reused makeup water. The sum of new makeup water for all refining operations for a day is equivalent to the daily water intake of the refinery.

The gross circulating water is the actual quantity of water circulating in a system. It is the same quantity as the makeup water if water is used only once and discharged to waste. If water is recirculated, it is the sum of the makeup and the recirculated water.

QUANTITATIVE REQUIREMENTS

PUBLISHED INFORMATION

Most descriptions of petroleum refining and processing given in the literature do not include data on water requirements. Those that do give such information usually show the total water requirements and do not subdivide the water needs by process or by type of use.

Published water requirements of selected refineries are given in table 1. The wide variation between maximum and minimum water requirements is shown by the four Standard Oil Co. of Ohio refineries reported in the table. One of these refineries that had a once-through water system used 1,870 gallons of water to refine a barrel of crude oil, whereas another that recirculated all cooling water required only 73 gallons per barrel. The possible reduction in water requirements by many refineries is suggested by this example of water conservation.

Another example of water conservation is the reduction in water requirements of the Baton Rouge refinery of the Esso Standard Oil Co. According to Miller and others (1953), in its early days the Baton Rouge refinery used about 100 gallons of water for each gallon of crude processed. Now, even though more heat and treatment for each gallon of crude are required owing to cracking and other intensive refining processes, the use of water has been reduced to 23 gallons per gallon of crude.

The literature shows that refinery processes have wide ranges of water requirements. The gallons of water used per barrel of feed stock for selected refinery processes are given in table 2. Processes with large water requirements are deasphalting, coking, reforming, and catalytic cracking.

FINDINGS OF THIS SURVEY

A typical (median) petroleum refinery of today has a daily capacity of about 16,000 barrels of crude oil. Approximately 22.5 million gallons of water circulate daily in the several water systems within the refinery. To maintain this circulation rate the refinery needs a source of water capable of providing 2 mgd (million gallons per day).

SOURCES OF WATER

Most of the 61 refineries surveyed obtained water from both surface sources and wells, although some obtained water from only one source. One refinery used sewage effluent, and nine used saline ground water or saline surface water to supply part of their requirements. About 86 percent of the total daily intake was from surface sources; nearly 14 percent was from wells; and 0.1 percent was sewage effluent. (See table 3.) Company-owned facilities supplied about 95 percent of the daily water intake, and public facilities supplied about 5 percent.

TABLE 1.—*Published total unit water requirements of selected refineries*

[Size of refinery is expressed in barrels of crude charge per day. Unit water use is expressed in gallons per barrel of crude charge except where otherwise noted]

Refinery or product	Size	Unit use	Source of information
Refinery			
Lubricating	(1)	440	Bell (1959).
Lubricating (complete)	(1)	540	Do.
Do	(1)	630	Do.
Do	(1)	1, 020	Do.
Do	(1)	1, 850	Do.
Skimming and cracking	(1)	910	Do.
Half skimming, half lubricating	(1)	250	Do.
Topping only 25 percent	(1)	210	Do.
Oil refining	(2)	[3] 770	Jordan (1946).
Complete refinery	(1)	800	Bell (1959).
Amoco, Yorktown, Virginia	35, 000		
Fresh water		43	Petroleum Processing (1957b).
Sea water (for cooling)		3, 060	Do.
Torrance Refinery, General Petroleum Corp	120, 000	34	Partin (1953).
Watson Refinery, Richfield Oil Corp	114, 000	44	Do.
Wilmington Refinery, Union Oil Co	110, 000		
Fresh water		55	Do.
Sea water (for cooling)		420	Do.
McPherson refinery, National Cooperative Refinery Association	25, 000–28, 000	47–52	Aeschliman and others (1957).
Standard Oil Co. of Ohio:			
Toledo, Ohio, refinery	21, 000	1, 870	Simonsen (1952).
Cleveland, Ohio, refinery	44, 000	311	Do.
Lima, Ohio, refinery	39, 000	144	Do.
Latonia, Kentucky, refinery	15, 000	73	Do.
Esso Standard Oil Co.:			
Baton Rouge, Louisiana, refinery	232, 000		
Total water		966	Standard Oil Co. (1950).
Cooling water		924	Do.
Linden, N.J., refinery	134, 900		
Total water		982	Do.
Salt water		953	Do.
Product			
Gasoline	(2)	357	Besselievre (1952).
Do	(2)	[4] 7–10	Gorman (1943).
Aviation gasoline	(1)	[4] 25	Youngquist (1942).

[1] Data not given in source.
[2] Average of a number of plants.
[3] Gallons per barrel of product.
[4] Gallons per gallon of product.

TABLE 2.—*Published unit water requirements of selected processes*

[Size of refinery unit is expressed in barrels of crude charge per day. Unit water use expressed in gallons per barrel of crude charge except where otherwise noted]

Process	Size	Unit use	Source of information
ANHYDROUS AMMONIA			
Service water	(1)	[2] 12, 800	Petroleum Processing (1956a).
Boiler-feed water	(1)	[2] 165	Do.
ALKYLATION			
Sulfuric acid (Kellogg):			
Refinery 1:			
Steam	(1)	[3] 74	Petroleum Processing (1957a).
Cooling water	(1)	[3] 3, 841	Do.
Refinery 2:			
Steam	(1)	[3] 83	Do.
Cooling water	(1)	[3] 4, 410	Do.
Refinery 3:			
Steam	(1)	[3] 111	Do.
Cooling water	(1)	[3] 4, 637	Do.
HF: Process (Phillips):			
Steam	(1)	[3] 1	Oil and Gas Journal (1955a).
Cooling water	(1)	[3] 68	Do.
CATALYTIC CRACKING			
Thermofor continuous percolation:			
Steam	(1)	22	Petroleum Processing (1956c).
Cooling water	(1)	1, 333	Do.
Houdry:			
Steam	10, 000	3	Kimball and Scott (1948).
Water	10, 000	1, 840	Do.
Fluid:			
Steam	2, 000	6	Read (1946).
Cooling water	2, 000	360	Do.
Fluid:			
Steam	10, 000	12	Kimball and Scott (1948).
Water	10, 000	1, 350	Do.
Thermofor:			
Steam	10, 000	9	Do.
Water	10, 000	1, 082	Do.
Thermofor:			
Boiler water to kiln	4, 500	12	Pfarr (1948).
Cooling water	4, 500	536	Do.
Net steam consumed	4, 500	7	Do.
CATALYTIC HYDROGENATION			
Autofining:			
Steam	3, 500	4	Oil and Gas Journal (1955b).
Cooling water	3, 500	27	Do.

See footnotes at end of table.

TABLE 2—*Published unit water requirements of selected processes*—Continued

Process	Size	Unit use	Source of information
CATALYTIC HYDROGENATION—Con.			
Hydrodesulfurization:			
Standard Oil Co. of Indiana:			
Steam	8, 500	1	Petroleum Processing (1956f).
Cooling water	8, 500	315	Do.
Gulf HDS process:			
West Texas crude oil, fixed bed:			
Cooling water	20, 000	1, 460	McAfee and others (1955).
Boiler-feed water	20, 000	10	Do.
Modified fixed-bed [4]:			
Cooling water	20, 000	3, 750	Do.
Boiler-feed water	20, 000	20	Do.
Hydrogen treating:			
Cooling water	10, 000	432	Petroleum Processing (1956e).
Steam	10, 000	7	Do.
ISOMERIZATION			
Catalytic (Phillips Petroleum Co.):			
Steam	(1)	82	Petroleum Refiner (1956b) and Oil and Gas Journal (1956b).
Water, makeup	(1)	45	Do.
Water, gross circulating	(1)	1, 500	Do.
Pentafining (Atlantic Refining):			
Total:			
Steam	2, 000	2	Petroleum Processing (1956d).
Cooling water	2, 000	114	Do.
Pentafiner:			
Steam	1, 783	2	Do.
Cooling water	1, 783	22	Do.
Pentane splitter:			
Steam	3, 758	0	Do.
Cooling water	3, 758	92	Do.
Once-through plant:			
Steam	4, 000	10	Nordburg and Arnold (1956).
Cooling water	4, 000	396	Do.
Plant recycling hydrocarbon:			
Steam	4, 000	80	Do.
Cooling water	4, 000	2, 520	Do.
CATALYTIC REFORMER			
Hydroforming:			
Cooling water	10, 000	821	Murphree (1951).
Boiler-feed water	10, 000	10	Do.
Hyperforming:			
Cooling water	1, 100	344	Petroleum Processing (1955).
Powerforming for octanes:			
Steam	10, 000	1	Petroleum Processing (1957c).
Cooling water	10, 000	533	Do.

See footnotes at end of table.

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TABLE 2.—*Published unit water requirements of selected processes*—Continued

Process	Size	Unit use	Source of information
SO_2 EXTRACTION PROCESS			
Straight SO_2 refineries:			
Refinery 1:			
Steam	[1]	8	Wilkinson and others (1953).
Cooling water	[1]	750	Do.
Refinery 2:			
Steam	[1]	9	Do.
Cooling water	[1]	830	Do.
Refinery 3:			
Steam	[1]	10	Do.
Cooling water	[1]	930	Do.
Modified refinery:			
Steam	[1]	13	Do.
Cooling water	[1]	1, 600	Do.
THERMAL CRACKING			
Thermal cracking refinery:			
Steam	10, 000	5	Kimball and Scott (1948).
Water	10, 000	392	Do.
Fluid coking:			
Steam	10, 000	6	Petroleum Processing (1956b).
Cooling water	10, 000	864	Do.
Visbreaking:			
Steam	16, 240	7	Boone and Ferguson (1954).
Cooling water	16, 240	266	Do.

[1] Size not given.
[2] Gallons of water per ton of ammonia produced.
[3] Gallons of water per barrel of product.
[4] Kuwait vacuum bottoms—light catalytic furnace oil distillate blend.

TABLE 3.—*Source and amount of water intake of the refineries visited, in million gallons per day*

Source	Number of refineries	Surface water			Ground water			Sewage	All water and sewage	Percent of total intake
		Fresh	Saline	Total	Fresh	Saline	Total			
Public	5	6. 1	--------	6. 1	0. 6	2. 4	3. 0	1. 3	10.[illegible]	1. 1
Self-supplied	26	157	--------	157	85	. 7	86	--------	243	6
Public and self supplied	30	321	308	629	37	--------	37	--------	666	[illegible]
All sources	61	484	308	792	122	3. 1	126	1. 3	919	100
Percent of total intake	----------	53	33	86	13	. 4	14	. 1	100	--------

TOTAL REQUIREMENTS

The average unit water intake of the refineries surveyed by the author and by Searcy was 468 gallons per barrel. The U.S. Bureau of Mines (White and others, 1959) showed that 2.54 billion barrels of crude oil was refined in 1954. The U.S. Bureau of the Census (1957) reported a total water intake of 1,220 billion gallons for petroleum refineries in the same year. These values indicate an average water intake of 480 gallons per barrel of crude refined in 1954. The close agreement between the two averages indicates that the refineries surveyed were representative.

Although the average water intake was 468 gallons per barrel of crude oil, most refineries used less than average amounts. The median water intake was 95 gallons per barrel of crude charge. (See table 4.) The water intake for 109 refineries ranged from 6.5 to 3,240 gallons per barrel of crude charge and depended on the type of refinery, variations in the refining process, and whether or not water was recirculated. The median water intake for refineries that recirculated water was only 57 gallons per barrel of charge as compared to 700 gallons for those that used the once-through system. Refineries without cracking units used less makeup water than those with cracking units; the median water intake for the former was 75 gallons per barrel of charge as compared to 100 gallons for the latter.

TABLE 4.—*Total water intake, 1955, by type of cooling system, in gallons per barrel of crude charge*

[Data from 61 refineries surveyed in 1956 and 48 in 1951]

Type of refinery	Type of cooling system: Reuse	Once-through	Combined	All systems
ALL REFINERIES				
Number of refineries	62	17	30	109
Minimum	6. 5	133	46	6. 5
Lower quartile	35	300	108	49
Median	57	700	240	95
Upper quartile	86	1, 200	800	285
Maximum	403	3, 240	1, 950	3, 240
Average	81	1, 360	571	468
REFINERIES WITH CRACKING				
Number of refineries	52	12	27	91
Minimum	17	133	46	17
Lower quartile	42	300	105	54
Median	63	700	280	100
Upper quartile	92	1, 300	850	280
Maximum	403	2, 210	1, 950	2, 210
Average	80	1, 450	574	471
REFINERIES WITHOUT CRACKING				
Number of refineries	10	5	3	18
Minimum	6. 5	186	--------	6. 5
Lower quartile	15	--------	--------	26
Median	27	550	--------	75
Upper quartile	50	--------	--------	260
Maximum	249	3, 240	--------	3, 240
Average	112	720	128	374

The total gross circulation was considerably greater than intake or new makeup, because some water was used more than once by most refineries. The median gross circulation was 1,400 gallons per barrel of charge as compared to 95 gallons of new makeup per barrel and ranged from 14 gallons to 7,290 gallons (table 5). Refineries without cracking units required less gross circulation; their median requirement was 500 gallons per barrel of charge as compared to 1,600 gallons per barrel for cracking refineries. Median values also indicate that refineries with cracking units consume more water than those without cracking units: 38 gallons per barrel of charge as compared to 24 gallons per barrel. This is because refineries with cracking units generally circulate more water per barrel than those without cracking units.

COOLING-WATER REQUIREMENTS

About 91 percent of the water intake of the refineries surveyed in 1956 was used for cooling. The balance was used as shown in figure 43. The amount of water used for purposes other than for cooling and for boiler-feed water makeup is shown as one value, as the amount for each of the several individual uses was negligible.

Tables 6, 7, and 8 show the gross circulation, the makeup, and the consumption of cooling water by type of cooling system and by type of refinery. The median and average makeup-water uses for total and for all types of water use, except cooling, of refineries with cracking units exceeded the values given for those with no cracking units. The corresponding cooling-water values were larger for refineries without cracking units; this difference was due to the greater use by refineries without cracking units of once-through cooling, which has correspondingly larger makeup-water needs.

Refineries with recirculating cooling systems circulated approximately twice as much cooling water, used about 25 times less makeup, and consumed about 24 times as much water per barrel of crude charge as those with once-through systems.

REQUIREMENTS FOR SELECTED OPERATIONS

Petroleum is refined by subjecting crude oil or other petroleum materials to a series of processes. Information on the water uses of individual processing units may therefore be useful in analyzing the water requirements of petroleum refineries.

Where available, data for the total makeup water used by the processing units and the amounts used by each for cooling, boiler feed, and other miscellaneous uses were obtained during the survey. Similar data for gross circulation, consumptive uses, and quantities of effluents were obtained where available. Because data on the quantities and types of charges to the various process units were not avail-

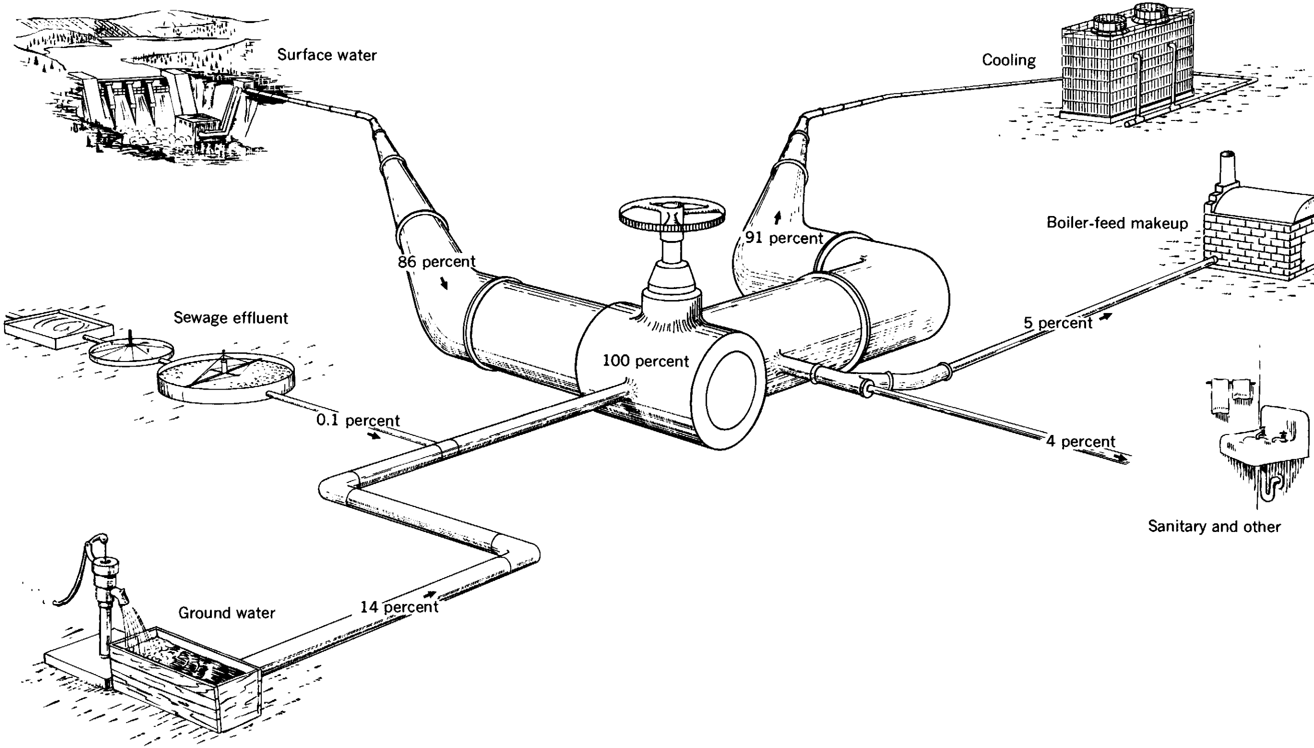

FIGURE 43.—Source and use of water intake.

TABLE 5.—*Water requirements and disposition by type of use and type of refinery, in gallons per barrel of crude charge*

Water requirements and disposition	All refineries				Refineries with cracking units				Refineries without cracking units			
	Cooling water	Boiler-feed water	Sanitary and other water	Total water	Cooling water	Boiler-feed water	Sanitary and other water	Total water	Cooling water	Boiler-feed water	Sanitary and other water	Total water
Gross circulation:												
Number of refineries	61	61	61	61	47	47	47	47	14	14	14	14
Minimum	7. 5	5. 5	0	14	39	12	0	88	7. 5	5. 5	0	14
Lower quartile	750	20	2. 2	850	1, 100	22	3. 5	1, 200	145	14	. 8	190
Median	1, 350	25	8. 5	1, 400	1, 550	27	11	1, 600	400	23	3. 1	500
Upper quartile	1, 900	35	22	2, 000	2, 050	34	25	2, 100	900	42	10	960
Maximum	7, 220	483	166	7, 290	7, 220	141	166	7, 290	3, 120	483	39	3, 240
Average	1, 620	29	19	1, 670	1, 660	28	19	1, 710	644	44	11	699
New makeup:												
Number of refineries	61	61	61	109	47	47	47	91	14	14	14	18
Minimum	2. 6	0	0	6. 5	2. 6	0	0	17	5. 4	0	0	6. 5
Lower quartile	25	13	2. 0	49	30	14	3. 0	54	12	6. 8	. 8	26
Median	60	19	8. 0	95	56	19	8. 3	100	70	19	3. 0	75
Upper quartile	250	26	20	285	175	25	17	280	400	31	11	260
Maximum	3, 120	125	79	3, 240	1, 880	60	79	2, 210	3, 120	125	39	3, 240
Average	376	20	17	468	374	20	17	471	418	16	11	374
Consumption:												
Number of refineries	61	61	61	61	47	47	47	47	14	14	14	14
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Lower quartile	12	2. 5	0	24	18	3. 4	0	27	. 6	1. 2	0	6. 0
Median	25	8. 7	0	36	26	10	0	38	9. 0	2. 8	0	24
Upper quartile	36	20	. 3	55	36	20	. 8	53	27	24	. 3	57
Maximum	94	125	13	304	94	34	13	304	52	125	1. 4	125
Average	28	10	1. 2	39	29	10	1. 2	40	9. 8	6. 4	. 3	16

Effluent:												
Number of refineries	61	61	61	61	47	47	47	47	14	14	14	14
Minimum	0	0	0	0	0	0	0	0	1. 5	0	0	4. 6
Lower quartile	5. 5	1. 0	1. 8	20	5. 4	1. 1	2. 8	24	4. 9	. 7	. 9	9. 0
Median	23	5. 0	7. 2	51	21	6. 9	8. 8	45	38	1. 8	3. 0	60
Upper quartile	110	17	16	200	80	18	19	150	330	12	9. 6	400
Maximum	3, 120	121	79	3, 120	1, 860	121	79	1, 940	3, 120	48	39	3, 120
Average	345	12	17	374	343	12	17	371	407	11	10	429

NOTE.—The summation of the median, quartile, minimum, maximum and average water-use values for various types of water may not always equal the corresponding total water value. The median water-use value for cooling may be that of one refinery, whereas the median for some other type of water use or for the total may be that of the same or another refinery.

able, total water requirements were divided by the capacities of the process units given in the Oil and Gas Journal (1956c) to obtain the unit water-use values in gallons of water per barrel of capacity.

Distillation units, either vacuum or crude, require less makeup and gross circulation per barrel of crude charge than cracking units owing to the much lower temperature in the distillation processes as compared to the cracking processes. (See tables 9 and 10.) Consumption of cooling water in distillation units is also less than in cracking units. Similarly, new makeup for and consumption of boiler-feed water by distillation units is less than for cracking units.

TABLE 6.—*Gross circulating cooling water, 1955, by type of cooling system and by type of refinery, in gallons per barrel of crude charge*

Type of refinery	Type of cooling system			
	Reuse	Once through	Combined	All systems
ALL REFINERIES				
Number of refineries	30	7	24	61
Minimum	7. 5	161	189	7. 5
Lower quartile	520	410	1, 300	750
Median	1, 200	700	1. 590	1, 350
Upper quartile	1. 750	1, 290	1, 900	1, 900
Maximum	7, 220	3, 120	3, 250	7, 220
Average	1, 700	804	1, 630	1, 620
REFINERIES WITH CRACKING				
Number of refineries	24	2	21	47
Minimum	39	--------	819	39
Lower quartile	880	--------	1, 400	1, 100
Median	1, 500	--------	1, 680	1, 550
Upper quartile	2, 030	--------	1, 980	2, 050
Maximum	7, 220	--------	3, 250	7, 220
Average	1, 740	--------	1, 640	1, 650
REFINERIES WITHOUT CRACKING				
Number of refineries	6	5	3	14
Minimum	7. 5	161	--------	7. 5
Lower quartile	--------	--------	--------	145
Median	140	520	--------	400
Upper quartile	--------	--------	--------	900
Maximum	1, 030	3, 120	--------	3, 120
Average	606	693	--------	64

TABLE 7.—*Cooling-water makeup, 1955, by type of cooling system and by type of refinery, in gallons per barrel of crude charge*

Type of refinery	Type of cooling system			
	Reuse	Once through	Combined	All systems
ALL REFINERIES				
Number of refineries	30	7	24	61
Minimum	2.6	161	25	2.6
Lower quartile	15	370	61	25
Median	30	740	140	60
Upper quartile	48	1,500	500	250
Maximum	178	3,120	1,880	3,120
Average	45	784	511	376
REFINERIES WITH CRACKING				
Number of refineries	24	2	21	47
Minimum	2.6	--------	25	2.6
Lower quartile	20	--------	68	30
Median	34	--------	150	56
Upper quartile	52	--------	620	175
Maximum	178	--------	1,880	1,880
Average	46	--------	515	374
REFINERIES WITHOUT CRACKING				
Number of refineries	6	5	3	14
Minimum	5.4	161	--------	5.4
Lower quartile	--------	--------	--------	12
Median	11	520	--------	70
Upper quartile	--------	--------	--------	400
Maximum	31	3,120	--------	3,120
Average	23	693	--------	418

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TABLE 8.—*Consumptive cooling water, 1955, by type of cooling system and by type of refinery, in gallons per barrel of crude charge*

Type of refinery	Type of cooling system			
	Reuse	Once through	Combined	All systems
ALL REFINERIES				
Number of refineries	30	7	24	61
Minimum	.8	0	0	0
Lower quartile	12	--------	22	12
Median	24	0	33	25
Upper quartile	29	--------	48	36
Maximum	94	48	74	94
Average	31	1.3	29	28
REFINERIES WITH CRACKING				
Number of refineries	24	2	21	47
Minimum	.8	--------	0	0
Lower quartile	16	--------	23	18
Median	25	--------	28	26
Upper quartile	34	--------	39	36
Maximum	94	--------	74	94
Average	31	--------	29	29
REFINERIES WITHOUT CRACKING				
Number of refineries	6	5	3	14
Minimum	1.4	0	--------	0
Lower quartile	3.3	--------	--------	.6
Median	9.6	0	--------	9.0
Upper quartile	23	--------	--------	27
Maximum	30	48	--------	52
Average	16	2.5	--------	9.8

TABLE 9.—*Water requirements of crude distillation units, in gallons of water per barrel of crude charge*

[Computed from data obtained from 9 refineries without cracking and 25 refineries with cracking]

Water requirements and disposition	Cooling water			Boiler-feed water			Total water		
	Total	Cracking	Noncracking	Total	Cracking	Noncracking	Total	Cracking	Noncracking
Gross circulation									
Minimum	8.6	8.6	34	0.7	0.7	4.8	13	13	44
Lower quartile	160	175	63	3.7	3.0	6.8	175	190	69
Median	300	290	340	5.5	4.8	12	310	300	440
Upper quartile	470	430	690	11	7.8	29	510	445	790
Maximum	905	725	905	435	70	435	916	748	916
Average	356	347	512	7.5	5.1	46	365	352	560
New make-up									
Minimum	0	0	2.7	0	0	0	4.6	4.6	8.1
Lower quartile	4.8	4.0	12.5	1.8	1.4	3.9	8.7	8.1	21
Median	10	7.9	43	3.5	2.9	7.9	16	11	51
Upper quartile	62	26	210	6.9	4.9	18	74	35	235
Maximum	725	725	652	44	12	44	725	725	660
Average	85	63	451	3.8	3.4	9.3	90	67	461
Consumption									
Minimum	0	0	0	0	0	0	0	0	0
Lower quartile	2.5	2.8	.9	.3	.2	.3	3.8	4.2	1.5
Median	6.0	5.4	12	1.3	.9	3.0	7.9	6.7	20
Upper quartile	8.0	7.1	21	4.3	3.7	15	12	10	34
Maximum	31	31	26	31	12	31	52	42	52
Average	6.1	6.2	4.3	1.2	1.1	2.5	7.4	7.5	6.7
Effluent									
Minimum	0	0	0	0	0	0	0	0	0
Lower quartile	1.0	.9	1.7	.05	.05	.2	2.7	2.4	3.9
Median	3.0	2.4	17	.9	.6	1.6	5.2	4.5	27
Upper quartile	49	13	170	2.9	2.2	6.9	59	17	125
Maximum	725	725	652	44	19	44	745	745	660
Average	78	55	444	2.5	2.2	7.7	81	58	453

TABLE 10.—*Water requirements of selected operations, in gallons of water per barrel of crude charge*

[Charge as reported in Oil and Gas Journal (1956c)]

Water requirements and disposition	Crude distillation units			Vacuum distillation units			Thermal cracking units			Catalytic cracking units			Catalytic reforming units			Polymerization units			Alkylation units		
	Cooling	Boiler feed	Total	Cooling	Boiler feed	Total	Cooling	Boiler feed	Total	Cooling	Boiler feed	Total	Cooling	Boiler feed	Total	Cooling	Boiler feed	Total	Cooling	Boiler feed	Total
Gross circulation																					
Number of refineries	34	34	34	13	14	16	22	23	24	19	20	23	17	17	19	14	14	16	9	10	10
Minimum	8.6	.7	13	19	.8	36	23	.4	88	294	1.4	299	9.7	0	21	806	0	840	21	4.2	64
Lower quartile	160	3.7	175	118	2.8	140	260	4.4	270	520	8.0	670	520	2.2	700	1,440	4.0	1,250	1,400	47	1,400
Median	300	5.5	310	215	5.8	230	500	8.3	500	1,000	11	1,000	840	5.0	950	2,350	35	2,000	2,600	51	3,300
Upper quartile	470	11	510	345	11	480	950	15	950	1,400	16	1,400	1,150	12	1,230	4,200	92	3,500	4,400	68	4,790
Maximum	905	435	916	655	17	954	2,470	278	2,480	2,060	39	2,100	1,900	158	2,040	11,840	177	12,010	7,010	133	7,080
Average	356	7.5	365	223	5.4	334	348	7.4	32	884	10	961	882	8.1	874	2,470	26	2,350	2,940	78	3,290
New makeup																					
Number of refineries	34	34	34	14	15	16	22	23	24	20	21	23	17	17	19	15	15	16	9	10	10
Minimum	0	0	4.6	.07	.8	3.9	0	.3	1.8	6.2	.7	13	6.7	0	8.4	24	0	39	1.5	1.0	2.5
Lower quartile	4.8	1.8	8.7	4.3	1.4	12	12	3.3	15	19	5.2	27	13	1.9	23	57	4.9	82	26	16	64
Median	10	3.5	16	12	4.0	21	19	6.1	25	31	8.0	38	26	5.0	37	108	22	125	69	28	123
Upper quartile	62	6.9	74	31	8.8	34	43	7.3	50	43	12	53	38	11	49	140	54	390	165	50	235
Maximum	725	44	725	96	13	623	1,330	23	1,340	294	36	707	80	93	781	1,180	150	1,200	429	127	562
Average	85	3.8	90	27	4.2	37	81	3.6	73	45	7.2	109	29	6.3	116	322	18	396	195	61	254
Consumption																					
Number of refineries	34	34	34	13	14	16	22	23	24	19	20	23	17	17	19	14	14	16	9	10	10
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	4.1	0	4.1	0	0	0	1.2	0	1.3
Lower quartile	2.5	.3	3.8	3.0	.1	4.3	5.0	.08	3.8	7.6	.8	16	10	.3	15	20	0	25	19	3.5	35
Median	6.0	1.3	7.9	5.7	1.3	8.2	12	1.9	12	15	3.3	19	17	1.4	22	37	2.2	44	60	20	79
Upper quartile	8.0	4.3	12	9.0	5.6	15	17	6.0	19	25	7.2	26	24	8.8	31	67	42	64	92	35	116
Maximum	31	31	52	46	9.5	21	96	23	103	40	18	50	80	88	98	238	133	282	168	53	221
Average	6.1	1.2	7.4	6.2	2.1	10	5.3	1.4	6.4	14	2.7	20	18	3.3	23	37	12	48	60	15	77
Effluent																					
Number of refineries	34	34	34	13	14	16	22	23	24	19	20	23	17	17	19	14	14	16	9	10	10
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lower quartile	1.0	.05	2.7	.7	.01	1.8	1.0	.01	1.2	2.2	.2	5.0	.9	0	1.5	2.0	0	16	1.6	2.2	4.4
Median	3.0	.9	5.2	4.1	.7	5.3	4.6	.9	7.6	6.0	1.6	11	3.0	.5	5.5	28	2.2	33	11	6.2	41
Upper quartile	49	2.9	60	25	1.7	14	34	2.4	24	12	5.2	20	14	2.2	17	115	7.2	100	59	24	91
Maximum	725	44	745	108	5.6	102	1,240	16	1,240	294	20	671	22	9.5	744	1,180	20	1,200	349	127	477
Average	78	2.5	81	20	1.6	19	76	1.8	66	27	2.6	85	11	2.5	9	232	3.5	299	133	46	173

WATER-QUALITY REQUIREMENTS

The various uses of water within a refinery have different water-quality requirements. For example, in a gulf coast refinery described by Resen (1957) salty water is used for once-through cooling, and high-quality demineralized water is used for high-pressure boilers. Although water quality is less important than quantity for petroleum refineries, a water of good quality is desirable. Most sources of water provide both sufficient quantities and suitable qualities for all water needs. Most refineries use sources that will yield sufficient water and will satisfy the quality requirements by treatment. In some refineries special equipment is installed to permit low-quality water to be used without treatment for some processes. As cost is the deciding factor in choosing between the treatment of water of poor quality and the installation of special equipment for its use, quality is a problem of economics. Brooke (1954) showed that complete treating and softening of all cooling water became profitable in less than 4 years and provided many intangible benefits.

Technical literature contains many references to methods of treating the intake water of petroleum refineries (Forbes, 1954a and b; Kelly, 1946). Usual tolerances, undesirable effects, and methods of removal of the undesirable constituents in water as suggested by Forbes (1954a and b) and Betz (1950) are given in table 11.

TABLE 11.—*Undesirable effects and methods of correction for common constituents in water*

[Data modified from Forbes (1954a) and Betz (1950)]

Impurity	Undesirable effects	Usual limit or tolerance	Method of correction	Residual after treatment, (ppm)
Hydrogen sulfide.	Odor, corrosion, and chlorine demand.	<0.5 ppm.	Aeration, Chlorination, and Filtration.	<1
Carbon dioxide.	Corrosion if alkalinity is low.	$\frac{\text{Alkalinity}}{\text{Carbon dioxide}}>3$	Aeration, neutralization with alkalies, and acid treatment of boiler-feed wastes.	5–10
Oxygen.	Corrosion and pitting.	<0.007 ppm in boilers and economizers.	Hot deaeration.	<0.007
			Cold vacuum deaeration.	0.1–0.3
Suspended solids.	Impede water flow, retard heat transfer, aid corrosion.	<5 ppm.	Sedimentation and filters.	<5
			Plus coagulant chemicals where necessary.	<1
Oil.	Causes sludges to bake on in form of scale. Causes boiler foaming.	1 ppm (7 ppm max).	Coalecing followed by skimming.	5
			Absorption with preformed floc followed by filtration.	<1

TABLE 11.—*Undesirable effects and methods of correction for common constituents in water*—Continued

[Data modified from Forbes (1954a) and Betz (1950)]

Impurity	Undesirable effects	Usual limit or tolerance	Method of correction	Residual after treatment, (ppm)
Alkalinity.	Promotes boiler foaming; forms CO_2 in steam causing condensate corrosion; causes boiler embrittlement; interferes with pH control.	For boilers, 300 ppm.	Cation exchange (hydrogen cycle).	Any desired residual.
		Concentration ratio: For ice, 30–50 ppm. For drinking, <300 ppm.	Sulfuric acid addition; lime with or without gypsum.	$\leqq$60
Chlorides.	Boiler foaming and corrosion.	Generally 100–300 ppm max where possible.	Anion exchange.	<3
Sulfate.	Scale formation.	100–300 ppm max where possible.	Barium treatment.	17–25
			Anion exchange.	0–3
Silica.	Scale.	3–20 ppm, depending on boiler pressure.	Adsorption on $Fe(OH)_3$ or $Mg(OH)_2$; anion exchanged with or without fluoride addition.	0.10–0.30
Iron and manganese.	Corrosion and scale.	0.3 ppm.	Aeration followed by filtration (pH control may be required); deionization.	0.1–0.3
Calcium.	Scale formation.	Generally 60–80 ppm for process use and boilers; 0–10 ppm max.	Cold lime soda.	25–35
			Hot lime soda.	12–15
			Cation exchange (sodium or hydrogen cycle).	0–5
Magnesium.	Scale formation.	Generally 60–80 ppm max.	Same as Ca.	0–5
Sodium.	Boiler foaming corrosion.	Low as possible.	Cation exchange (hydrogen cycle).	0–5

Chemical analyses were obtained of untreated water from 82 sources used by 56 of the refineries visited in 1956. Of these analyses, 47 were furnished by the refineries and 35 were obtained from U.S. Geological Survey publications. Analyses of water supplied by private water companies or municipalities were of the water delivered to the refineries. The chemical and physical characteristics of untreated water for all uses are given in table 12.

Because the minimum water-quality requirements for cooling, boilerfeed, process, and sanitary water are different, requirements for each use are discussed separately. For each use of water, a brief discussion is given of the desired characteristics and suggested tolerances, the source and quality of untreated water, and the water-treatment methods for each type of water used.

TABLE 12.—*Quality characteristics of untreated water for all uses*

[Data expressed in parts per million unless otherwise indicated. These data are based on individual observations available and are not balanced analyses]

Constituent	Number of samples	Concentration: Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	52	2.4	6.6	12	18	60
Iron (Fe)	38	.00	.04	.10	.57	14
Calcium (Ca)	64	2.8	18	42	69	220
Magnesium (Mg)	63	.7	4.4	12	25	83
Sodium and potassium (Na+K)	34	1.0	7.8	19	54	266
Bicarbonate (HCO_3)	69	17	76	167	270	484
Sulfate (SO_4)	64	.8	17	59	152	565
Chloride (Cl)	75	1.0	15	28	66	1600
Fluoride (F)	28	.0	.0	.1	.4	1.2
Nitrate (NO_3)	28	.0	.4	1.5	4.5	8.1
Dissolved solids	50	46	146	265	520	3500
Hardness as CO_3:						
Total	76	10	67	144	275	850
Noncarbonate	63	0	0	20	56	550
Color	19	1	3	5	10	22
pH	74	6.0	7.2	7.6	7.8	9.1

COOLING WATER

Water for cooling, the largest use in refineries, ranges in quality from sea water for once-through systems to high-quality water for circulating systems. In general, cooling water should be of sufficiently good quality to keep corrosion, scale formation, organic slimes, and deposits of sediment to a minimum. Temperature is a major consideration in the selection of a source, especially where once-through cooling is used. Quality tolerances of water for cooling as suggested by the American Water Works Association are given in table 13.

TABLE 13.—*Quality tolerances of cooling water suggested by American Water Works Association*

[Data modified from Am. Water Works Assoc. (1950)]

Constituent or property	*Limiting values (ppm)*
Hardness as $CaCO_3$	50
Iron (Fe)	.5
Manganese (Mn)	.5
Iron plus manganese	.5
Turbidity	50
Corrosiveness	None
Slime formation	None

PUBLISHED INFORMATION

In an extensive survey of refinery cooling-water systems, Helwig and McConomy (1957) reported that fouling and corrosion occurred in all cooling-water systems when no treatment was provided. They noted that where dissolved solids, specific conductance, temperatures, and velocities were high, corrosion was accelerated. Their survey indicated that, in general, corrosion increased in circulating-water systems if the pH dropped below 7.5, whereas corrosion was mild if the pH was above 8.0. Refineries were actively and effectively combating fouling and corrosion by chemical treatment, cathodic protection, and the use of special construction materials. The most prevalent treatment methods reported were (a) pH adjustment with sulfuric acid or soda ash, (b) control of slime and algae growth with chlorine and other algicides, and (c) control of corrosion and fouling with polyphosphates, chromates, and silicates. Helwig and McConomy also reported on the effectiveness and cost of the various types of chemical treatment.

Miller (1951) also discussed the objectives and techniques of cooling-water treatment. He noted that when open-circulating cooling-water systems were used, treatment problems increased owing to concentration effects.

In coastal areas low-quality water, such as sea water, is used by refineries for cooling. An average use of 128.5 mgd of sea water for most cooling in the Bayway refinery of the Standard Oil Co. (1950) is described in "The Lamp."

The successful utilization of sewage effluent for cooling and for boiler-feed water by the Big Spring refinery of the Cosden Petroleum Corp. is reported by McCormick and Wetzel (1954). Sewage effluent created such problems as foaming in boilers and excessive slime growth in cooling systems, but these problems were corrected by modifications of standard treatment procedures. The authors noted that, with the exception of the additional expense due to increased chlorine demand, the cost of treating sewage effluent is only slightly higher than the cost of treating chemically comparable natural water.

FINDINGS OF THIS SURVEY

In the 1956 survey data were obtained on the chemical and physical characteristics of the untreated cooling water used by 68 petroleum refineries. The chemical analysis of one treated sewage effluent as delivered to the refinery was obtained, but no analyses of sea water were included. Several refineries use the same source of water for once-through and circulating cooling systems. The sum of the number of analyses of cooling water will not therefore, always be equal to the total number of analyses of water from all sources.

Table 14 shows the chemical and physical characteristics of untreated water that was supplied to the circulating cooling systems of 48 refineries and to the once-through systems of 26 others. Minimum, lower quartile, median, upper quartile, and maximum values are given for each constituent and characteristic of once-through and circulating water for which there are a sufficient number of samples.

TABLE 14.—*Quality characteristics of untreated cooling water*

[Results expressed in parts per million unless otherwise indicated. These are based on individual observations available and are not balanced analyses]

Constituent or property	Once-through						Circulated					
	Number of samples	Concentration					Number of samples	Concentration				
		Minimum	Lower quartile	Median	Upper quartile	Maximum		Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	24	2.4	5.8	9.8	14	46	34	2.4	7.2	12	22	60
Iron (Fe)	19	.00	.04	.12	.71	14	23	.00	.02	.15	1.0	8.7
Calcium (Ca)	28	4.0	16	51	72	204	41	2.8	18	45	83	204
Magnesium (Mg)	28	.7	4.2	13	24	83	40	.7	4.1	13	27	83
Sodium and potassium (Na+K)	19	1.0	6.2	13	52	102	17	1.0	6.2	52	146	266
Bicarbonate (HCO_3)	30	17	68	142	248	484	45	22	113	198	332	484
Sulfate (SO_4)	30	.8	14	38	145	536	40	.8	18	68	156	558
Chloride (Cl)	32	1.0	12	26	58	900	52	1.0	19	30	64	900
Fluoride (F)	15	.0	.0	.1	.2	1.2	14	.0	.1	.2	.5	1.2
Nitrate (NO_3)	14	.0	.7	2.0	5.6	7.6	12	.0	.3	.9	1.5	2.6
Dissolved solids	21	46	97	228	442	629	32	46	193	296	624	1,170
Hardness as $CaCO_3$:												
Total	33	12	52	160	326	850	51	10	68	160	319	850
Noncarbonate	27	0	5	22	58	550	40	0	0	10	56	550
Color	10	1	3	8	14	22	7	1	3	5	13	14
pH	31	6.0	7.0	7.4	7.8	8.9	49	6.4	7.2	7.6	7.9	9.1

Additional information on dissolved solids, total hardness, bicarbonates, and sulfates is shown in figures 44 and 45.

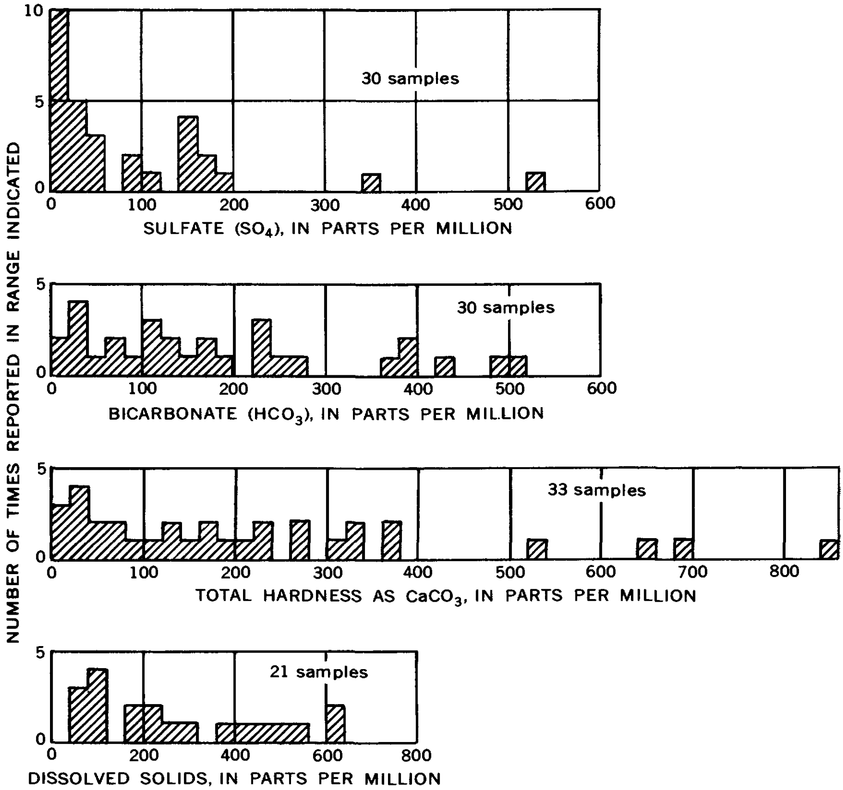

FIGURE 44.—Frequency distribution of selected chemical constituents in untreated water for once-through cooling.

Waters used for once-through and for circulating cooling were similar in quality; however, water used for once-through cooling was of slightly higher quality. The use of higher quality water for once-through cooling is not due to higher requirements but is probably due to the availability of better quality water in areas of plentiful supply where recirculation is not necessary.

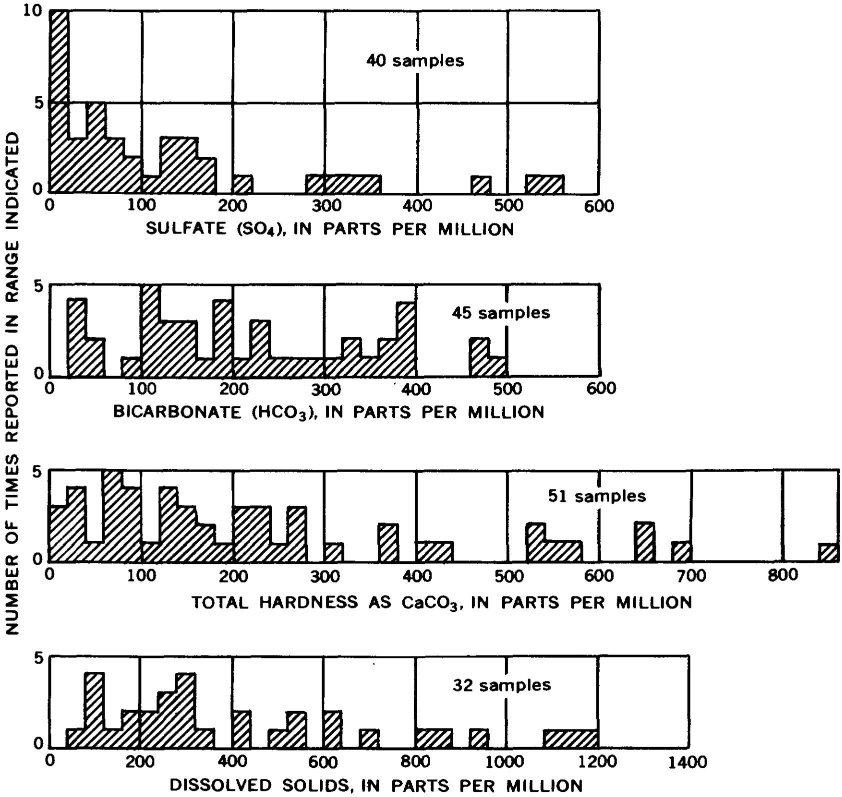

FIGURE 45.—Frequency distribution of selected chemical constituents in untreated water for recirculated cooling.

Most refinery intake water is treated to provide the desired quality of cooling water. Although water from only 10 of the 39 sources of once-through cooling water was given treatment, which varied from screening to sedimentation and filtration, water from 52 of the 69 sources of circulating water was given some type of treatment. Table 15 shows the methods used for treating once-through and circulating cooling water at the refineries visited.

BOILER-FEED WATER MAKEUP

Large amounts of high-quality water are used by petroleum refineries to produce low- and high-pressure steam. Untreated water is generally not satisfactory for this use; therefore, careful consideration is given to the selection and treatment of makeup water for boiler-feed to prevent excessive corrosion, scale formation and embrittlement.

Experience at a gulf coast industrial plant indicates the importance of high-quality boiler feed. During World War I the plant had three boilerhouses: one on steam, one on standby, and one being cleaned. The boiler-feed water was not treated, and the average on-stream time for a boiler was 2 to 3 weeks. Later the feed water was given internal treatment, and the boilers could be operated for as long as 2 months between cleanings. Modern boilers, which operate on softened and internally treated waters, may never need cleaning and will be opened only for annual inspection (Brooks, 1954).

TABLE 15.—*Treatment of makeup water for cooling*

[Figures refer to frequency of use of various types of water treatment. Prior treatment of purchased water is not considered]

Type of treatment	Once-through cooling water						Circulating cooling water								
	Self-supplied				Public supplied	Total	Self-supplied				Public supplied				Total
	Ground water		Surface water		Surface water		Ground water		Surface water		Ground water		Surface water	Sewage effluent	
	Fresh	Saline	Fresh	Saline	Fresh		Fresh	Saline	Fresh	Saline	Fresh	Saline	Fresh		
No treatment	12	1	8	4	5	30	4	------	------	1	1	------	4	------	10
Screening	------	------	1	------	------	1	------	------	------	------	------	------	------	------	------
Coagulation	------	------	------	------	------	------	------	------	4	------	1	------	1	------	6
Sedimentation	------	------	1	------	------	1	------	------	4	------	1	------	------	------	5
Filtration	------	------	3	------	------	3	1	------	3	------	1	------	------	------	5
Softening:															
Lime-soda	------	------	------	------	------	------	5	------	3	------	------	------	1	1	10
Zeolite	------	------	------	------	1	1	1	------	1	------	1	------	------	------	3
Disinfection and algae control:															
Chlorination	1	------	2	------	------	3	12	------	7	------	------	------	1	------	20
Organic compounds	------	------	------	------	------	------	5	------	2	------	1	------	1	------	9
Other	------	------	------	------	------	------	8	1	1	------	2	1	------	------	13
Corrosion and scale control:															
Chromates	------	------	------	------	------	------	6	------	2	------	2	------	------	------	10
Phosphates	2	------	------	------	1	3	12	------	3	------	2	------	4	------	21
Dianodic	------	------	------	------	------	------	2	------	------	------	------	------	1	------	3
pH adjustments	------	------	------	------	------	------	15	1	3	------	3	1	4	------	27
Other	------	------	------	------	------	------	6	------	1	------	1	------	------	------	8

PUBLISHED INFORMATION

There are many textbooks and manuals on industrial water conditioning (for example: Nordell, 1951; Powell, 1954; Betz, 1950; and the Permutit Co., 1947) that discuss the general problems caused by impurities in boiler-feed water and the treatments used to remove undesirable impurities. The boiler-feed water problems of petroleum refineries, however, are usually individual problems and require specialized treatments for satisfactory solutions.

Resen (1957) described the solution of a makeup-water problem for high-pressure boilers, at the Port Arthur, Tex., refinery of the Gulf Oil Corp., by the use of special treatment. The surface water used for boiler-feed makeup in the generation of low pressure steam had been treated by coagulation, gravity filtration, and zeolite softening. Steam turbines obtained to drive centrifugal compressors and other equipment required the use of high-pressure steam. This steam must be free of silica to prevent the deposition of silica on the turbines, which causes reduced efficiencies and early maintenance shutdowns. The desired high-quality water for the high-pressure boilers was obtained by passing the gravity-filtered makeup water through an ion-exchange demineralization unit, which lowers the mineral content to less than 6 ppm of dissolved solids and the silica content to less than .01 ppm.

McCormick and Wetzell (1954) described the use of sewage effluent instead of hard ground water for boiler-feed water makeup. In early 1944 the refinery was using water with hardness ranging from 700 to 1,300 ppm. Scaling was a serious problem in boilers and in other heat exchange equipment, and water treatment experts could not provide a practical solvent for the scale. In July 1944, Cosden contracted for use of the sewage effluent from the city of Big Spring, Tex. At first the effluent used for boiler-feed water makeup was treated by the hot-lime process, anthracite filtration, and internal phosphate treatment in the boiler drums. This treatment was not entirely satisfactory as foaming and priming resulted. McCormick and Wetzel reported, however, that satisfactory operation was attained by changing to a hot-phosphate treatment in an external treater followed by the injection of a foam suppressing agent into the boiler drum.

FINDINGS OF THIS SURVEY

Chemical analyses of the untreated makeup waters for boiler feed used by the refineries surveyed were obtained where possible. Analyses were obtained of water from 55 sources: 40 were company wells or surface water, 14 were public supplies, and 1 was sewage effluent. Two samples from company wells could be classified as slightly to moderately saline (Krieger and others, 1957), as the dissolved solids content of both were over 1,000 ppm. None of the refineries surveyed used sea water for boiler-feed makeup.

The quality characteristics of untreated makeup water for boiler feed used at 54 refineries are given in table 16. Figure 46 shows the

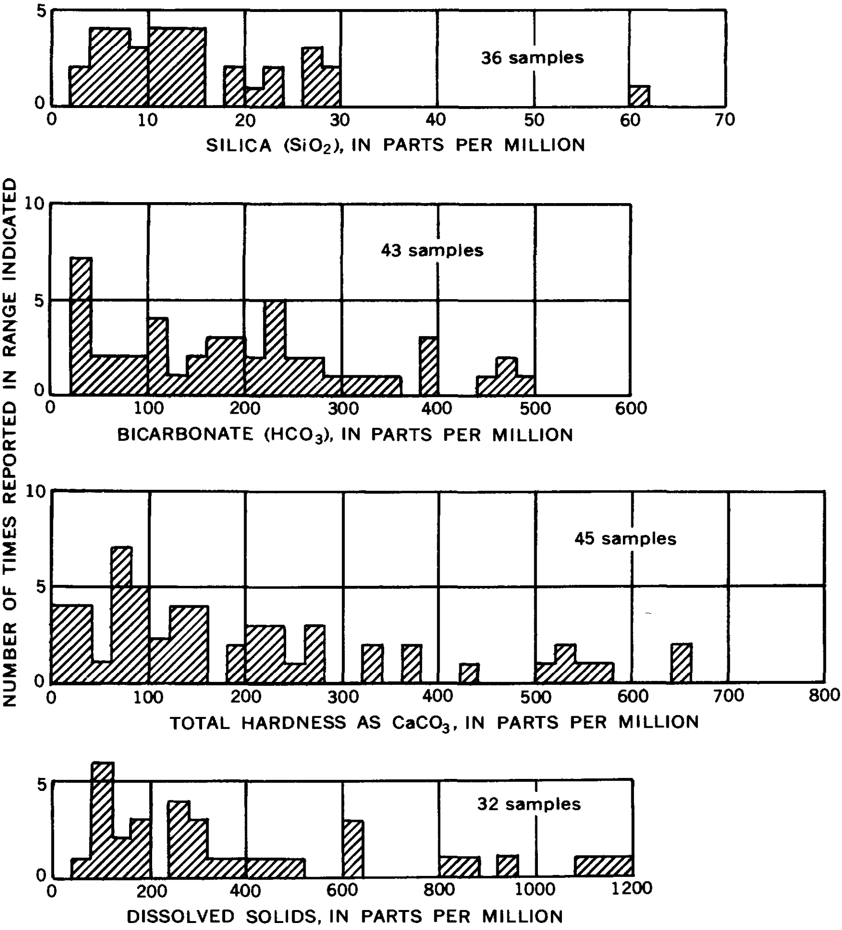

Figure 46.—Frequency distribution of selected chemical constituents in untreated makeup water for boiler feed.

frequency distribution for some important chemical constituents in boiler-feed makeup water.

Water-quality tolerances for boiler-feed water makeup suggested by Moore (1940) are shown in table 17. A comparison of the quality characteristics of the untreated water with the suggested tolerances indicates a need for treatment by most refineries.

Many of the refineries employed industrial water consultants to make water analyses, to interpret these analyses, and to recommend

TABLE 16.—*Quality characteristics of untreated boiler-feed makeup water*

[Results expressed in parts per million unless otherwise indicated. These are based on individual observations available and are not balanced analyses]

Constituent or property	Number of samples	Concentration				
		Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	36	2.4	6.9	12	19	60
Iron (Fe)	24	.00	.03	.10	.58	7.2
Calcium (Ca)	43	2.8	18	39	68	173
Magnesium (Mg)	43	.7	4.1	14	25	56
Sodium and potassium (Na+K)	21	1.0	6.0	24	69	266
Bicarbonate (HCO_3)	49	22	86	186	270	484
Sulfate (S)[4]	45	.8	18	62	148	558
Chloride (Cl)	54	1.0	18	33	74	465
Fluoride (F)	15	.0	.1	.2	.5	1.2
Nitrate (NO_3)	15	.0	.7	1.5	4.0	7.6
Dissolved solids	33	46	151	286	622	1170
Hardness as $CaCO_3$:						
Total	55	10	66	142	272	644
Noncarbonate	44	0	0	14	52	416
Color	10	1	3	5	14	22
pH	51	6.4	7.2	7.6	7.8	9.1

TABLE 17.—*Suggested water-quality tolerance for boiler-feed water*

[Data from Moore (1940)]

Constituent	Suggested water-quality tolerance (ppm.) at pressure (psi) indicated			
	0–150	150–250	250–400	>400
Oxygen consumed	15	10	4	3
Dissolved oxygen [1]	1.4	.14	.0	.0
Hydrogen sulfide (H_2S)	[2] 5	[2] 3	0	0
Total hardness as $CaCO_3$	80	40	10	2
Aluminum oxide (Al_2O_3)	5	.5	.05	.01
Silica (SiO_2)	40	20	5	1
Bicarbonate (HCO_3) [1]	50	30	5	0
Carbonate (CO_3)	200	100	40	20
Hydroxide (OH)	50	40	30	15
Total solids [3]	500–3,000	500–2,500	100–1,500	50
Color	80	40	5	2
pH value (minimum)	8.0	8.4	9.0	9.6
Turbidity	20	10	5	1
Sulfate-carbonate ratio [4] (Na_2SO_4:Na_2CO_3)	1:1	2:1	8:1	3:1

[1] Limits applicable only to feed water entering boiler, not to original water supply.
[2] Except when odor in live steam would be objectionable.
[3] Depends on design of boiler.
[4] American Society of Mechanical Engineer standards.

treatment of the boiler-feed water. In other refineries consideration of problems of water quality and treatment ranged from giving no thought to the problems to assigning several full-time staff members to the work.

Of the 137 sources of makeup water for boiler feed, 3 received no treatment by the refinery; 2 were municipal supplies and 1 was a company well. External treatment of makeup water for boiler feed, either by the lime-soda or by the zeolite process, was the most common method (table 18). Internal treatment with chemicals for scale and corrosion control was second in frequency of use.

TABLE 18.—*Treatment of makeup for boiler-feed water*

[Figures refer to frequency of use of various types of water treatment. Prior treatment of purchased water is not considered]

Type of treatment	Self-supplied			Public supplied			Total
	Ground water		Surface water	Ground water	Surface water	Sewage effluent	
	Fresh	Saline	Fresh	Fresh	Fresh		
No treatment	1			2			3
Coagulation			2	1			3
Sedimentation			4	2			6
Filtration	2		4	2			8
Softening:							
Lime-soda	16	1	4	2	4	1	28
Zeolite	10		7	10			27
Distillation	1						1
Other	1		3	2			6
Disinfection and algae control:							
Organic compounds	4						4
Other	2						2
Corrosion and scale control:							
Phosphates	11	1	2	1	2	1	18
Dianodic			1				1
Deaeration	2						2
Embrittlement protectors	1						1
pH adjustment	2		2		1		5
Antifoam	2		2	1			5
Other	10	1	2	2			15

PROCESS AND SANITARY WATER

The quantity of water used for process and sanitary services is negligible compared to that for other refinery uses, but some of this water is of necessity the highest quality used by the refinery.

Quality tolerances for process water vary widely with the purpose for which it is used. In general, process waters should be clear, colorless, and free from iron, manganese, hydrogen sulfide, and organic growths (Nordell, 1951). Water for product washing may need to be equivalent to drinking water or of a higher quality, whereas water for general refinery cleanup may be much lower in quality. Sanitary and service water may also vary in quality. Water used in washhouses may be of lower quality than that for drinking. Water for drinking usually satisfies sanitary quality standards suggested by local or State health departments. These standards are generally equivalent to those of the U.S. Public Health Service (1956). Usually the same quality of water and very often the same water is used in washhouses and sanitary fixtures.

Fifty quality analyses of water used for sanitary purposes and 49 analyses of process water were obtained in the survey. Water from three sources (two rivers and one well) was saline. Part of the process needs of one refinery was supplied by sea water, but no chemical analysis of this water was obtained. Figures 47 and 48 are frequency

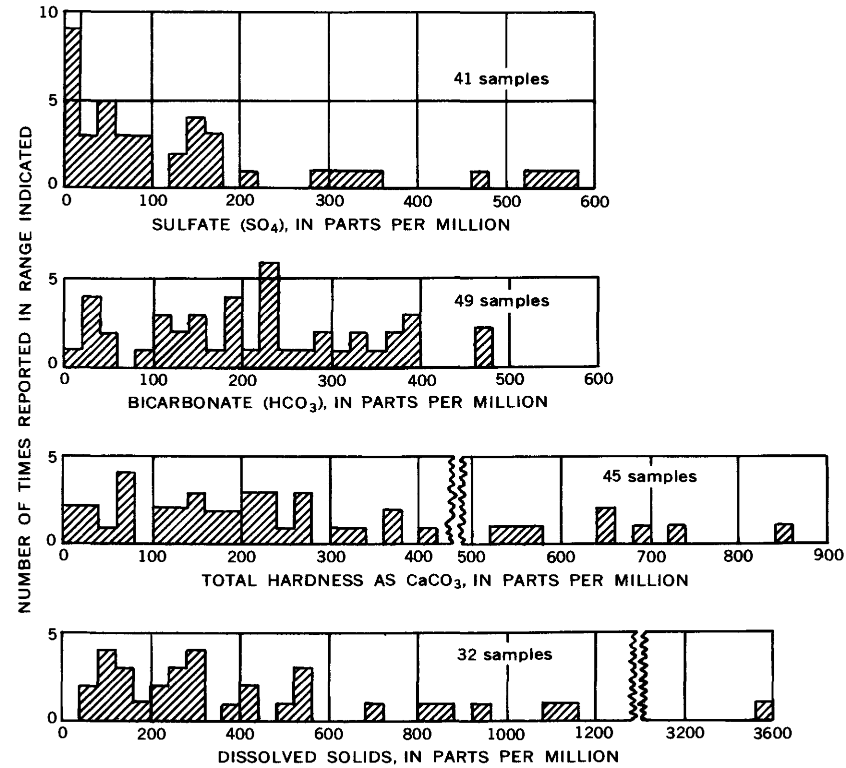

FIGURE 47.—Frequency distribution of selected chemical constituents in untreated process water.

distribution charts showing the occurrence of dissolved solids, total hardness, bicarbonates, and sulfates in untreated process and sanitary water. Table 19 shows median, maximum, minimum, and quartile values of the chemical and physical constituents of these waters.

Extensive, partial, or no treatment of refinery intake water may be necessary to provide the desired water quality for process and sanitary needs. Tables 20 and 21 list the methods used to treat process and sanitary water at the refineries surveyed. Water for these needs received less treatment at the refinery than water used for other purposes because public supplies that had received previous treatment

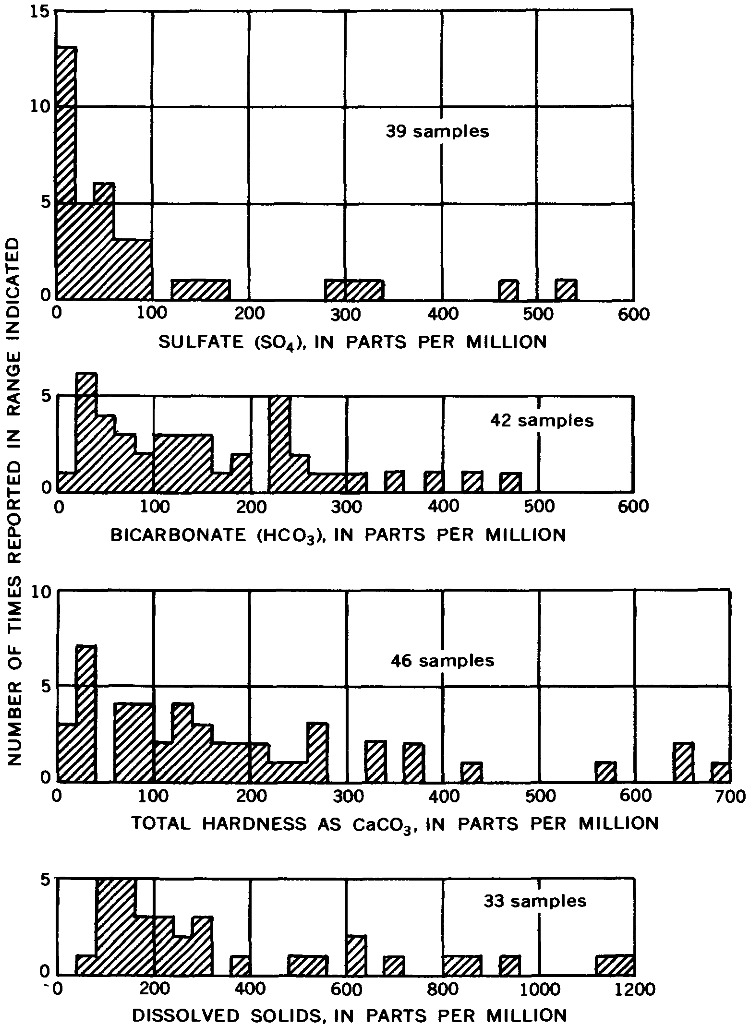

FIGURE 48.—Frequency distribution of selected chemical constituents in untreated sanitary and service water.

were the source of process water for a quarter of the refineries and the source of sanitary water for half of the refineries. Process water from only 18 of the 58 sources and sanitary water from only 13 of the 65 sources received treatment at the refinery. Several refineries had multiple sources of water; the low-quality needs were supplied from sources receiving no treatment, and the high-quality needs were obtained from sources receiving previous treatment.

TABLE 19.—*Quality characteristics of untreated process and sanitary water*

[Results expressed in parts per million unless otherwise indicated. These are based on individual observations available and are not balanced analyses]

Constituent or property	Process						Sanitary					
	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum	Number of samples	Minimum	Lower quartile	Median	Upper quartile	Maximum
Silica (SiO_2)	30	2.4	8.4	14	26	60	35	2.4	6.4	11	15	60
Iron (Fe)	22	.0	.05	.12	.71	14	28	.0	.02	.1	.32	4.5
Calcium (Ca)	38	2.8	21	52	75	220	38	2.8	18	36	60	173
Magnesium (Mg)	37	.7	4.2	14	28	83	39	.7	4.0	10	25	56
Sodium and potassium (Na+K)	20	1.0	7.4	18	58	227	26	1.0	7.8	20	65	266
Bicarbonate (HCO_3)	43	17	111	215	317	475	42	17	48	130	234	466
Sulfate (SO^4)	41	.8	30	89	174	565	39	.8	14	40	90	536
Chloride (Cl)	44	1.0	16	32	64	1,600	45	1.0	11	29	62	465
Fluoride (F)	16	.0	.1	.2	.4	1.2	21	.0	.1	.2	.4	.9
Nitrate (NO_3)	17	.2	.9	1.5	3.4	7.6	22	.0	.5	1.4	2.8	8.1
Dissolved solids	32	46	159	291	530	3,500	33	46	143	228	574	1,170
Hardness as $CaCO_3$:												
Total	45	10	80	200	350	850	46	10	62	126	241	644
Noncarbonate	37	0	0	22	71	550	40	0	0	17	46	416
Color	9	3	3	5	10	22	13	1	3	3	6	10
pH	45	6.0	7.2	7.6	7.8	8.9	45	6.8	7.4	7.6	7.9	9.1

TABLE 20.—*Treatment of makeup for process water*

[Figures refer to frequency of use of various types of water treatment. Prior treatment of purchased water is not considered]

Type of treatment	Self-supplied				Public supplied		Total
	Ground water		Surface water		Ground water	Surface water	
	Fresh	Saline	Fresh	Saline	Fresh	Fresh	
No treatment	17	1	4	3	2	10	37
Screening	------	------	1	------	------	------	1
Coagulation	------	------	1	------	------	1	2
Sedimentation	------	------	1	------	------	------	1
Filtration	1	------	3	------	1	1	6
Softening:							
Lime-soda	1	------	------	------	1	------	2
Zeolite	1	------	------	------	1	------	2
Other	------	------	1	------	1	------	2
Disinfection and algae control: Chlorination	1	------	------	------	------	------	1
Corrosion and scale control:							
Phosphates	2	------	------	------	1	------	3
Dianodic	1	------	------	------	------	------	1
pH adjustment	1	------	------	------	------	------	1
Other	1	------	1	------	1	------	3

TABLE 21.—*Treatment of makeup for sanitary water*

[Figures refer to frequency of use of various types of water treatment. Prior treatment of purchased water is not considered]

Type of treatment	Self-supplied				Public supplied			Total
	Ground water		Surface water		Ground water		Surface water	
	Fresh	Saline	Fresh	Saline	Fresh	Saline	Fresh	
No treatment	17	1	1	1	32	1	------	53
Coagulation	------	------	1	------	------	------	1	2
Sedimentation	------	------	2	------	------	------	------	2
Filtration	1	------	2	------	1	------	------	4
Softening:								
Lime-ash	3	------	------	------	------	------	------	3
Zeolite	2	------	------	------	1	------	------	3
Other	1	------	------	------	------	------	------	1
Disinfection and algae control: Chlorination	5	------	2	1	------	------	1	9
Corrosion and scale control:								
Deaeration	1	------	------	------	------	------	------	1
Other	1	------	------	------	------	------	------	1

FACTORS AFFECTING WATER USE

The results of the current survey were studied to find an explanation for the wide variation in water use. The effect of availability of water, size of refinery, operating procedures, type of process, and temperature and quality of the water upon the water use was investigated.

AVAILABILITY OF WATER

Location seems to affect water use, but its effect is actually due to the variation of availability of water. The unit makeup-water requirements of the refineries surveyed varied with the runoff of the area in which the refinery was located. The water uses of refineries in arid areas in which the runoff was 1 inch or less were compared with the uses in areas in which the runoff was more than 10 inches.

The makeup-water requirements of 20 refineries in high-runoff areas exceeded 100 gallons per barrel of charge, whereas only 4 refineries in arid locations had makeup requirements this high. The median makeup-water use in arid locations was about 75 gallons per barrel of charge, whereas the median for high-runoff areas was about 250 gallons per barrel.

SIZE OF REFINERY

Analyses of the data indicate that the unit makeup-water requirements of the refineries surveyed were not directly affected by size. Even though the large refineries had greater makeup-water requirements than smaller refineries, the greater requirements were due to factors other than size.

Five refineries with capacities of more than 100,000 barrels per day were visited during the 1956 survey, and each was located in an area with an abundant supply of water. Four of the five refineries required more than average amounts of makeup water, owing to the large proportion of once-through cooling water used. Therefore, the greater amounts of makeup water used were due to the favorable water situations at the refinery locations rather than to their sizes.

There was a negligible difference in the average makeup-water needs of refineries with capacities between 10,000 and 100,000 barrels per day and those with capacities less than 10,000 barrels. The average makeup requirements of both size groups were less than those of refineries with capacities in excess of 100,000.

The negligible effect of size on water requirements is further illustrated by the small variation in the average unit gross circulating-water needs among the three size groups.

TYPES OF PROCESSES

The type of refinery and processing units and the operating procedures affect the water requirements. The water requirements of refineries with cracking units were considerably larger than the requirements of those without cracking units. Table 5 shows that the median gross circulating-water requirements and the makeup-water requirements for refineries with cracking facilities were 1,600 and 100 gallons per barrel of charge, respectively. The corresponding values for refineries without cracking were 500 and 75 gallons per barrel.

Most refineries have several processing units, and the combination of the units affects the water use of the refinery. Unit water requirements of processing units are shown in tables 9 and 10. Median makeup-water needs for the processes ranged from about 125 gallons per barrel for polymerization and alkylation units to 15.5 gallons per barrel for distillation units.

OPERATING PROCEDURES

Makeup-water requirements of refineries can be substantially reduced by recirculating as much cooling and other water as possible. It is essential to use such systems in arid and other water-short areas. Conservation measures should also be used where low-quality water must be treated before use or where high-priced city water must be used.

A 10,000 barrel-per-day refinery with cracking facilities and a once-through cooling system would require a source of makeup-water of 7 million gallons per day, based upon the median water-use value shown in table 4. If a circulating cooling-water system were used for the same refinery, probably no more than 630,000 gallons of makeup water would be required daily.

Although 16 of the 21 refineries in arid locations reused their water more than 10 times, only 6 refineries in high-runoff areas reused their water this many times.

The data for average and median unit-makeup-water use by refineries with once-through, circulating, and combined cooling systems (table 4) show the decrease in makeup-water requirements when water is reused.

The operating temperatures and pressures of boilers affect the quality of water that must be supplied for boiler-feed makeup. The quality requirements of feed water become more exacting as operating pressures and temperatures increase. Suggested water-quality tolerance in concentrations of some chemical constituents in boiler-feed water at certain operating pressures are given in table 17.

QUALITY AND PHYSICAL CHARACTERISTICS OF WATER

Water temperature affects the use of water by refineries. Several refineries that used water from rivers for cooling had auxiliary ground-water supplies for use in summer when the river temperatures were too high for effective cooling. Other refineries continued using the river supply but increased the withdrawal for cooling as the river temperature increased.

Low-quality water may require substantial treatment before it can be used. Treated water is usually used in a recirculating cooling system rather than discharged to waste from a once-through system. In a recirculating cooling system, the solids content of the water increases owing to evaporation. The solids content of the recirculating water is reduced by discarding a part of the circulating water (tower blowdown) and by the addition of new makeup water which contains less dissolved solids. Therefore, the quantity of makeup water required for a recirculating system increases with a decrease in water quality, because low-quality water will become concentrated and require dilution sooner than high-quality water.

REFINERY WASTE WATER

Waste products from refineries consist of oils, chemicals (especially acids, alkalies, sulfides, and phenols), and suspended solids. The major sources of these wastes are equipment leakages and spills, releases during shutdown or startup of equipment, condensate from steam-stripping operations, waste water from crude oil desalters and from storage tanks, equipment cleaning, regeneration of ion-exchange units, backwashing of filters, boiler and cooling tower blowdowns, storm water, lavatories, and washhouses.

Spent clays from clay treating units and bottom sediments from separators and traps are examples of waste solids in refineries. Spent clays are usually disposed of by dumping, whereas the other waste solids are withdrawn as slurry and pumped to settling ponds.

Waste treatment is different for each refinery. Some refineries treat each waste stream at its source, and others collect all wastes for treatment in a single plant. Most modern refineries segregate their wastes so that similar wastes are collected for treatment in one plant, and the waste streams that require special treatment are treated at the source.

The initial treatment of refinery wastes commonly is to remove oils by an API gravity-type separator. The remaining oil is treated to break the emulsion.

Some chemical wastes from petroleum refineries must receive individual treatment. Acid and alkaline waste waters are neutralized by mixing with each other. Sulfides in waste water are neutralized and stripped in an absorption tower. Phenols in waste water have been treated by aerobic biological processes and in trickling filters, oxidation ponds, and cooling towers.

Sanitary waste water at most refineries is collected in a separate sewer system and treated in septic tanks, primary settling tanks, and oxidation ponds, or discharged into city sewers.

Waste-water treatment methods used by the refineries surveyed are shown in table 22. The most common method of waste treatment was the API separator, which was used for treating 41 waste-water streams. Eleven waste-water streams received no treatment at the refinery, but five of these were discharged into city sewers.

TABLE 22.—*Waste-water treatment*

Treatment	Frequency of occurrence		
	Refineries without cracking facilities	Refineries with cracking facilities	Total
API separator	7	34	41
Ponding	2	14	16
Sedimentation		6	6
Coagulation		2	2
Filtration	1	1	2
Skimming	2	3	5
pH adjustment		1	1
Chlorination		1	1
Septic tank or cesspool (sanitary sewage)	1	2	3
No treatment	4	7	11

FUTURE WATER REQUIREMENTS

As noted previously (p. 325), many factors affect the total and the unit water requirements of petroleum refineries. The effect of some factors on water needs are rather uncertain, whereas the effect of others can be more accurately determined. Analysis of some of these factors is necessary to make a reasonably accurate estimate of the future water requirements of the petroleum refining industry and of the areas of the United States in which new refineries will probably be located.

LOCATION OF REFINERIES

Important factors that must be considered in selecting sites for petroleum refineries are sources of crude oil, proximity to a market for the refinery output, and the transportation facilities available. The necessary utilities and labor supply available and their cost are other factors of less importance.

Water has been a minor factor in site selection, but in water-short areas refinery operations have been adapted to conserve water. Factors other than water will probably continue to control selection of future sites, but water conservation within refineries will become more important.

An analysis of current refinery locations should be useful since areas in which refineries are currently located are areas of possible future expansion.

There were 294 operating refineries in the United States with an average total operating capacity of 8,380,801 barrels per day in 1955 (Kirby, 1956). These refineries were scattered through 37 States from coast to coast. Approximately three-fourths of the operating refineries—90 percent of the national capacity—were located within the 12 States of Texas, California, Louisiana, Pennsylvania, Illinois, Indiana, New Jersey, Ohio, Oklahoma, Kansas, Michigan, and Wyoming. One-fourth of the total operating capacity was located in Texas, and the refining capacity of Texas combined with that of California and Louisiana accounted for more than one-half of the operating capacity of the Nation.

The tidewater location, the nearness to a crude-oil supply, and the cheap and abundant supply of natural gas available for fuel are factors that make the gulf coast areas of Texas and Louisiana an excellent location for petroleum refineries and account for the large number of refineries located in this area. Most of the crude oil used by the refineries in this area is transported by pipelines from inland Texas and Louisiana oil fields, and the major part of the refinery output is transported by tanker to east coast markets. Reuse of water is the general practice in this area. Some industrial plants are using sea water successfully for cooling, and air-cooled heat exchangers are also used to supplement water cooling.

East coast refineries are usually market oriented and are located near large population centers, such as Philadelphia, New York City, and Boston. The larger refineries are at tidewater, because most of the crude-oil supply is delivered by tankers from South America, the Middle East, or the gulf coast. Reuse of cooling water is not as general in this area. Many east coast refineries have long used sea water for cooling; several new tidewater refineries are using sea water for cooling.

Although California is the second largest crude-producing State in the Nation, it does not produce sufficient crude oil to meet all west coast demands, and crude from Canada, South America, Sumatra, and the Middle East is imported to supply the deficit. Most west coast refineries are located near such population centers as Los Angeles, San Francisco, and the Puget Sound area, because these centers provide a large market for the refinery output. The Los Angeles area is one of the few places in the country that has all the important conditions for a favorable refinery location—namely, a large source of crude, a large market for refined products, and excellent transportation facilities. An additional condition favoring the area for refinery location is the natural gas that is available for use as fuel. The single deterrent to refinery expansion in this area is the water shortage. Refineries in the Puget Sound area are connected to Canadian oil fields by pipeline, and expansion in this area to supply the west coast demands is probable. In addition to these tidewater refineries, supply-oriented refineries are located in or near oil fields in the Central Valley of California.

Conservation of water is essential in the water-short Los Angeles area, and therefore most refineries recirculate cooling water. Recirculation of cooling water is also a common practice in refineries in the Central Valley area. Sea water has been used for cooling by refineries in the Los Angeles and San Francisco areas.

Most midwestern refineries are located near markets and are supplied primarily from midcontinent oil fields. Some refineries located on navigable rivers and in the Great Lakes area use water transportation, but pipelines are used extensively by most refineries in the Midwest to transport crude oil to the refinery and finished products to market. Large refining centers in this area are Chicago, Kansas City, and St. Louis.

Many refineries in this area are located adjacent to large rivers or lakes and have sufficient water to use once-through cooling systems. Other parts of this area have water-shortage problems, and refineries reduce their water requirements by recirculating cooling water.

Possible refinery locations have been increased manyfold with the advent of the transcontinental pipeline. The source of crude supply can be extended from the oil field to any point along or to the terminus of a pipeline, and refinery markets can be expanded to include any territory connected to the refinery by a pipeline.

Pipelines will possibly affect the selection of future refinery locations by allowing more consideration to be given to water availability. Refineries could be located in areas with favorable water supplies, and pipelines could carry crude supplies to refineries and deliver finished petroleum products to market areas.

GROWTH OF INDUSTRY

The petroleum refining industry began in 1854 when Samuel W. Kier constructed a small refinery in Pittsburgh, Pa. The refinery distilled 5 barrels of crude oil per day and produced a cheap illuminating oil similar to coal oil. The expansion of the industry was limited by the small supply of crude oil that could be reclaimed from creeks, springs, and salt wells in the Oil Creek area of Pennsylvania.

The first oil well in the United States was successfully completed by Colonel Edwin L. Drake in Titusville, Pa., on August 27, 1859. Thereafter, many additional wells were drilled in the area, and many refineries were constructed to keep pace with the rapidly increasing oil production.

Early refining operations were very simple, because the refineries were operated mainly to obtain illuminating oil (kerosene) by simple distillation. In these early refineries the lighter and more volatile gasoline and the heavy residue remaining after the kerosene was obtained were considered worthless and were either discarded or burned. This residue was soon being used as fuel, and poor quality lubricants were manufactured from crude oil as early as 1865. The quality of lubricants and other products continued to improve as refining methods improved. The advent of the automobile in the early 1900's created a demand for gasoline and lubricating oils which soon exceeded the quantities that could be supplied by simple distillation and forced the development of secondary operations.

The Burton cracking process was introduced in 1913; it is a thermal cracking process for converting high-boiling fractions of petroleum into hydrocarbons of low boiling points for use as gasoline. This was the first commercial cracking process to be operated successfully in the United States (Kraemer, 1941). Many new refining processes such as catalytic cracking, polymerization, alkylation, and reforming have been developed and are used by refineries to meet the continuing demand for more and better gasoline for automobiles.

Thus, in just slightly over 100 years the petroleum industry has grown from a simple beginning to one of the largest industries in the world which ranks with transportation, public utilities, and agriculture. Refining has grown from Kier's single 5-barrel-per-day refinery to an industry consisting of 294 refineries processing an average of 7,480,000 barrels of crude oil per day in 1955. Large modern refineries have increased in complexity and size to include single refineries capable of producing about 3,850 gallons of motor gasoline, 900 gallons of home heating oil, 300 quarts of motor oil, and hundreds of other products in 1 minute.

Increased water requirements have accompanied the growth of the refining industry. As the number, size, and complexity of refineries increased, the total water requirements of the industry increased. Although total water needs have increased, the unit water requirements have decreased as the industry grew. This decrease was caused by improved water-conservation practices that generally accompany additional water needs resulting from refinery growth. Estimates of the future growth of the petroleum refining industry should serve as a guide for making a reasonably accurate appraisal of the future water requirements.

Figure 49 traces the increases in demand for major petroleum products in the United States and in the free world from 1950 through 1960 and indicates the percentage distribution of the total demand between the United States and the free world.

Hill, Hammer, and Winger (1957) noted that demand for major refinery products in the free world increased at an average annual rate of 6.3 percent during the 1920–56, and the demand accelerated in the post-World War II period to an average of 7.9 percent per year. The annual rate of increase was about 6 percent in both of these periods in the United States.

At the end of World War II the demand for refinery products was 2,588 million barrels per year for the free world, including 1,792 million barrels per year in the United States. The demand in the United

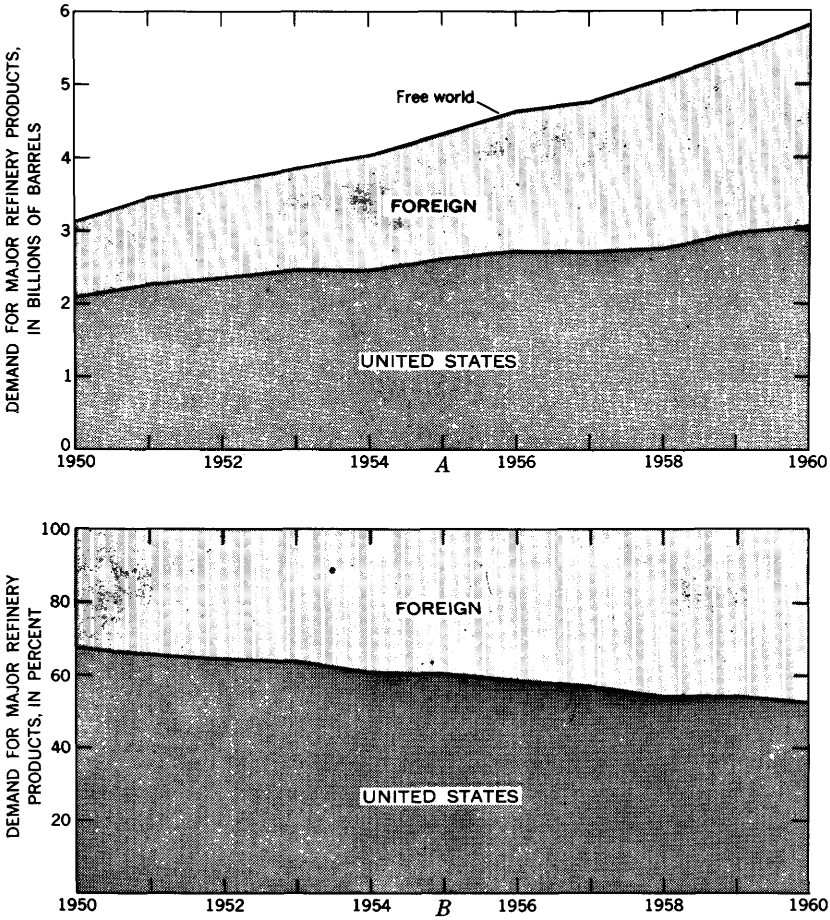

FIGURE 49.—Demand for major refinery products in the United States and the free world by (*A*) quantity and (*B*) percent, 1950–60.

States increased to 2,634 million barrels per year in 1955 and to 3,042 million barrels in 1960. The free-world demand increased at a faster rate to 4,329 million barrels in 1955.

The quantities and percentages of crude runs to refineries in the United States and the free world from 1950 through 1960 are shown in figure 50. Annual percentage increases in crude charges to refineries in the United States approximately paralleled the yearly increases in demand for major refinery products in the period 1950 through 1960. Average increases in yearly rates of crude runs to refineries in the free world slightly exceeded the average percentage increase

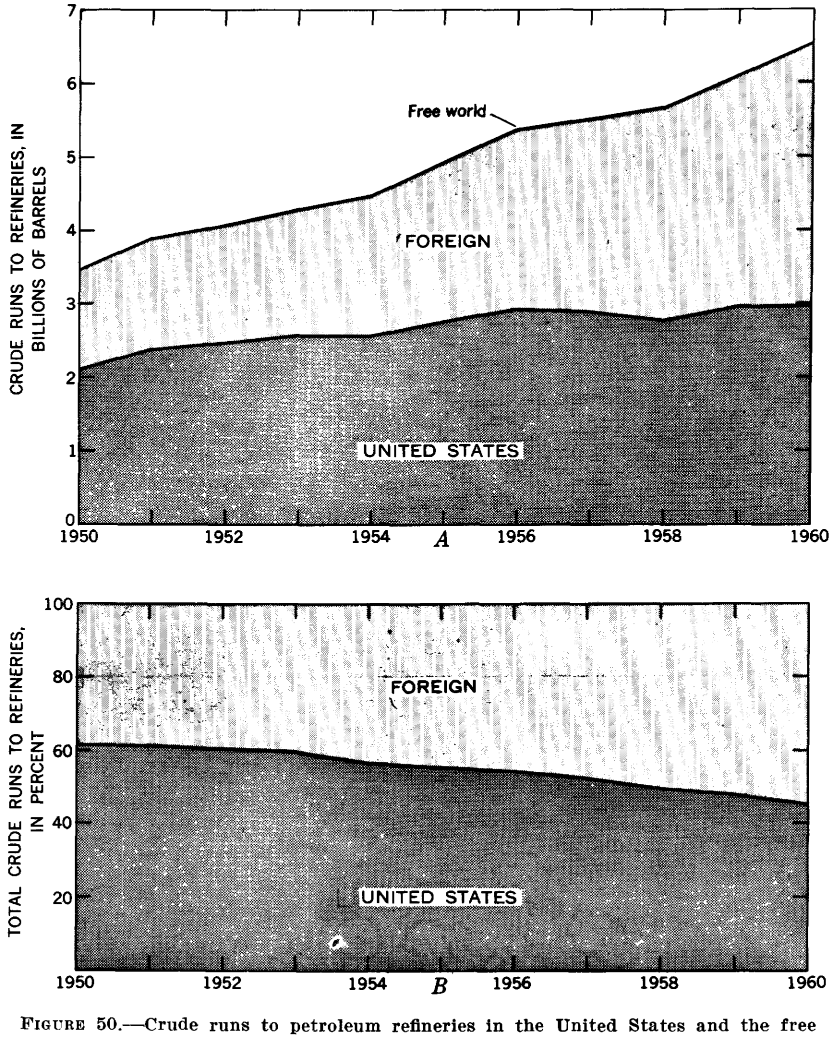

FIGURE 50.—Crude runs to petroleum refineries in the United States and the free world by (*A*) quantity and (*B*) percent, 1950–60.

in demand for refinery products during the same period. Crude runs to refineries in the United States amounted to 1,730 million barrels per year in 1946 and increased to 2,730 million barrels in 1955 and to 2,953 million barrels in 1960. Crude runs to free world refineries were 2,475 million barrels in 1946, 4,945 million barrels in 1955, and 6,528 million barrels in 1960.

TRENDS IN PETROLEUM REFINING IN THE UNITED STATES

The President's Materials Policy Commission (1952) estimated that the 1975 consumption of petroleum products in the United States would amount to about 5 billion barrels per year, or 13.7 million barrels per day. This would be an average increase in domestic demand of about 3 percent per year between 1950 and 1975. On this basis, the domestic demand for 1966 would amount to 10.4 million barrels per day.

Hill, Hammer, and Winger (1957) noted a slackening in the rate of growth in demand for petroleum products in the United States and to a lesser degree in the free world; however, these authors predict that the domestic demand for petroleum products in the United States will increase at an annual rate of 5 percent between 1956 and 1966 and provide a domestic demand of 14.3 million barrels per day by 1966.

An increase in the demand for petroleum products in the United States at an average rate of 2.0 to 2.5 percent per year from 1960 to 1965 is estimated by Jameson (1960). He assumed that the total demand for crude oil would increase by only 1.0 to 1.5 percent per year for the same period. The lower rate of demand for crude will be due to part of the demand for petroleum products being satisfied by increased production of natural-gas liquids and increased yield of additional lighter products from a barrel of crude oil.

Figure 51 shows the total domestic demand for petroleum products and the crude oil runs to refineries in the United States from 1920 through 1960. Since 1946 the domestic demand has grown at an average rate of 5 percent per year, and refinery runs have increased at 4 percent per year. Assuming the same annual rates of growth, I have extended the curves to show the probable demand and crude runs in 1966. This extension indicates a probable domestic demand of 4,746 million barrels per year, or 13.0 million barrels per day in 1966. This value is somewhat higher than the demand of 10.4 million barrels per day calculated for 1966 from data published by the President's Materials Policy Commission (1952) but lower than the 14.3 million barrels per day estimated for 1966 by Hill, Hammer, and Winger (1957).

The extension of the crude-run curve indicates probable runs of

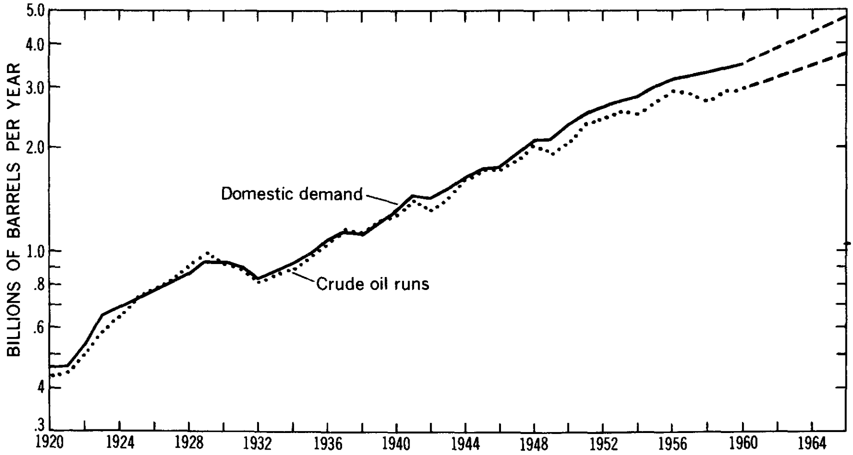

FIGURE 51.—Crude oil runs by refineries and demand for petroleum products in the United States, 1920–60 with curves extended to 1966.

3,736 million barrels per year, or 10.2 million barrels per day in 1966. On the basis of this value and the average unit water-requirement value of the 1956 survey, a probable water intake of 4,770 million gallons per day will be needed by petroleum refineries in the United States in 1966.

SUMMARY

QUANTITATIVE WATER REQUIREMENTS

This survey was not conducted to determine the minimum amounts of water used by refineries, but it was primarily concerned with the current water requirements of the petroleum refining industry.

The average water intake of the refineries surveyed in 1951 and 1956 was 468 gallons per barrel of crude charge. The median intake and gross circulation was 95 gallons and 1,400 gallons per barrel, respectively. In 1955 the estimated average total water requirements for the petroleum refining industry was 3,500 mgd, or about 3 percent of the estimated daily withdrawal of industrial water in the United States.

Median water-use values for refineries with cracking facilities were greater than those for refineries without cracking facilities. The median intake for refineries with cracking facilities was 100 gallons per barrel of crude, and the gross circulation was 1,600 gallons per barrel. The corresponding values for refineries without cracking units were 75 gallons and 500 gallons per barrel.

Consumptive use of water in the petroleum refining industry is high; the median for the refineries surveyed was 36 gallons per barrel, or 40 percent of the intake. The high consumptive use is mainly due to the accumulative evaporation and to windage losses in cooling towers.

QUALITATIVE WATER REQUIREMENTS

Water of good quality is desirable for the petroleum refining industry; however, the quantity available is of more importance than the quality. The quality needed will differ with the use within the refinery, but most refineries provide the necessary quality by treatment.

Median values of selected chemical constituents and physical characteristics of untreated once-through and recirculated water used for cooling, boiler feed makeup, process operations, and sanitary purposes are summarized in table 23.

Water used for once-through cooling by the refineries surveyed was of slightly higher quality than that used for circulating cooling. The use of higher quality water for once-through cooling was probably not due to higher quality requirements but resulted from the favorable water situation at the refinery location. Petroleum refineries used large amounts of high-quality water to produce steam. Untreated water was generally not satisfactory for this use, and careful selection and treatment of makeup for boiler-feed water was necessary to prevent scale formation, excessive corrosion, and embrittlement.

TABLE 23.—*Summary of the median of selected quality characteristics of untreated water used for various refinery purposes*

[Results expressed in parts per million unless otherwise indicated. These data are based on individual observations available and are not balanced analyses]

Constituent or property	Cooling water once-through	Circulated	Boiler-feed makeup	Process operations	Sanitary purposes
Silica (SiO_2)	9.8	12	12	14	11
Iron (Fe)	.12	.15	.10	.12	.10
Calcium (Ca)	51	45	39	52	36
Magnesium (Mg)	13	13	14	14	10
Sulfate (SO_4)	38	68	62	89	40
Total hardness as $CaCO_3$	160	160	142	200	126
Color	8	5	5	5	3
pH	7.4	7.6	7.6	7.6	7.6

TRENDS IN WATER REQUIREMENTS

The petroleum-refining industry is a relatively new industry that is accustomed to change. The industry is quick to adopt new refining methods and equipment that increase the operating efficiency of the refinery. There is a tendency for petroleum refineries to reuse an increasing amount of water, especially cooling water, with a resulting decrease in refinery intake. This decrease, however, is accompanied by an increase in consumptive use and a decrease in waste-water discharge. Some refineries are using air cooling to further conserve water where only limited temperature reductions are required.

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