WATER

ITS PURIFICATION AND USE IN THE INDUSTRIES

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Furnace Draft; Its Production by Mechanical Methods.

PREFACE.

MUCH of the material of this book appeared as a series of articles in "Industrial Engineering and Engineering Digest" for 1910–1911.

As far as possible the description of the different apparatus and methods of purification have been submitted to and approved by the makers of each. The intention is not to give a detailed description of each piece of machinery, but to endeavor to bring out the principal features of each apparatus.

It is hoped that this book, containing, as it does, general information regarding water, also tables of value to users of water for manufacturing and industrial purposes, may prove a help not only to engineers, but also to students.

The writer has purposely omitted the names of all manufacturers and has endeavored by liberal employment of illustration to make every feature of the mechanical part of purification of water clear. He would be very grateful for any suggestions regarding the revision of the book and for any material that would give the book more value, also for any corrections that should be made if errors are found.

The writer has had in mind the use of water in various branches of industry rather than for drinking purposes, though the latter has been mentioned. He wishes to thank all who have assisted him in any way in connection with this book.

WILLIAM WALLACE CHRISTIE.

PATERSON, N. J., July 12, 1912.

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PURIFICATION OF WATER

CHAPTER I.

SOURCES OF WATER—IMPURITIES—USES—REAGENTS.

In these days, when the manufacturer is learning the lesson of "conservation" in many directions, and while large efforts of brain, brawn and capital are being spent to conserve the water resources of the country, more and more attention is being given to the water used and the water wasted in the various industrial operations.

There is nothing which we have or use in which water is not a constituent part. Even our own bodies are more than half water. Lavoisier * cannot claim that he was the first to obtain the facts concerning the true chemical nature of water. To Cavendish belongs the merit of having supplied the true experimental basis upon which alone accurate knowledge could be founded. James Watt, on the other hand, although reasoning from imperfect and indeed altogether erroneous data, was the first, so far as can be proven by documentary evidence, to state distinctly that water is not an element, but is composed, weight for weight, of two other substances, one of which he regarded as phlogiston and the other as dephlogisticated air. James Watt was a man of keen mental vision and of vigorous intellectuality. He loved the truth for truth's sake.

The chemical symbol for water is H_2O, or 2 parts of

* T. E. Thorpe, "Composition of Water," Sc. Am. Sup., Aug. 6, 1898.

hydrogen to 1 part of oxygen by volume; or 1 part of hydrogen to 8 parts of oxygen by weight.

The sources of water supply are many; the principal ones, however, are as follows:

Rain, which seldom gives pure water, for the rain in its descent through the air to the earth takes up soluble gases, carbonic acid, ammonia and sulphurous and chlorine gases. In the neighborhood of manufacturing plants, such as smelters and chemical works, the quantity of gases absorbed may be very large.

Surface water is rain water and water condensed from the atmosphere which has run over the soil and taken up some impurities. Spring water may also be mixed with surface rain water.

River water is surface water after it has run off from the earth to its natural channel, through which it travels to the ocean. River water may also contain spring water and is often contaminated by leaves and other vegetable matter picked up in the course of its travels. Albuminoids and free ammonia get into water supplies through the run-off water and give rise to many epidemics. River water is frequently contaminated with coloring matter, mill wastes and substances in suspension, much of which can be filtered out. Thus far we have considered what is generally known as soft water, except where spring water in rivers has been hard water.

Spring water, coming out of the earth, frequently contains gaseous impurities given off by decaying vegetable matter or animal matter; then, having taken up carbonic acid gas, the water can dissolve lime rock and becomes hard water.

Snow water is in the same class as rain water. Pure snow can only be obtained near the end of a storm, after a heavy fall of snow which has swept the atmosphere clear of all impurities.

TABLE I. — ANALYSIS OF A NATURAL SPRING WATER.

Color — None. Taste — Pleasant.	Odor — None.	
Data obtained by analysis.	Parts in 100,000.	Grains per gallon.
1. Free ammonia	0.001	0.0006
2. Albuminoid ammonia	0.002	0.0012
3. Oxygen required to oxidize organic matter	0.07	0.04
4. Nitrogen in nitrites	None	None
5. Nitrogen in nitrates	0.28	0.16
6. Chlorine	0.39	0.224
7. Total hardness	6.10	3.56
8. Calcium sulphate	1.63	0.95
9. Calcium and magnesium carbonates	4.47	2.61
10. Total solids	9.70	5.66
11. Mineral matter	8.90	5.20
(Mineral Matter — Analysis in Detail.)		
Silica	1.98	1.16
Alumina	0.19	0.11
Oxide of iron	Traces	Traces
Sodium chloride	0.63	0.37
Calcium sulphate	1.63	0.95
Calcium carbonate	3.45	2.01
Magnesium carbonate	1.02	0.60
Phosphate	Traces	Traces
12. Organic and volatile matter	0.60	0.46

Data obtained by bacteriological analysis.

No pathogenic bacteria (so-called disease germs) or other injurious micro-organisms are present.

Analysis made by Albert R. Leeds, Ph.D.

NOTE. — The U. S. gallon is taken at 58,334.95 grains.

Artesian well water. — The water from artesian wells, that is, driven or bored wells several hundred feet deep in the earth or rock, is liable to be hard, — some of it very hard, — containing mineral salts which the rain water has taken up in its descent through the earth from its surface. This is not universally true, however, as some wells in Louisiana and vicinity, parts of Colorado, near Chicago, and in Brooklyn, N. Y., prove.

Hardness. — Hardness is divided into two classes, temporary and permanent. Temporary hardness is due to the presence of carbonates of lime or magnesia. Permanent hardness is due to presence of sulphates and chlorides of lime or magnesia.

Standards of Hardness.

American. — Grains of calcium carbonate per "United States" gallon of 58,381 grains.

English. — Grains of calcium carbonate per "Imperial" gallon of 70,000 grains.

French. — Milligrams of calcium carbonate in 100 grams of water or parts per 100,000 of water.

German. — Milligrams of calcium carbonate in 100 grams of water or parts per 100,000 of water.

Occurrence. — Water manifests itself in three forms: Gaseous, as vapor or steam; liquid, as water; and solid, as ice.

Absorptive Power. — Nearly all waters contain oxygen in solution. One writer says: "At 32° F. it absorbs 4.9 per cent of its bulk; at 50° F., 3.8 per cent; and at 68° F., 3.1 per cent." Another states that cold feed water for boilers under 150 pounds pressure per square inch absorbs 3.2 pounds of oxygen per ton of water. Atmospheric air contains $\frac{1}{4000}$ of carbonic acid, while air in solution in water contains from 40 to 42 per cent of the same carbonic acid.

Peaty water from woodlands has a solvent action on lead pipes due to its acidity, which varies in terms of a sulphuric acid equivalent from 1 to 4 parts in 100,000.

The impurities in water may be classified thus:

IMPURITIES IN WATER.

- SUSPENDED
  - *Inorganic*: Mineral matter, Grit, Sand, Clay, etc.
  - *Organic*: Animal and Vegetable matter, Microörganisms, Algæ, Peaty matter
  - → MECHANICAL PURIFICATION
- DISSOLVED
  - *Gases*: Carbon dioxide, Hydrogen sulphide, Chlorine, etc.
  - *Solids*: Inorganic, Organic, Vegetable, Animal and Mineral matter
  - → CHEMICAL PURIFICATION

RESULT PURE WATER.

Still another classification with regard to its influence upon the human system is one made by Professor Edward B. Warman, who says:

"Raw water is an aquarium.

"Boiled water is a graveyard.

"Mineral water is premature old age.

"Filtered water is a gay deceiver.

"Distilled water is purity."

IMPURITIES OF WATER.

Calcium Carbonate ($CaCO_3$), commonly known as limestone, marble or chalk, does not form a hard scale, but causes much of the soft mud found in the bottom of boilers. Carbonic acid is driven off when the temperature of the water reaches 200° F., and carbonate of lime is precipitated. In combination with other substances it may form a very hard scale. It is readily soluble in water containing carbonic acid gas.

Calcium Sulphate ($CaSO_4$), also known as alabaster, plaster of Paris or gypsum, is responsible for the hardest kind of scale. In boilers it precipitates as heavy crystals when 50 pounds steam-boiler pressure has been reached, and is more adhesive to boiler shells than the carbonate of lime. It is slightly soluble in salt or pure water at or beyond 284 to 302° F., and more soluble at lower temperatures. It is a poor conductor of heat, according to Rankine, being forty-eight times as resistant to heat as is wrought iron.

Calcium Chloride ($CaCl_2$) is very soluble in natural water. It is corrosive, but does not form scale unless present with magnesium sulphate, when a transfer of acids causes a hard scale to form. Calcium chloride is sometimes used as a "nonfreezing" solution or brine in gas-engine jackets. With magnesium sulphate it forms magnesium chloride, which is very corrosive.

Calcium Nitrate [$Ca(NO_3)_2$] is corrosive only if present in large quantities. It forms scale when sulphate of soda is present, resulting in sulphate of lime. It is rarely found in feed waters and if treated with sodium carbonate, calcium monocarbonate is precipitated.

Magnesium Carbonate ($MgCO_3$) is a toilet preparation, its common form being more soluble in water than the calcium carbonate. In boilers it is quite unstable, decomposing into carbon dioxide, magnesium hydrate and magnesium oxide, all found in some boiler scales. It is used as a covering for boilers and steam pipes, being a good nonconductor of heat. Magnesium carbonate is held in solution by carbonic acid and is precipitated by the use of slaked lime, which drives off the gas. It has a tendency to cause foaming in boilers and a scum is formed by the precipitation. Wehrenfennig says that preheating is very necessary for waters containing this compound.

Magnesium Sulphate ($MgSO_4$), known as epsom salts, is easily soluble in cold or warm water, and does not form scale in boilers. When broken up by lime salts it forms scale composed of magnesia and calcium sulphate. It has a very corrosive action on boiler iron.

Magnesium Chloride ($MgCl_2$) is a corrosive mineral in boiler water, pitting and grooving boilers. It is very soluble in water, evolving heat, and is the destructive element of sea water. J. C. Sparks says that this compound is almost always found to accompany sodium chloride when the latter is found in a natural water supply.

Mr. A. W. Hargreaves, government analyst of South Australia, agrees with Mr. Stabler when he says that a solution of magnesium chloride is certainly more harmful to a boiler than a solution of sodium chloride. Mr. Hargreaves says * that the magnesium chloride is probably split up at the pressure and the temperature in the boiler and the magnesium ions, combining with the dissociated water precipitates magnesium hydroxide and interferes with the concentration of the chlorine ions so that these acid ions (potential hydrochloric acid) in turn combine with the iron of the boiler plate, giving rise to corrosion. As sodium does not form an insoluble compound its reaction in a water does not appear to lead to corrosion. In determining chlorine Mr. Hargreaves always uses for the indicator (K_2CrO_2) in place of ($K_2Cr_2O_7$).

Magnesium Nitrate [$Mg(NO_3)_2$] has the same action in boilers as the chloride.

Iron and Alumina Sulphates [$Fe_2(SO_4)_3$] and [$Al_2(SO_4)_3$], respectively known as copperas and alum, act in boilers, though they are salts, in a manner similar to sulphuric acid.

* Letter in *Engineering News* of July 19, 1909.

Iron and Alumina. — The bicarbonate is the usual form of combination, being a very unstable compound which converts iron to iron rust — red water seen coming from boilers. Carbonate of iron causes boiler scale to form. Aluminum oxide is insoluble in acids, but soluble in water.

Silica (SiO_2) is common sand and is contained in almost all waters, in greater amount in warm water than in cold water. It is sometimes combined with alumina. It does not form scale, but bakes to a hard crust.

Suspended Matter. — This is organic or inorganic matter, variable in quantity and quality. It cements other impurities in boilers, together forming scaley deposits.

Sulphuric Acid (H_2SO_4), also known as oil of vitriol, occurs most frequently in mine waters and in the neighborhood of mines. In boilers it quickly forms sulphate of iron, and is continuous in its performance or action.

Sodium Sulphate (Na_2SO_4), or glauber salt, is inert in boilers, from which it is blown out.

Sodium Chloride ($NaCl$), or common salt. — There is no practical way to remove this from boiler water, except by blowing out.

Sodium Nitrate ($NaNO_3$), or saltpeter. — None of the last three is objectionable in boiler water, except when they appear in large quantities, when they cause priming and foaming. They are not corrosive.

Sodium Carbonate (Na_2CO_3). — Washing soda, soda ash, soda crystals, Scotch soda, in large quantities, cause foaming. It is not corrosive and is soluble in water, evolving heat. It is a cheap reagent which is largely used in "cold process" treatment, known in other words as water softening, and is used for the conversion of sulphates, chlorides, nitrates, etc.

As the reaction between the sulphates and soda ash does not take place rapidly in cold water, in many waters, especially those containing magnesia, it is advisable to give the water a preliminary heating.

The English Boiler Inspection Co. recommends soda ash in preference to "crystals" to be pumped regularly with the feed water into boilers to prevent scale.* Soda ash is also advised by the Hartford Boiler Insurance and Inspection Company.†

Carbon Dioxide (CO_2). — Found in all natural waters — used in soda water and seltzer water. Its presence is favorable to pitting and corrosion. It can be completely removed.

Hydrogen Sulphide (H_2S), commonly known as sulphuretted hydrogen, is rare in natural waters and decomposes readily into its two elements.

Properties of Water for the Industries.

Every industry has something distinctive about it, even to the character its water supply must have to produce the best work. This is particularly true of the textile industries. Frequently more than one kind of water is necessary in the factory. The character of water that will be the best for one process being entirely unsuited for another.

The author has endeavored to bring together some of the requirements of the various trades.

Water in Concrete. — The water used in mixing concrete should be free from oil, acid, strong alkalies and vegetable matter.

Water in Brewing. — Soft water aids in the preparation of malt and adds to the clearness of the beer. For such purposes water should be colorless, odorless, insipid and free from organic matters. Mineral salts in general are harmful, but some are useful in improving the quality of the beer.

* See *American Machinist*, Dec. 13, 1883, page 7.

† See *American Machinist*, Oct. 25, 1884.

English ale brewers prefer sulphate waters, and some of them add calcium sulphate to soft waters. Organic matters tend to mold the grain, and poorly malted liquor results. Ammonia or nitrogenic salts are caused by decomposing organic matter in water.

Chlorides in water may be allowed in small quantities, but they interfere with the germination of the grain if in excess. Two per cent of sodium chloride is desirable. A sweet taste to the beer comes from a very minute quantity of chloride, and a bitter taste from too much chloride.

Zinc should not be used in steam boilers or in any apparatus where chlorides are in the water; especially is this to be noted where condensed steam is used in vats, and where the feed water contains chloride of magnesium, for instance. Salts of iron should be removed from water, as they give the beer a bad taste.

Water containing lead must not be used for any purpose whatever. Carbonates of calcium or magnesium should be present to a limited extent, as very hard waters give beer a bitter taste. Waters containing sulphates of calcium and magnesium are to be preferred to soft water, and have an advantage over calcium carbonate waters.

For ale, sulphate waters are preferred. For porter or stout, soft waters are best. Water should be free from organic matters and from microörganisms as well. This object can be attained by filtration or sterilization.

Water in Dyeing and Bleaching. — Dyers of fine fabrics in the United States claim to be unable to produce the same colors in these fabrics as the French dyers, because of the water. Just why this should be so is not apparent since we should be able to produce in any locality, by chemical treatment, water of the same quality. Magnesium lime salts and iron should not be present in water used for dyeing. The water should be colorless and all sediment filtered out. Great care must be used that the proper temperature exists for the best results in using dye and also for use of soap and rinsing. Indigo white may be changed to an insoluble blue by oxidation. Organic matters may putrefy the extracts used and spoil the textiles. Aniline colors do not dissolve readily in calcareous waters, and these waters are not adapted to the preparation of solutions of coloring matters. The salts of lime are necessary, however, to logwood or weld dyed in a mordant of iron and aluminum. Calcareous waters form an insoluble soap in the dye and the color is not uniform. For indigo dyeing iron in the water is of no particular moment. Calcareous substances kill the luster and make the colors fast, especially with silks. Filtration is most necessary for water used in dyeing and printing cloths.

Iron oxide burns the organic matters in the waters by causing them to part with their oxygen, and in dye waters it causes a flatness in the coloring. Condensed exhaust steam is occasionally the cause of spoiled goods in dyehouses and bleacheries. Modifications of boiler compounds are frequently necessary, if the steam is eventually to be condensed, or used as live steam in the dye tubs, or bleaching processes.

Hard water has a tendency with alizarine, direct and basic, dyes to throw down the color itself as an insoluble precipitate and when iron is present to produce red stains. Hard water used to wash off the loose dye, and to which no corrective can be applied, also has an injurious effect on the fiber and color.

Water in Tanning. — Quicklime and water are used first to get the roots of the hair out of the leather hide. Water containing calcium carbonate is not good for this purpose, as it prevents the absorption of the tannin, and may also cause brown stains. Carbonate of magnesia acts much in the same manner. Calcium and magnesium sulphates are very desirable, and, in fact, are necessary to the tanning water. Carbonic acid is also advantageous.

Waters containing the salts of iron or grease are of no value to the tanner.

Water in Ice Making. — The greatest care should be exercised in the selection of the water to be used for ice making, drinks, mineral waters, etc., as it is of the gravest concern to the public welfare. Natural ice is used to a great extent, but is liable to contamination, and should only be used for cooling the exterior of vessels containing drinking fluids — never put in them, unless the user is absolutely sure of its purity. Cold does not affect all bacteria; the typhoid bacillus, for example, is hardly affected by being frozen in water. Sterilized water is the only kind that should be used in the manufacture of ice, which, when melted, is taken directly into the human body.

If natural water is free, or nearly so, from mineral matter or contains carbonate of lime or carbonate of magnesia and suspended matter and air in solution, then, to obtain clear ice, vigorous boiling, with or without vacuum, and with or without filtration, will give satisfactory results. For drinking water it is more or less desirable to have a moderate content both of air and mineral matter.

In the manufacture of ice, after distilling, the water is passed through a condenser coil, cooled down by cold water, then run to the storage tank, where a direct-expansion ammonia coil further reduces its temperature to as near freezing point as possible.

Cloudy, hard water is always contaminated and should not be used for ice making. Softening eliminates carbonic acid and other gases.

Where water for freezing in ice plants is taken from the condensed steam used or made in the boilers, it is not desirable to use water containing large quantities of non-incrusting solids or sodium salts as boiler feed water. Boilers using such waters are liable to prime and the water and solids are carried over with the steam, which, when frozen, makes what is known as white ice.

Water for Laundries. — Hard water is wasteful of soap, and in the laundry cleanliness cannot be obtained without the use of soap. Hard water prevents the soap from doing its work, so soft water must be used; or, if it cannot be had, softening must be accomplished by means of chemicals. The cost of softening is much less than that of the extra soap required when using hard water.

A calcareous water can be softened by a soda salt. A sulphate water can be softened by use of sodium carbonate. Hard water, however, can be used in the rinsing and blueing processes.

Soap Consuming Power for Toilet and Laundry Purposes.

It is desirable to have water that will readily form a lather when soap is used. Calcium, magnesium, iron and aluminum in solution have a capacity of combining with soap and thereby destroying its power to produce a lather. As iron and aluminum are usually present in small amounts, the soap consuming power can be judged approximately by considering merely the content of calcium and magnesium. The smaller quantity of these two elements the better the water for toilet and laundry purposes. It must be remembered, however, that one part of magnesium consumes as much soap as 1.6 parts of calcium.*

* Water Supply Paper, 256, p. 59; "Mineral Analysis of Water," *Engineering News*, V., 60, p. 355, 1908; Revised in Water Supply Paper, 274, p. 165.

The laundryman should appreciate, if he does not already, that one degree of hardness in the water destroys $1\frac{7}{10}$ pounds of soap per 1000 gallons and the extra soap required to do the same work with soap at 5 cents a pound would make the soap cost $8\frac{2}{10}$ cents per 1000 gallons.

The cost of softening is generally given as from 2 to 3 cents per 1000 gallons. The hard water not only costs more to use in destruction of soap but it causes a sticky substance to form in the water which is very difficult to remove after washing the goods. Lime soap can be broken with spirits of salt (muriatic acid) which saponifies the fatty soaps, but as soon as the piece is washed out the hardness again forms in the water.

SOAP REQUIRED FOR PERMANENT LATHER.

Degrees, hardness.	Pounds of soap destroyed per 1000 gallons of water.	Cost of soap at 5 cents per pound.	Degrees, hardness.	Pounds of soap destroyed per 1000 gallons of water.	Cost of soap at 5 cents per pound.
5	8.5	$0.41	25	42.5	$2.05
10	17.0	.82	30	51.0	2.55
15	25.5	1.23	35	59.5	2.98
20	34.0	1.64	40	68.0	3.40

Water in Soap Making. — Water containing salt, sulphate of sodium, potassium, or magnesium should not be used, nor water containing organic or earthy material — this latter should be filtered out. Condenser water may be used.

Water in Paper Making. — The first consideration in locating a paper mill should be the water supply, its source, quality and quantity. Fine papers cannot be produced with water containing matters in suspension and solution. Settling basins need to be large; they are very wasteful of ground area and are slow in action. To hasten the process of clarification, sand filters are used.

From the earliest times the Chinese have treated waters for paper making by adding to them a little alum. A brown color in the water results when salts of iron are used, and the effect is the more noticeable when the paper is sized. Vegetable size and calcareous waters do not get along well together, nor does vegetable size keep as well as the animal-glue size formerly used. Water containing salts of calcium or magnesia must be corrected before being used in paper making, a simple means being to "run the water through a gravel filter and into a tank containing milk of lime in excess."

Sulphate of lime or iron makes the water hard, giving a bad product, and at the same time prevents the color coming up with the best effect. Lime and magnesia kill or neutralize a certain amount of size.

Water for Railroads. — Locomotives using hard water with clean boilers required calking at the end of the third week and also required 33 calkings in seven months, which was the life of the flues in a particular case. With soft water in the same locomotives calking was required but six times during 15½ months.

The requirements of locomotive boilers in the matter of feed water do not differ materially from those of boilers stationary in their setting, with a possible exception that the locomotive boiler being in a constant condition of agitation, bad water will make more trouble than the same water would in a stationary boiler in a fixed setting.

Water in Sugar Refining. — Sugar sirups are filtered through animal charcoal, and, if salt or calcareous water is used to wash the charcoal filter, the material loses its good qualities very quickly. Phosphates which are soluble, and phosphoric acid, do not have any harmful action when in water.

Magnesium chloride, which is a very dangerous element in boiler waters, is also bad in sugar making, as hydrochloric acid is liberated, which is sure to make trouble. Substances in the water that are molasses-forming in their nature prevent from one to six times their weight in sugar from crystallizing.

Weight and Specific Heat of Water. — These notes are taken from a paper read before the American Water Works Association, in 1905, entitled "Notes on the Density, Relative Volume, and Weight per Cubic Feet of Pure Water," by M. L. Holman.

Weight of a cubic foot of water:

	Lbs.
At maximum density (Legal or Metric system)	62.428
At 62° F	62.357
At boiling point, viz., 100° C. or 212° F	59.848
At maximum density-mean result I.B	62.427
At 62° F	62.355
At 100° C. or 212° F	59.846

These last three results are taken from the figures quoted in the above paper. It has been found that, where great precision is desired, one formula will not cover the range of temperature from freezing to boiling point. The specific heat of water is not constant between the freezing and the boiling points, hence two or more curves will, in all probability, be required to accurately and precisely determine the relative volumes for each degree of temperature from the freezing to the boiling point.

The specific heat of water is	1.0000 at 32° F.
The specific heat of water is	1.0568 at 446° F.

The specific heat of water is the heat required to raise one pound of water 1° F. The value S is given with sufficient accuracy by the formula, $S = t - 32 + 0.000000\ 103(t - 32)^3$ for the Fahrenheit scale.

Analysis. — The analysis of water is the starting point of all work in connection with its purification; it is likewise a matter on which there are decided differences of opinion even as to the apportionment of the constituents of an identical sample, but there are good and reliable chemists who can, and do, make careful and reliable analyses.

The old chemistry teacher of C. B. Dudley, late chemist of the Pennsylvania railroad, used to say: "No chemist can make an accurate analysis. There are chemists who can work near enough to accuracy so that their work is valuable. There are chemists who cannot. And that is the difference between chemists." Mr. Dudley adds in part: "Some analyses are accurate to one-half per cent; some to a tenth of one per cent, and some, perhaps, to a hundredth of one per cent; but none are the exact truth."

Attention is called to an article in the *Engineering News*, May 20, 1909, giving the different ways an analysis may be stated by different chemists. The results should be given in grains per United States gallon, or parts per 100,000. When water is to be used for drinking purposes the following analyses should be made; one for hardness; one a bacteriological analysis, then physical tests as to color and turbidity.

At Washington, D. C., for turbidity, an arbitrary method was used — the determination of the distance in inches at which a sphere of copper one inch in diameter could be seen with the naked eye through the water placed in a rectangular tube up to 36 inches in depth.

Clear when the sphere was visible from	36 to 22 in.
Slightly turbid when the sphere was visible from.	21 to 15 in.
Turbid when the sphere was visible from	14 to 8 in.
Very turbid when the sphere was visible from ...	7 to 0 in.

When the sphere is visible through 22 inches of water, no objection is made to the water on the score of its turbidity.

The chemical analysis of potable water consists in determining the parts per million of ammonia, nitrogen as nitrites and nitrates, chlorine, alkalinity, required oxygen, total solids, turbidity, color, odor and taste.

Ammonia. — The presence of ammonia in abnormal or suspicious quantity indicates pollution by animal matter, decayed or decaying.

Nitrogen as Nitrites and Nitrates. — The presence of nitrites is always to be looked upon with suspicion as indicating contamination. Nitrates indicate the former presence of nitrites more fully oxidized.

Chlorine. — The presence of more than the normal amount of chlorine is to be regarded with suspicion. Chlorine, due to common salt, is nearly always present in the water used for domestic purposes, and an excess is a positive indication of sewage contamination.

Alkalinity. — The determination of alkalinity is important as an indication of hardness. Very hard water is expensive, as it wastes soap, and "scales" in cooking utensils and steam boilers and frequently renders the water disagreeable to the taste.

In technical analyses waters are classed as alkaline, neutral or acid, according to their color reactions with methyl orange, an organic dyestuff used as an indicator. The indicator is colored yellow by alkaline water, pink by acid water and remains an orange color with neutral water.

By far the greater number of ground waters are alkaline in their reaction and the greater part of this alkalinity is due to the presence of the carbonates of calcium and magnesium and, to a less extent, to the carbonates of soda and potash.

An American degree of alkalinity is equivalent to one grain of calcium carbonate to one United States gallon, and is measured by the amount of a standard acid solution required to neutralize a given amount of the water.

The alkalinity of waters which do not contain carbonates of soda or potash is "roughly" equivalent to the temporary hardness.

Required Oxygen. — This determination gives a means of judging the amount of organic carbon present in water.

Turbidity. — This is determined chemically by ascertaining the total amount of solids in suspension.

Color. — This is determined ocularly by comparison with standards.

Odor. — This is determined by smell.

Taste. — This is determined by physical test.

No absolute standards can be established by which a water may be condemned as unfit for domestic purposes, for the source of supply must always enter into consideration and an excess in any item of determination may be traced to harmless causes.

The following are some of the standards quoted from Professor William P. Mason's treatise on "Water Supply."

Ammonia. — Professor Mallet gives from analyses of 15 drinking waters believed to be wholesome, for albuminoid ammonia, 0.125 part per million. Dr. Leeds gives for the highest limits as a standard for American waters, free ammonia 0.01 to 0.12 parts per million.

Nitrites. — Mallet gives 0.0135 parts per million. Leeds gives (American rivers) 0.003 parts per million.

Nitrates. — Mallet gives as an average of 13 samples 0.42 parts per million. Extremes, 0 to 1.04.

Chlorine. — Leeds gives 3 to 10 parts per million. Ordinary sewage contains 110 to 160 parts per million. Human urine contains 5872 parts per million.

Hardness. — Leeds gives, in parts per million, 50 for soft and 150 for hard waters.

Total Solids. — Dr. Smart, National Board of Health, 1880, gives, as a safe limit, 300 parts per million; to be condemned, 1000 parts per million. Leeds gives, as a standard for American rivers, 150 to 200 parts per million.

Required Oxygen. — Leeds gives 5 to 7 parts per million.

These standards are shown below in tabular form:

Total Solids	150	to	300
Free ammonia	0.01	to	0.12
Albumin, ammonia	.10	to	.28
Nitrites	.0135	to	.003
Nitrates	.0	to	1.04
Chlorine	3	to	10
Required oxygen	5	to	7

The chemical analysis of water for the industries includes the determination of: Acids and Bases, Hardness, Causticity, Alkalinity, Metacidity, Acidity, Odor, Appearance, Probable Combinations of Chemicals in the Water, Incrusting Solids, Nonincrusting Solids, Volatile Matter.

Electrical Analysis of Water. — Regarding Electrical Analyses, Harry R. Johnson in "Water Resources of Antelope Valley, Cal.," says — "In order to study the character of the water of the valley in a general way, analyses were made of special waters whose electrical resistance had been previously determined by means of a modification of the Wheatstone bridge, an instrument devised in accordance with the principle that the resistance offered to the passage of an electric current through water decreases as the proportion of dissolved solids in the water increases. The resistance as actually measured is reduced to an equivalent resistance at a standard temperature of 60° F., and by the use of a curve based on actual analyses and corresponding bridge tests, resistance may be reduced to proportionate parts of solid matter in a given water. Although the electrolytic method of determining the quantity of dissolved solids in a water is not accurate, it furnishes a simple and rapid means of distinguishing relative amounts of total solids with sufficient correctness for many purposes."

Johnson says — "Although waters which contain 150 parts or less of solid matter per million parts of water may be considered excellent, those containing more than 500 or 600 parts per million are inferior, and those with intermediate amounts represent ordinary types of natural water."

CHAPTER II.

WATER SOFTENING. COLD PROCESS SYSTEMS.

Water Softening. — Water softening is the chemical purification of water by means of which the salts which give the water its soap-destroying properties are either removed or changed to salts which do not destroy soap. The hardness is not readily reduced below three (3) or four (4) grains of hardening salts, or scale-forming ingredients. The system was invented sixty odd years ago by Dr. Clarke, who, by the use of lime, removed the calcium and magnesium carbonates. Then came the soda-ash process of Dr. Porter, which was used to remove the sulphates of calcium and magnesium. After this the Porter-Clarke process, a combination of the two systems, was used.

As before noted the Chinese used alum for clarification of water hundreds of years ago.

There are two general methods now in use which may be classified as:

Cold-process systems, intermittent and continuous; and hot-process systems.

Engineer "Q" builds a water softener of the continuous type having two principal features — a large settling chamber in which the chemical reaction occurs and where the water is freed from dissolved scale-forming and suspended materials and a lime saturating tank where clear lime water of uniform strength is made.

The machine is clearly illustrated by colored cross-sectional view, the detail perspective of the top part of the machine, Fig. 1; and the exterior view of the machine, Fig. 2.

Raw water is delivered by pressure or gravity to the distributing tank on the very top of the machine through a double-inlet valve. The upper part of the double valve is connected

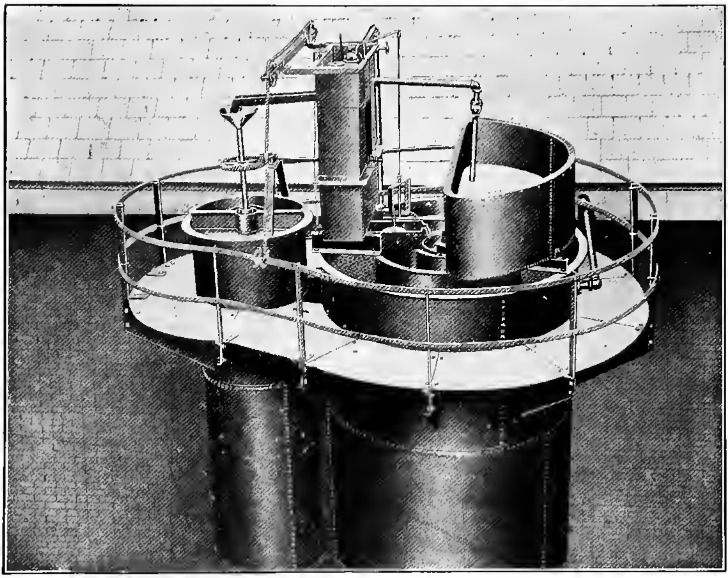


Fig. 1. — The Detail Perspective of the Top Part of the Machine.

to a float in the upper part of the decanting tank. This valve is used to automatically start and stop the machine. Water is supplied in any volume up to its rated capacity, the method of control being such that, while operating, the machine runs at full speed. This method of control is designed to give perfect results for any rate of flow within the maximum capacity of the machine.

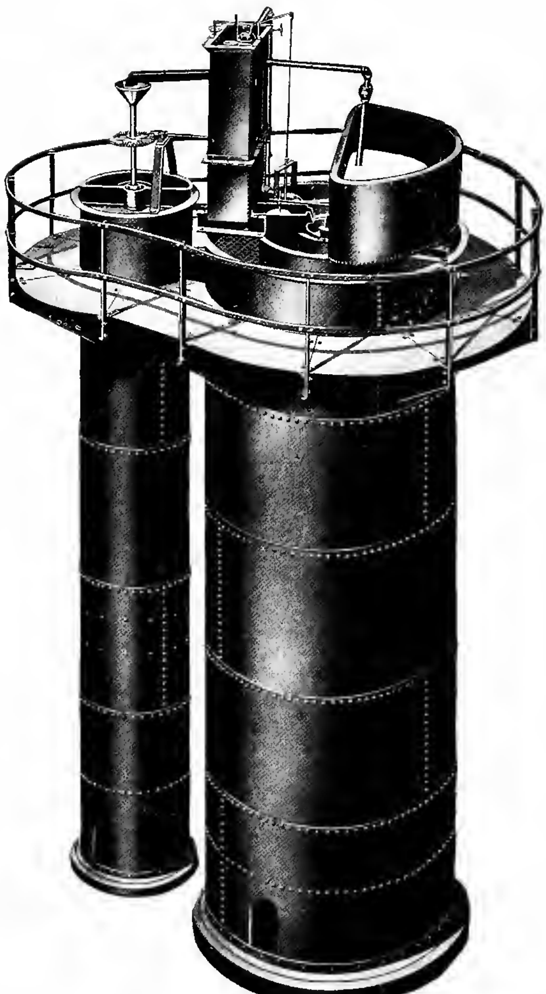


FIG. 2. — Exterior View of Water Softening Machine "Q."

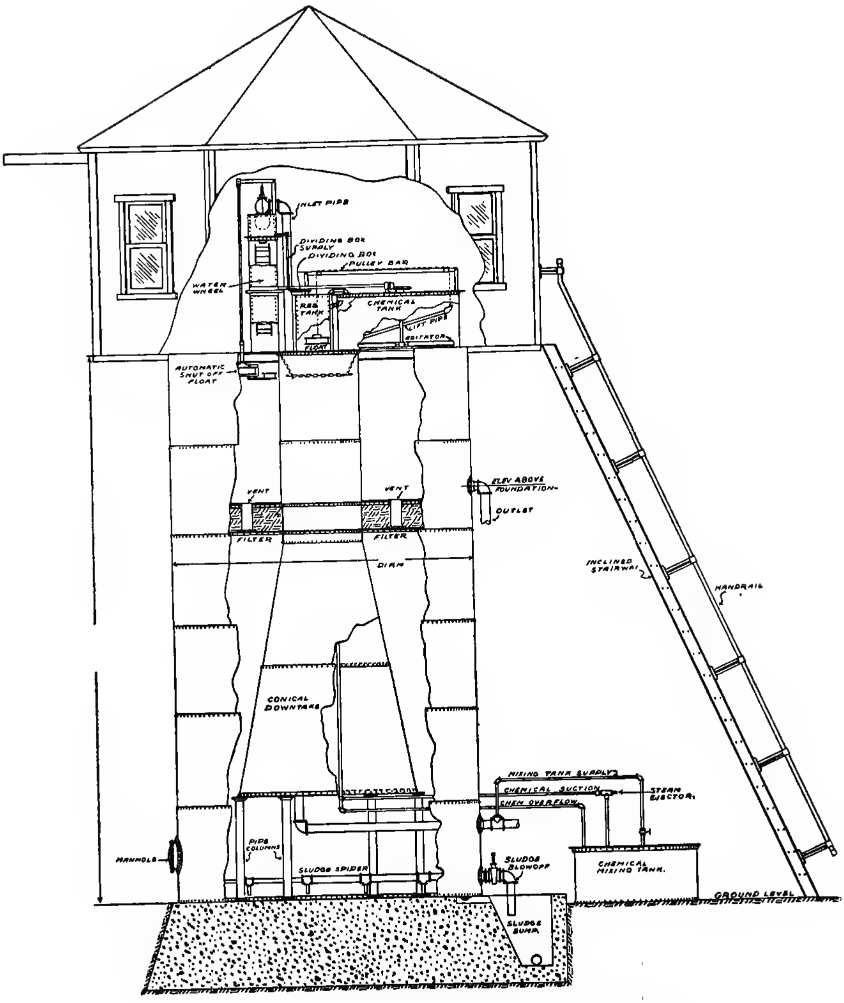


FIG. 3. — Ground Operated Type "N" Water Softener.

The bottom of this valve contains a butterfly or throttling device, controlled by a float maintaining a constant predetermined head of water in the tank, regardless of any variation in the pressure on the raw water line. The adjustment is made so that only a definite amount of water, corresponding to the maximum capacity of the machine, is admitted from this upper tank. A portion of the raw water is fed into the lime tank, the smaller one of the two large tanks. The operator can control the amount of water flowing to the lime tank and vary it to suit changes in the nature of the raw water, that is, the changes in its chemical make-up. The water leaves the downtake pipe through openings in the lower end and enters the tank proper, where it is mixed, by the stirring arms or paddles, with milk of lime or slaked quicklime, which descends through the large tube from the lime compartment at its top. The water ascending through the stirring arms or paddles absorbs all of the lime it can hold in solution, thus becoming saturated or of constant strength. The solution overflows by displacement, entering water at the bottom displacing water at the top, from which it runs into the main softening tank.

By avoiding the direct use of milk of lime, which varies in strength and contains all the impurities in the lime as well, and using saturated lime water, which has a definite strength, and a constant-strength soda solution, precision of treatment is secured.

The remaining portion of raw water falls over the water wheel into the main tank. This wheel supplies all the power necessary to drive the stirring device in the lime tank. The water, after leaving the water wheel, goes into a mixing pan in the top of the inner tube, where it comes in contact with the water from the lime tank. It also comes in contact with a stream of soda-ash solution, which solution is also subject to quick regulation, and is fed through a hard rubber float and flexible tube from auxiliary tank *C*. This float contains an adjustable center tube through which the solution flows. A small float in the tank, through which the raw water flows after passing over the water wheel, opens wide and closes the valve near the bottom of the soda tank whenever the machine is started or stopped, the rubber float in the soda tank, however, controlling the volume of the flow.

The chemical reaction is carried on as the mixture travels down the center tube, and the scale-forming solids are precipitated and settled down into the cone and on the series of spiral plates. After passing downward through this center tube the water reverses its direction, rising upward spirally among the plates. The plates are set at a sharp incline so that the soft sludge does not adhere to them but flows to the bottom of the cone through sludge catchers *P*. The sludge, therefore, is carried out of the precipitation zone of the up-flowing water.

After this the water passes through a filter of excelsior near the top of the large tank. This filter is said to require renewal every four to eight months, which depends, of course, upon the quality of the water. From above the filter bed the purified water enters a clear-water reservoir.

This machine is automatically cleaned by opening the valves at the bottom of the two main tanks for a few seconds once or twice daily. This also cleans the filter by reversing the flow.

In cases of special waters where it is found advisable to use heat, and where the chemical reaction is not complete or satisfactory without it, this engineer installs a heating drum, where the raw or incoming water is heated by exhaust steam or otherwise to the proper temperature required for treatment.

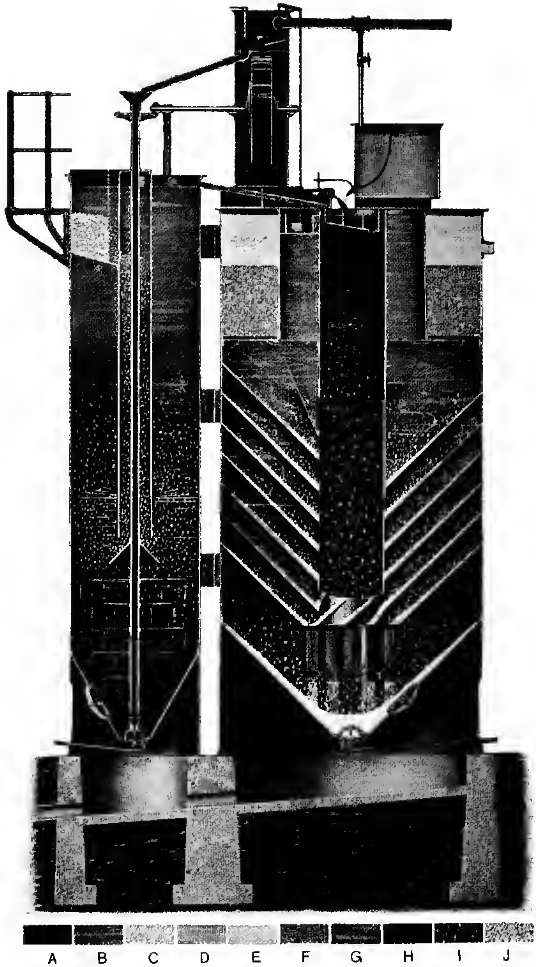


FIG. K. WATER SOFTENING MACHINE

MEANING OF LETTERS UNDER SECTIONAL COLORED PRINT.

"A" — Raw, hard water either clear or turbid, as it enters machine, by either pressure or gravity, for treatment.

"B" — Clear saturated lime solution, produced from the raw water that has been diverted to lime tank.

"C" — Quicklime in basket, which gradually gravitates down into tube and is mixed with raw water by stirring arms.

"D" — Tank in which soda-ash solution is made. A uniform flow is assured by feeding from top through float.

"E" — Treated and filtered water.

"F" — Wood fiber filter for entrapping floating particles. Is cleaned by reversed flow of water when flushing machine.

"G" — Water in which chemical treatment has been completed, but which has not yet passed through filter.

"H" — Intermixture of raw water and reagents, before it leaves the downtake tube and enters decanting chamber.

"I" — Note deposition of precipitates on spiral plates as chemical process continues after water leaves tube.

"J" — Sludge as deposited on spiral plates and gravitating to cone, from whence it is flushed to sewer.

Fig. 3 shows a water softener with storage capacity for softened water in the top of the sedimentation tank. The chemicals are prepared at the ground level and, after being mixed with water at the ground level, are raised to the top by means of a steam siphon.

The water enters through the inlet pipe, which rises on the inside of the softener to protect it from freezing, and is discharged from this pipe into the raw-water box above the water wheel. This raw-water box has two openings, one large opening from which the greater part of the water enters to, and over, the water wheel to furnish the little power that is necessary for agitating the chemicals in the chemical tank and then to discharge from the bottom of the water-wheel shield into the top of the downtake; and a smaller opening which is connected by a pipe to the regulating tank. As the regulating tank is filled very slowly by the water coming through the smaller opening from the raw-water box, the float in the regulating tank rises and the open end of the lift pipe, which is connected by a chain over pulleys with the float in the regulating tank, gradually lowers, allowing the chemicals to flow out into the top of the downtake, where they are mixed with the entering raw water. As the head of water in the raw-water box is always the same over the two openings, the flow into the regulating tank is always proportional to the flow of raw water through the large opening, so that the chemicals are always in exact proportion to the amount of raw water entering the softener. It will readily be seen that when the supply to the softener is cut off the supply to the regulating tank will also be stopped, and the chemicals cease to flow. If the supply to the softener is doubled, the depth of water in the raw-water box increases, increasing also the flow to the regulating tank. Within reasonable limits the softener should operate very effectively with any amount of water delivered to it up to its rated capacity. The parts regulating the feed of chemicals do not come in contact with the chemicals and therefore are not subject to stoppage and cannot be affected by the chemicals.

The downtake has the shape of a cone and directs the course of the water at a constantly decreasing rate of flow to the bottom of the sedimentation tank, thus helping the precipitate, which is acted upon by gravity, to settle away from the water. After reaching the bottom of the downtake, which is a few feet above the bottom of the sedimentation tank, the course of the water is reversed and it passes upward with decreasing velocity until it finally reaches the excelsior filter, where it is moving at its lowest rate of flow.

At the bottom of the sedimentation tank there is a specially designed spider for blowing off the sludge. This is so

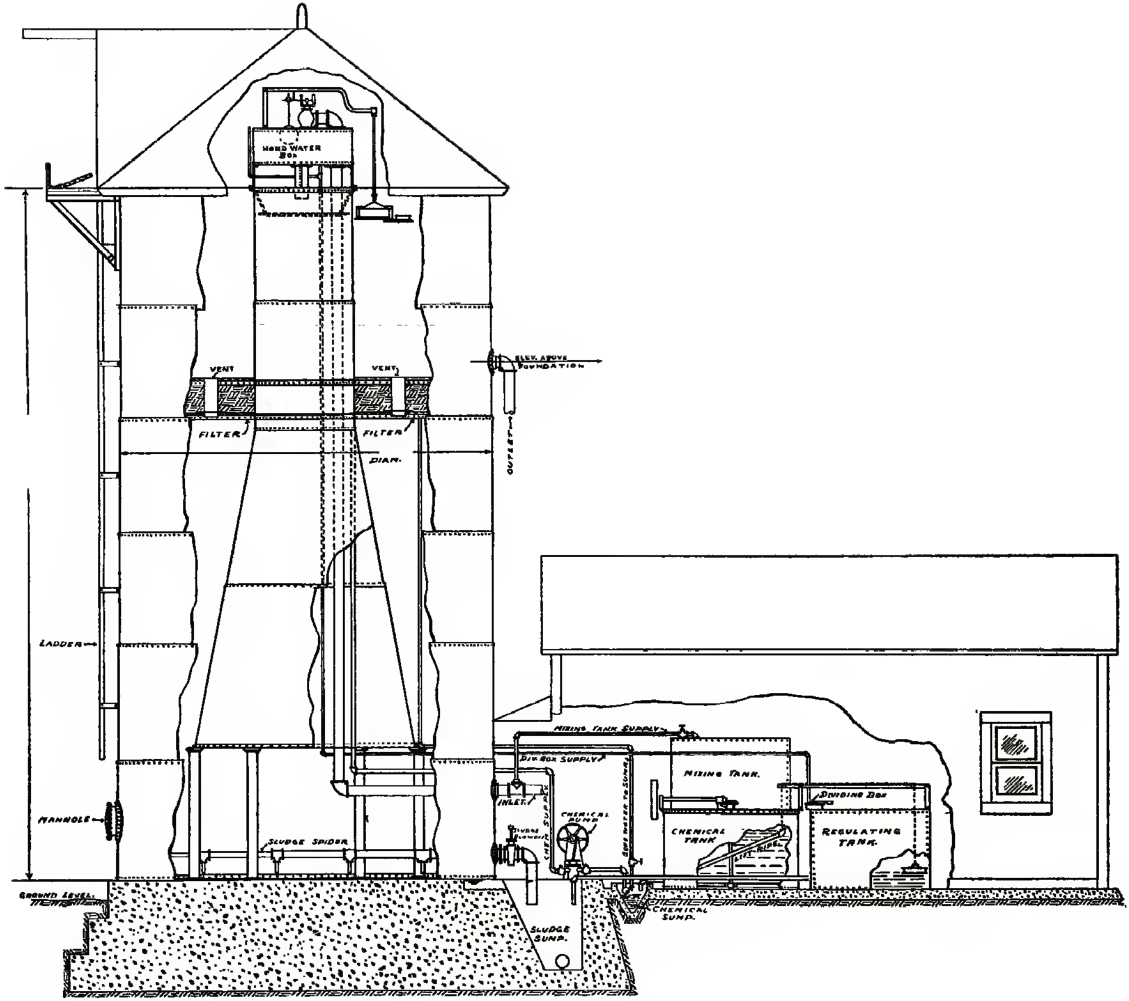


FIG. 4. — Operating Mechanism of Type "Q" Water Softener.

arranged that the pick-ups enter the mains at acute angles (an important point in the design of a spider blow-off). None of the currents impinge against each other. The resistance of the main discharge pipe is less than the sum of the resistances of all the individual pick-ups (and the same is true of every pipe), so that all of the pick-ups work at their maximum efficiency. The removal of the sludge is effected by opening a single valve for a short time each day.

When the consumption of the softened water taken from the outlet is less than the rated capacity of the water softener, the soft water accumulates in the storage space between the filter and the top of the sedimentation tank until it reaches the top of the float pot near the top of the sedimentation tank, when the float pot immediately fills and raises the float, closing the valve in the inlet pipe, so that the sedimentation tank will not overflow. As soon as enough softened water has been used to lower the surface below the small auxiliary float attached to the float pot, the lowering of the small float opens a valve in the bottom of the float pot allowing the water to run out, when the float quickly drops, opening wide the valve in the intake pipe, when the softener resumes its operation at its regular rate.

Fig. 4 shows a similar water softener with the exception that the chemical tanks and apportioning apparatus are placed at ground level and the chemicals fed into a sump made in the floor of the house covering the apportioning apparatus. From this sump the chemicals are pumped (after being greatly diluted with softened water) into the top of the downtake under the hard-water box. The diluting of the chemicals with the softened water is effected by operating the pump at a speed such that the chemical solution is taken from the sump much faster than it is fed through the lift pipe into the sump. This will cause a lowering of the surface of the solution in the sump, which allows the valve operated by a float to open allowing a stream of softened water to enter through a pipe which is brought down from a point above the filter in the top of the sedimentation tank.

Fig. 5 shows a water softener similar to Fig. 3, with these exceptions — there is no additional storage for the softened water in the top of the sedimentation tank. The tank has a conical bottom with a single opening closed by a plunger valve instead of a flat bottom with sludge spider. This company uses the conical bottom where the dimensions of the sedimentation tank do not exceed 10 feet.

It is said that this particular machine has accomplished the removal of spores of algæ from water which were so fine that they could pass through the interstices of a sand filter, where, as in this apparatus, they were finally arrested by coagulation and sedimentation.

The type "L" softener, Fig. 6, is operated from the ground level, and is of the continuous type. The main tank, as well as the mixing tanks, is usually built of steel, although the main tank is sometimes constructed of wood. The water flowing into the softener furnishes all the power required for operating the softener apparatus. The sediment collects on the bottom of the settling tank and is occasionally blown out through a valve in the bottom of the tank. The filter, through which the water passes when softened, is made of excelsior wood fiber. The chemical mixing tank is fitted with a number of agitators set at different heights in the liquid. A chemical regulator, controlled and operated by the entering raw water, regulates the amount of chemicals to suit the flow. The softened water rises at a low velocity to give as much time as possible for sedimentation, after which the water passes out near the top of the tank. A very ingenious arrangement of

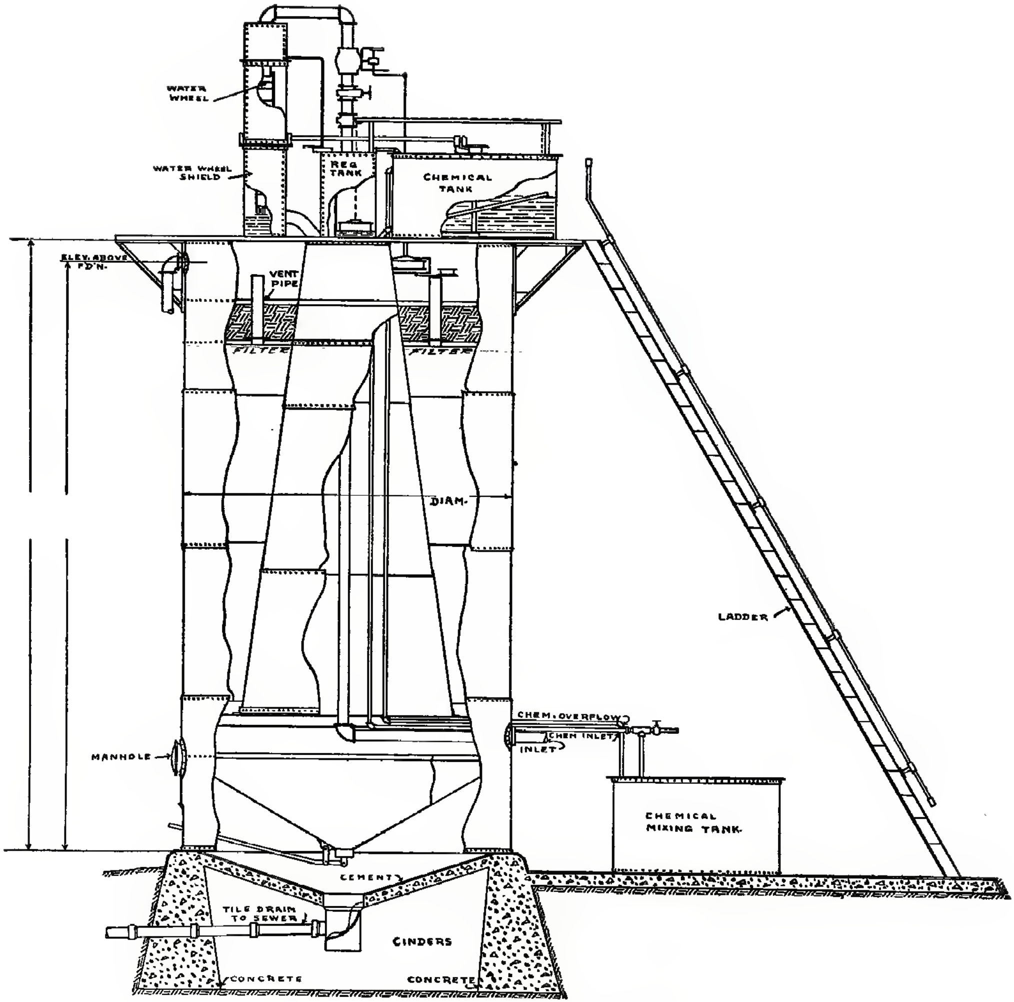


Fig. 5. — Cone Bottom Type "N Water" Softener.

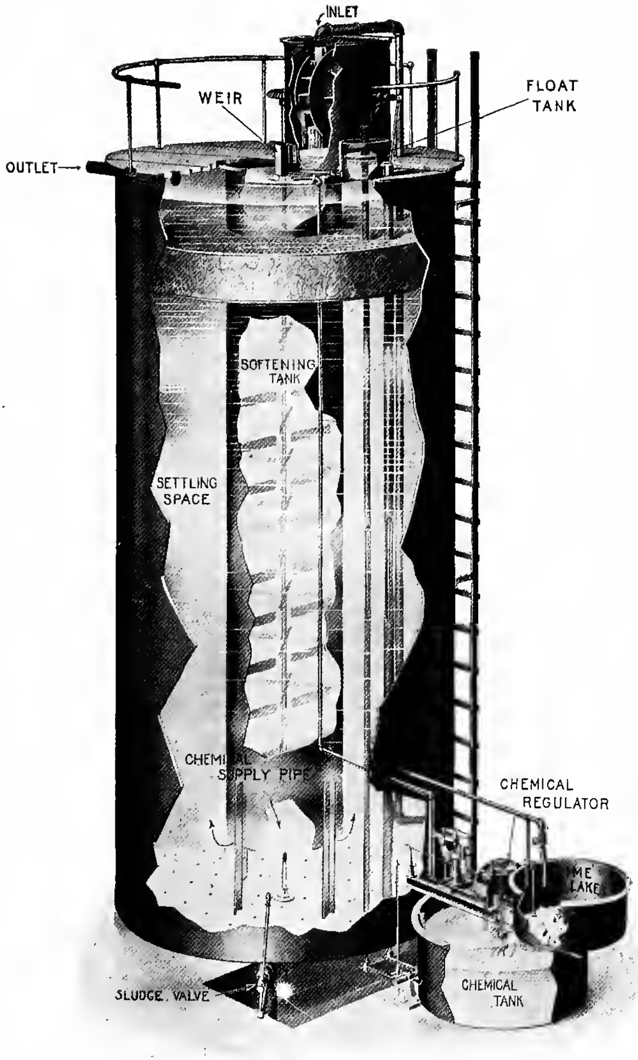


Fig. 6. — Section through Tanks, Type "L" Softener.

cranks and levers controls the various operations; and an overshot wheel is also employed in this device.

A softening plant equipped by this company has been

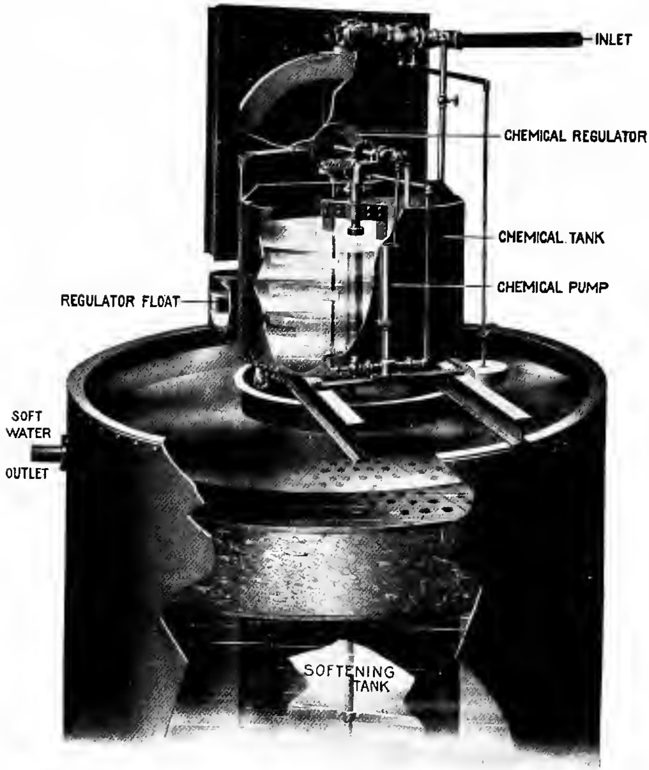
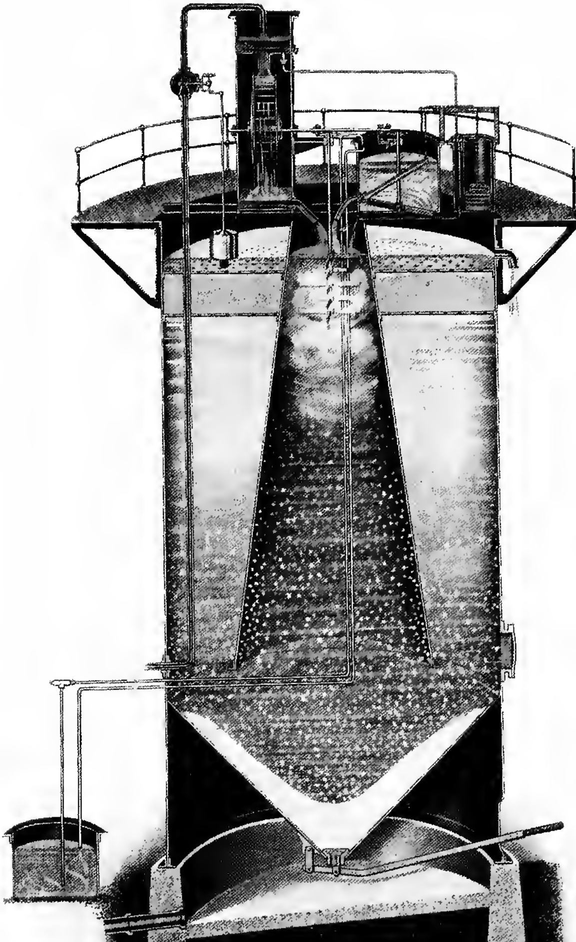


FIG. 7. — Upper Part, Water Softener Type "L."

successfully treating a water containing large quantities of free sulphuric acid and also sulphates of iron and aluminum, and handles 10,000,000 gallons of water daily.



All of the working parts of this softener requiring daily attention are conveniently located at ground level for ease in operation and inspection.

Type "G" is made by the same people as type "L" but is operated from the top of the tank, and is more simple in construction. Raw water enters through the balanced or float valve and, flowing over the overshot wheel, furnishes

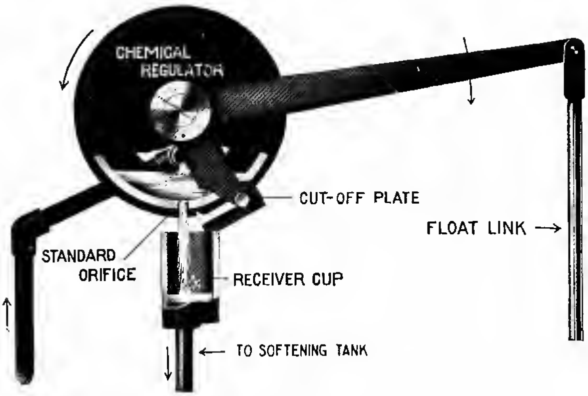


Fig. 8. — Chemical Regulator, Type "L" Softener.

the power to perform the various operations. The softening chemicals, hydrated lime and soda ash, after being dissolved, are fed to a rotary chemical regulator, which is keyed to the water-wheel shaft. No agitators are required within the regulator, as the chemical regulator by its rotation on the shaft mixes the liquid.

Another water softener which is built by Engineer "W" is of the continuous type. The raw water operates a small motor, without waste, and rises to the top of the machine, where it discharges into a triangular oscillating bucket with two compartments. This is so mounted as to oscillate freely, and as one compartment fills, the center of gravity changes, causing the bucket to tip, thus emptying that compartment and bringing the second compartment under the discharge to be filled.

Above this oscillating bucket is a tank containing the treating chemical, continuously supplied by the pump on the

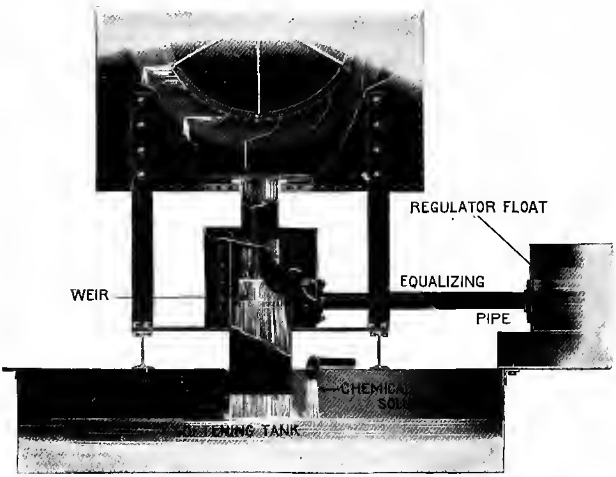


FIG. 9. — Weir for Type "L" Softener.

mixing apparatus at the ground floor. A proportionate amount of this chemical is added to the raw water at each tip of the bucket through a chemical valve in the bottom of the chemical tank, operated by a wheel located on the bucket, and a shoe and lever connected with the valve.

The water and chemical dump from the tipping bucket into a square tank, where they are further mixed by a paddle on the bottom of the tipping bucket. This paddle also serves the further purpose of lessening the shock of the tip. From this tank the mixture of crude water and chemicals are conveyed to a downcomer by a pipe set at an angle, which gives a whirling motion to the water in downcomer. This causes a further mixture and effects a coagulation of the precipitated matter and facilitates sedimentation. The

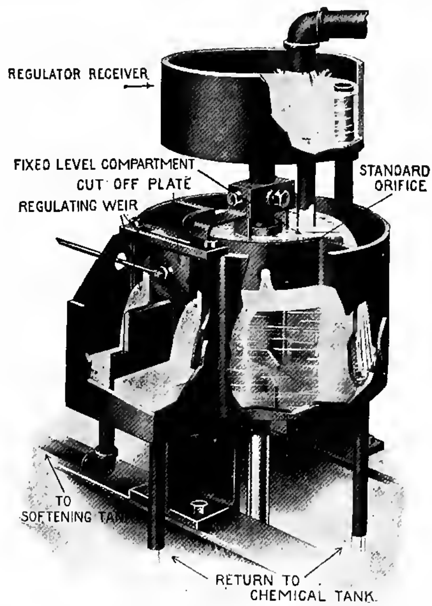


FIG. 10. — Chemical Regulator and Weir, Type "L" Softener.

most of the precipitated matter settles out before the water starts on its upward flow. This upward flow is much retarded, allowing further sedimentation before the filtering medium is reached.

The chemical solution is prepared in the tanks on the ground floor. Lime is slaked in the upper small tank and is dropped through a screen into the lower tank, where the soda ash is added. The water motor, above referred to, constantly stirs the mixture and elevates it by means of a small pump to the tank above the tipping bucket. This pump is large enough to furnish an excess of chemicals, thus

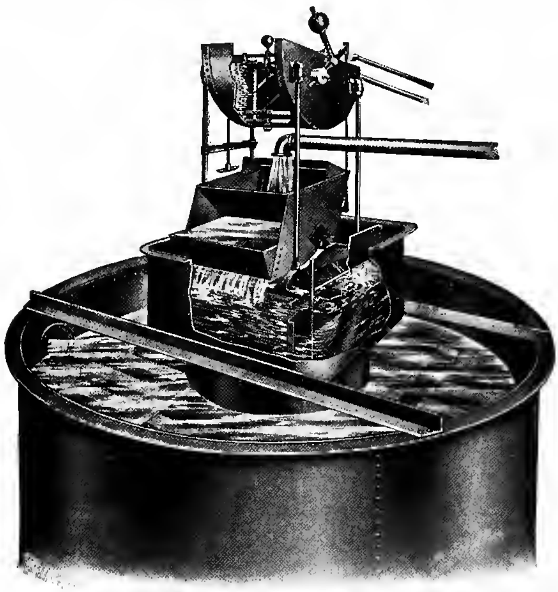


FIG. 11. — Mechanism on Top of Softener "W."

maintaining a fixed depth of chemicals over the chemical valve. The surplus returns to the mixing tank by means of an overflow pipe.

This engineer also manufactures a machine adapted for small quantities of water. In such plants the solution is run directly into the chemical tank. In order to provide against

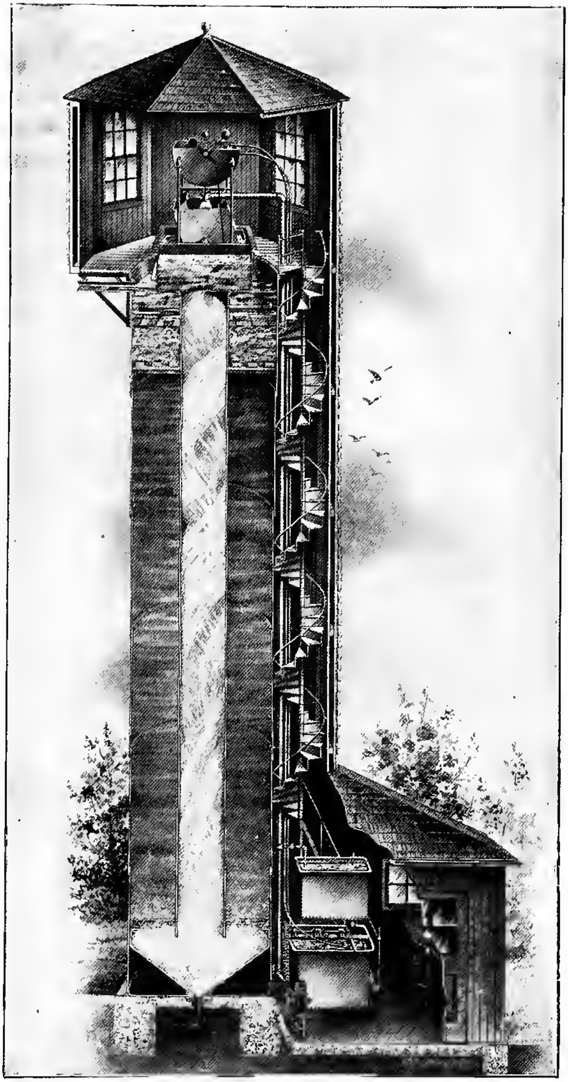


Fig. 12. — Type "W" Softener.

a "diminishing head," this chemical tank is divided into two parts, with the division wall slightly lower than the other walls of the container. The stirrers within this tank are made scoop shape, and, at each oscillation of the tipper, carry a quantity of the solution into the valve compartment in excess of that required, the excess flowing back over the lower partition wall into the storage end of container, thus a "constant head" is maintained over the valve at all times.

The operation of this type is similar to the one already described, except that instead of a large circular downtake, the settling tank has a baffle running down close to the bottom, thus using one end of the tank as a downcomer.

By having another compartment in this tank, a storage is provided, and by means of a float valve on the raw-water supply line, the apparatus may be automatically stopped and started as the level of softened water rises, or falls in this compartment.

Another type of water softening apparatus is that made by Engineer "K," shown by Fig. 13, and is a continuous type machine.

The water enters the softener through a supply pipe into the raw-water regulating box placed over the water wheel, which wheel furnishes the operating power. The water-softening solution is in the chemical regulating tank placed on top of the large tank.

After the water and chemical solution are properly proportioned, they are thoroughly mixed by the agitating paddles in the downtake pipe through which this mixture passes, and then from the bottom flow upward into the filter placed at the upper part of the tank, from thence it flows into the purified water chamber, and out by gravity.

Fig. 14 shows a general view of the top of water softener. At the bottom of the downtake pipe hoods and cones are

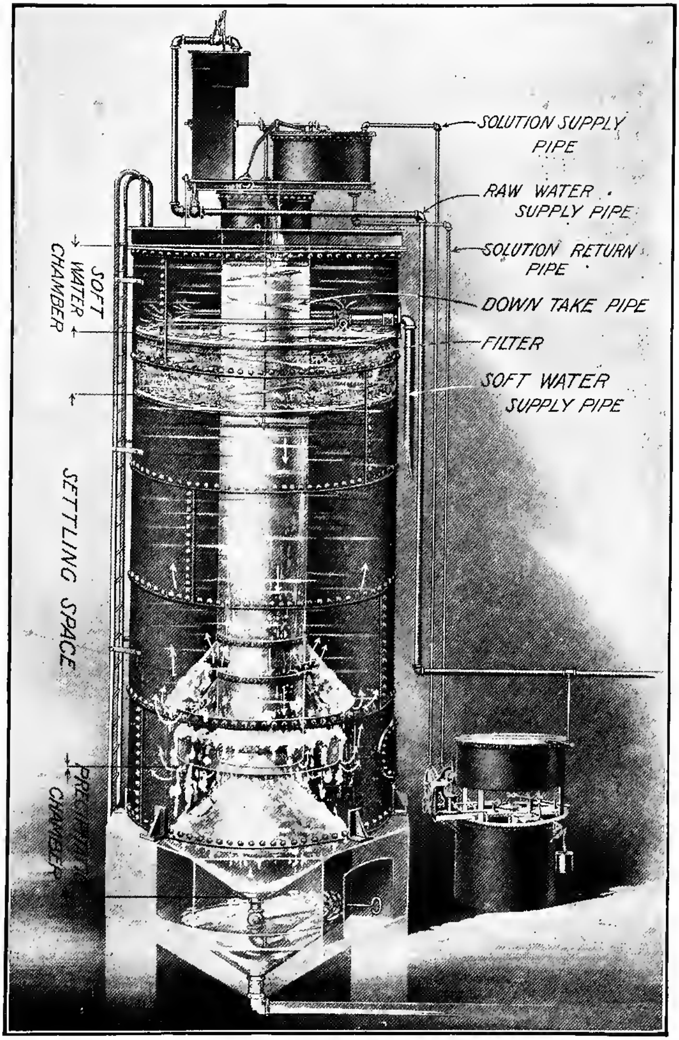


FIG. 13. — General View, Softener "K."

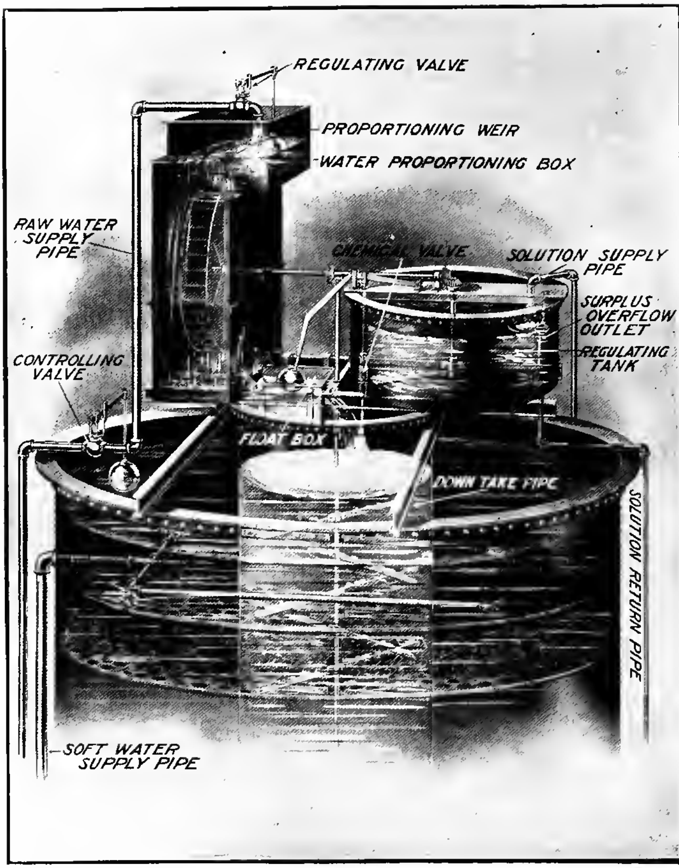


FIG. 14. — General View of the Top of Softener "K."

provided to help the sedimentation and decrease the tendency of the lighter particles to rise upward toward the filter.

The contracted area at the outlet at the bottom of the downtake pipe gives a higher velocity than the same amount of water would have distributed over a larger circumference. This decrease is accomplished by a baffle hood, which throws the water toward the circumference of the shell of the softener, distributing it over a much larger area, thereby decreasing the velocity and giving more time for the precipitate to settle, and consequently more complete sedimentation.

The precipitated matter settles on the top of the inverted cone shown in Fig. 13, and the tendency is for it to slide to the outer edge of the cone bottom of the main settling tank; upon the opening of the sludge discharge valve the suction is not from the area directly over the outlet, but from the entire bottom of the tank, sliding the maximum amount of sludge toward the discharge pipe, with a minimum waste of treated water.

This machine is provided with a ground-level mixing and chemical solution storage tank, shown by Fig. 15, which tank is provided with an automatic water regulator, which apparatus can be placed at a distance from the main tank.

The water from a pipe line is allowed to run into the chemical mixing tank until the proper amount is in the tank. Lime is weighed by scales and added to the water. The revolving blades are machine operated. After the thorough slaking and mixing of the lime the mixture runs through a strainer into the lower tank from which it is pumped to the automatic feeding device at the top of the large tank.

Engineer "Z" builds a water-softening and purifying system of the intermittent type in which measured quantities of water are always treated with definite weights of

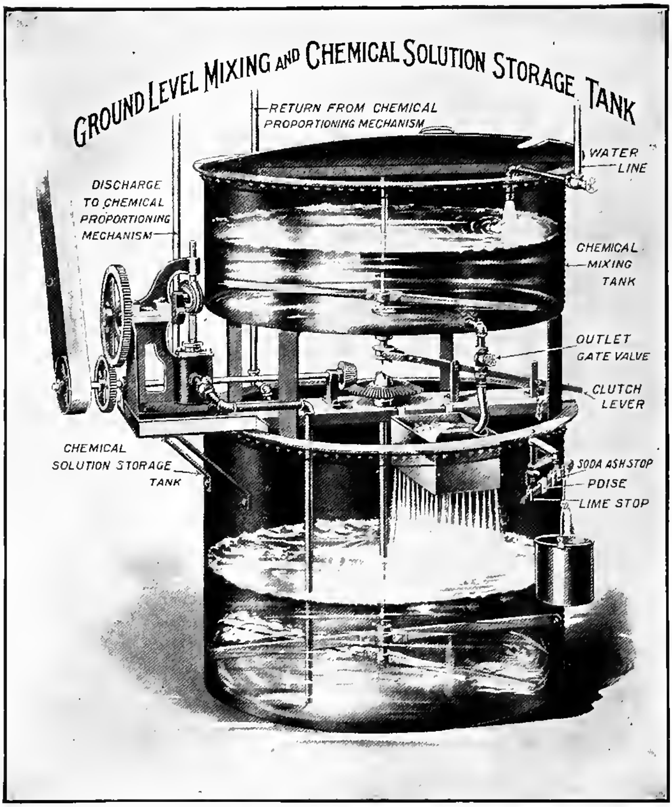


FIG. 15. — Ground-level Mixing Tank and Chemical Solution Storage Tank, Type "K" Softener.

reagents, thus insuring accurate treatment, for the introduction of reagents is entirely independent of the rate of flow of water into or out of the apparatus. Accuracy of treatment can be maintained and a uniform water obtained regardless of variations in the quality of raw water, or in

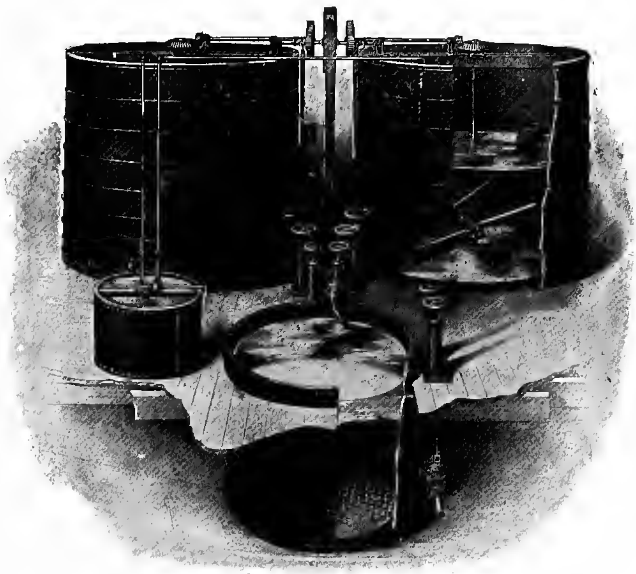


FIG. 16. — Intermittent Softener "Z."

the rate at which the water is used. The treating tanks of this system act as storage tanks, consequently there is always a supply of treated water available.

This system consists essentially of two or more treating and settling tanks, fitted with mechanical stirring devices operated by power; a small steel reagent mixing tank with stirring device; means for introducing the reagents into the treating tanks, and a quartz filter of either the gravity or pressure type. The power required to operate stirring devices varies from one-half to five horse power, depending upon

FIG. 17. — Automatic Continuous System "Z." (Patented.)

the size of the system. Power is only used during the time of mixing the reagents with the water. This system can be designed for any capacity.

Another type of water-softening and purifying system is built by Engineer "Z" and is known as the Siphon System. This is an automatic system not dependent upon moving mechanical devices for reagent introduction. The water enters the receiving tank to which is connected a siphon, into the long leg of which smaller siphons from the solution tanks connect. When the main siphon begins to flow, it starts the small siphons which introduce the reagents during the period of siphon discharge. The siphon starts to discharge only when the receiving tank fills; it is not dependent upon the rate at which the water enters the receiving tank. This system is built with an excelsior filter in which the water used for washing the filter is not mixed with the water in the settling tank. The excelsior filter is divided into a number of units, making it possible to wash it without shutting down the system. The washing of the excelsior filter is accomplished by means of a manifold with spray nozzles located in the filter proper.

In addition to the excelsior filter just described, where it is desired to obtain a water that is absolutely clear, this system is supplied with quartz filters of either gravity or pressure type and with mixing devices suitable to quantity and quality of water to be treated. Like other softeners it can be arranged to be operated either from the ground or from the top as may be desired.

Another type of automatic continuous water-softening and purifying system built by this engineer is the one which consists essentially of a treating tank having separate lime reaction, soda reaction and settling compartments, solution tanks and pumps, water motor, reagent mixing tank, and an excelsior filter of the type described above, also with the quartz filter of either the gravity or pressure type. The reagent solutions are introduced with pumps operated by a

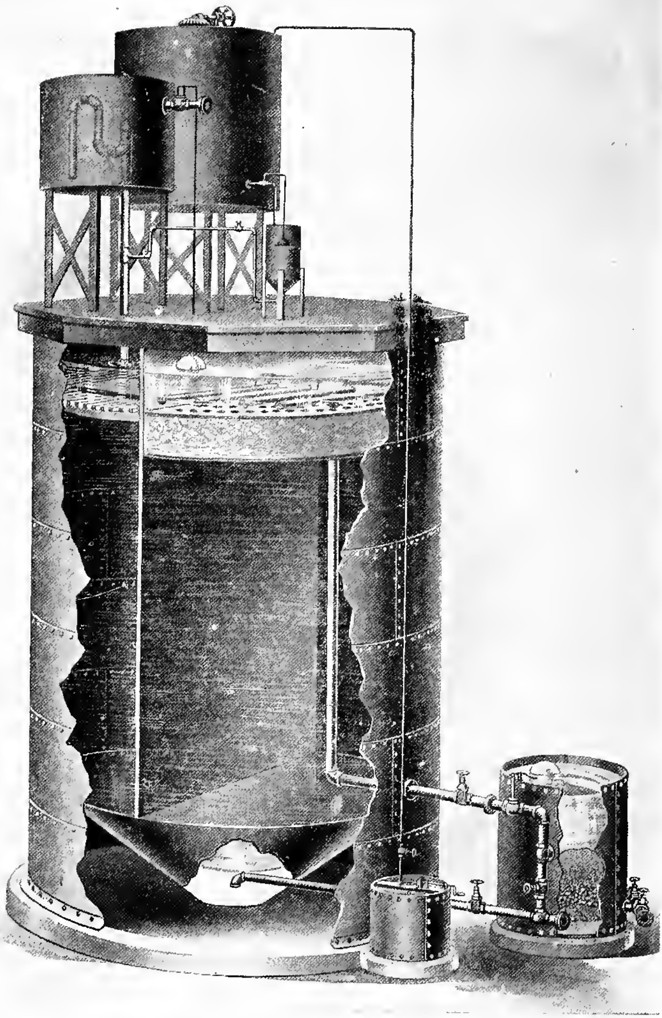


FIG. 18. — Siphon System "Z." (Patented.)

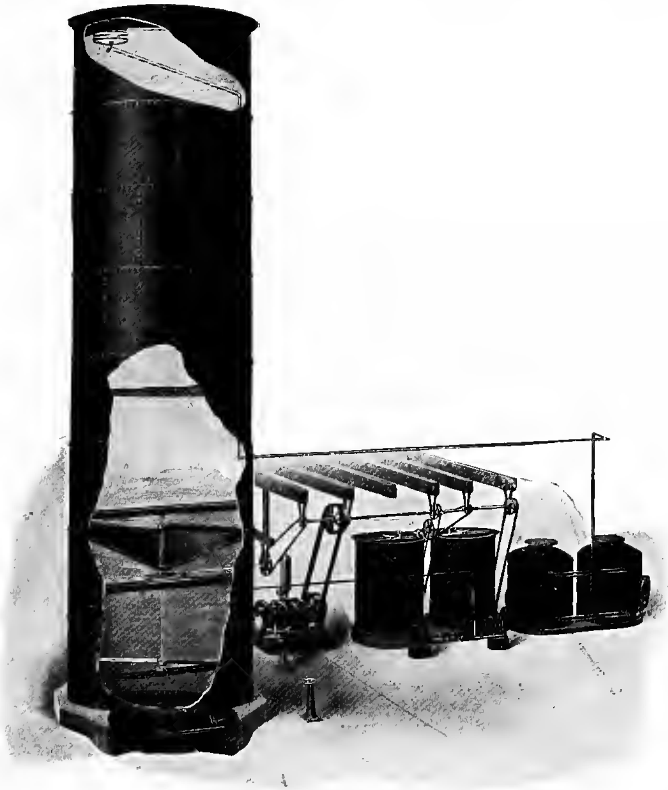


FIG. 19. — Continuous System Ground-Operated Softener "Z." (Patented.)

water motor with speed proportional to volume discharged. When desirable, a lime saturator is furnished instead of the lime-solution tank and pump, in which case the lime saturator is fed either by a weir or by some other proportional device.

The settling tank compartment can be made large enough to permit of the storage of the treated water, the water being taken from the settling compartment by means of a floating pipe, the float of which also controls the supply to the system. This system is entirely ground-operated, there being no part of the reagent-introducing device on the top of the system. The excelsior filter is arranged to be washed from the ground, all valves controlling the same being located on the ground.

In addition to the three types of systems just described, the same company manufactures other continuous systems.

Still another type, known as the automatic continuous system is manufactured by this engineer.

This system consists essentially of a reaction and settling tank, lime saturator, soda solution feeder, and a filter of either the excelsior or quartz type, depending upon the requirements and the water supply. The lime treatment is made by means of a proportional weir feeding device in connection with a lime-saturating tank, and the soda-ash treatment by means of a siphon similar to that described under the Siphon System. This system is automatic in its operation and requires no outside power.

The water softeners built by Engineer "R" are of different types to meet individual conditions but are all designed upon the method of chemical proportionment illustrated by diagrammatic cut, Fig. 20. The water to be treated flows into a hard-water chamber in which there are three openings situated upon the same level. In this tank the water is divided into three streams, the main portion flowing through the largest opening into a reaction tank, the second portion flowing through an opening into a control tank and a third portion flowing through an opening into the chemical tank.

The softening chemicals, hydrated lime and soda ash, are mixed with water in the chemical tank and are kept in uniform suspension by being agitated by inclined paddles. Near the top of the chemical tank is a large rectangular opening in the shell, through which the chemicals flow to the

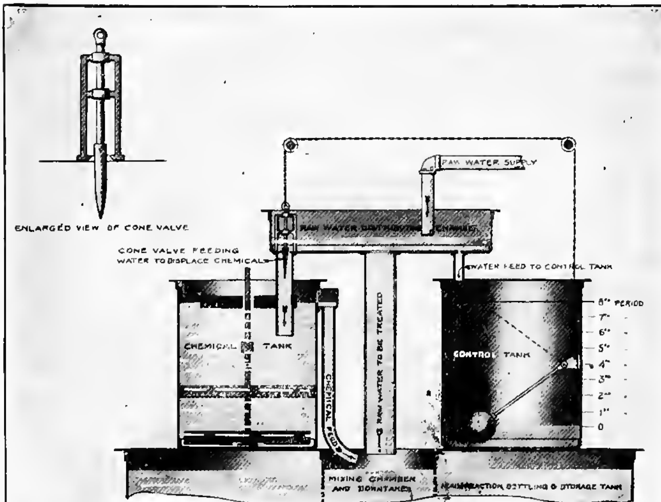


TABLE OF CHEMICAL PROPORTIONMENT

ASSUMING THAT 1000 GALLONS OF WATER REQUIRE 1# OF CHEMICAL									
NUMBER OF PERIOD	0	1ST	2ND	3RD	4TH	5TH	6TH	7TH	8TH
TOTAL GALLONS OF WATER TREATED	0	1000	2000	3000	4000	5000	6000	7000	8000
GALLONS OF WATER IN CONTROL TANK	0	10	20	30	40	50	60	70	80
POUNDS OF CHEMICAL DISPLACED DURING PERIOD	0	1	1	1	1	1	1	1	1
POUNDS OF CHEMICAL IN CHEMICAL TANK	10	10	9	8	7	6	5	4	3
GALLONS OF WATER ADDED TO DISPLACE CHEMICAL	0	10	11 1/9	12 1/2	14 2/7	16 2/3	20	25	33 1/3
GALLONS OF LIQUID CHEMICAL IN TANK	100	100	100	100	100	100	100	100	100

FIG. 20. — Chemical Proportioning Apparatus, Softener "R."

reaction tank. The height of chemical in the chemical tank remains level with the lowest edge of this orifice, the surface being kept level by means of stationary baffles. The chemical is proportioned entirely by being displaced from the chemical tank by means of added hard water. By this method no mechanical proportioning device comes in contact with the chemical solution. As the water enters the chemical tank it is immediately mixed with the chemical and displaces a volume of chemical equal to the amount of water added. The chemical thus displaced flows into the reaction chamber, where it meets the incoming stream of hard water. As the hard water flows into the chemical tank and displaces some of the chemical, the strength of the chemical solution is weakened. To compensate for this dilution the amount of water added to the tank is increased in direct proportion to the dilution by increasing the area of the opening by means of a tapered plug hung in the opening in the hard-water tank. The position of this plug is governed by means of a float in the control tank. This tank receives a certain amount of the water entering the apparatus, so that the amount of water in the control tank depends directly upon the amount of water which has been treated. As the float rises with the increase of water it gradually withdraws the plug from the opening.

The table accompanying Fig. 20 shows the relation maintained by the water in the control tank, the water treated and the chemical displaced. After a 12- or 24-hour continuous run the control tank is emptied and enough chemical added to the chemical tank to renew the strength. The emptying of the control tank replaces the tapered plug to the initial position required where the chemical is of full strength. The control tank is emptied by means of a siphon, so that after the tank is emptied to the proper level the outlet is automatically sealed. An indicator is furnished with each apparatus so that a new chemical charge may be made up at any time. This method of chemical proportionment

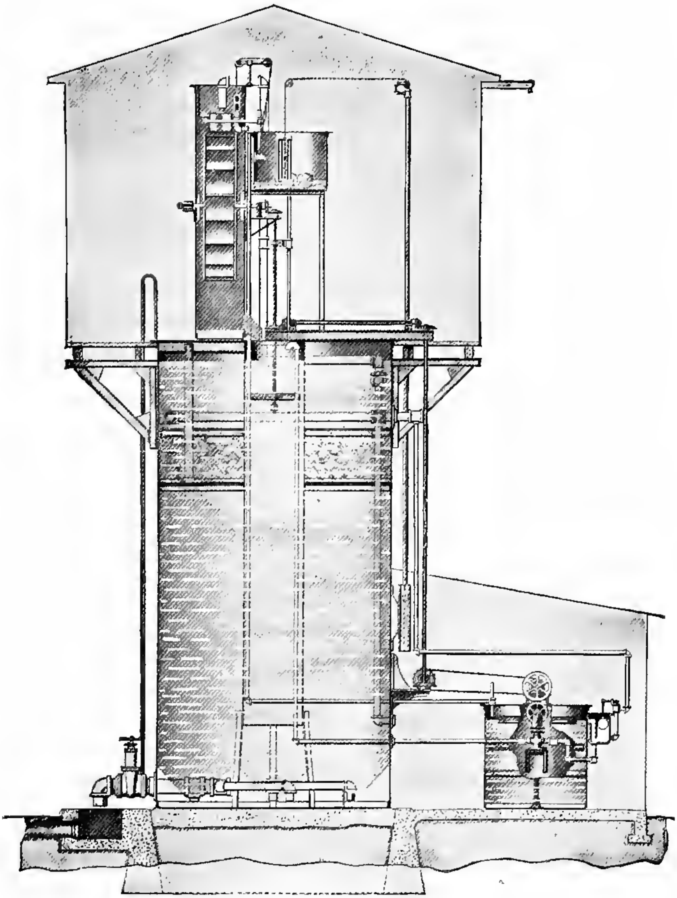


FIG. 21. — Softener "R."

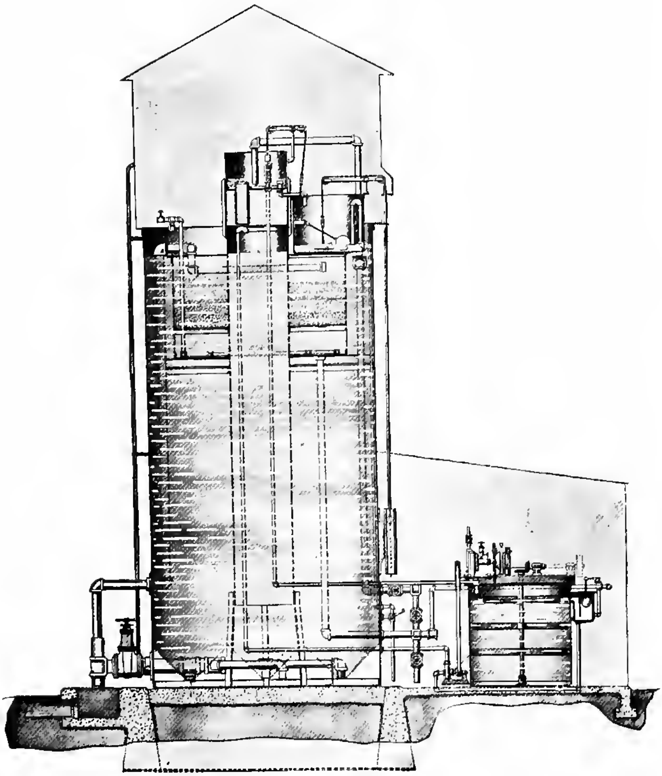


FIG. 22. — Softener "R."

prevents any clogging or filling up of mechanical proportioning apparatus due to lime settling and carbonating upon it.

This method of chemical proportionment is embodied in the three types of apparatus illustrated by Figs. 21, 22, 23.

The chemical and the water are thoroughly mixed as they flow into the reaction tank, which is of such capacity that the greatest part of the chemical reaction is obtained before the water reaches its lowest extremity.

The settling tank and filters are shown in Figs. 21, 22 and 23. The water and precipitated solids flow downward through a cylindrical reaction chamber from which they enter an annular settling space of much larger area than the tube. As this increase in area materially decreases the speed of the water, the inertia of the precipitated ingredients throws them into the quiet water at the bottom of the tank.

As the water rises in the settling chamber the precipitated hardening ingredients settle away from the uprising water. At the top of the settling tank the water flows either upward through an excelsior filter bed contained between two perforated steel plates or over a filter chamber and then downward through a bed of crushed quartz. In the excelsior type of apparatus the softened, filtered water is withdrawn from a soft-water chamber located above the filter. In the quartz filter the softened water is withdrawn from below the filter.

To clean the quartz filter, a steam ejector supplies a large volume of compressed air through a series of perforated pipes located below the quartz, which effectively opens the filter material. At the same time the flow of water through the filter is reversed upward, the water carrying away the sludge to an overflow pipe.

The sludge which settles to the bottom of the settling tank

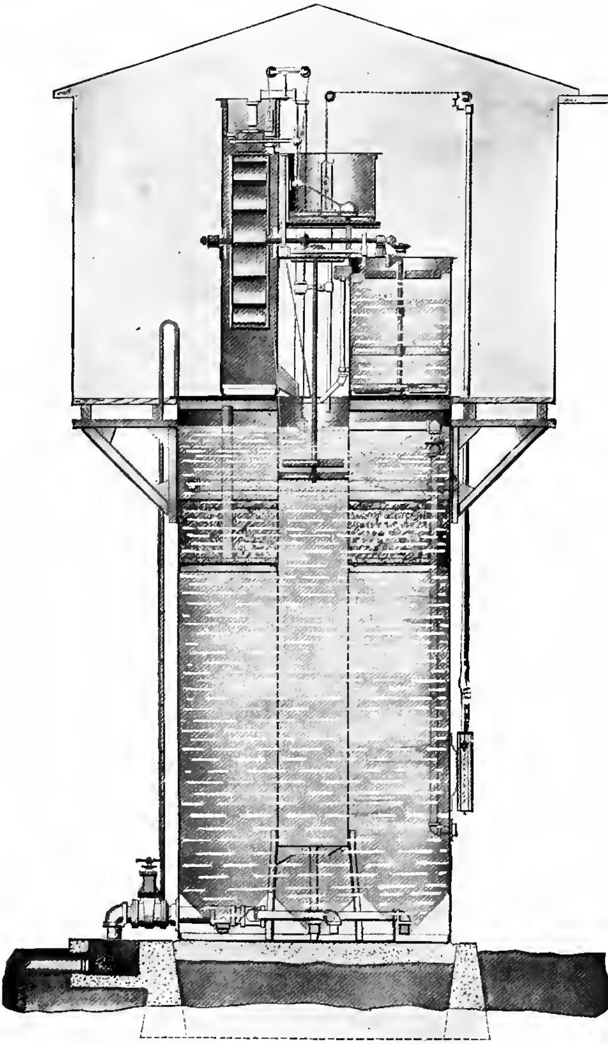


FIG. 23. — Softener "R," Top-operated Machine.

is removed through an external valve and internal piping as shown in cuts.

The quartz type of filter is illustrated in Fig. 22, the excelsior filter being shown in Figs. 21 and 23. In the type of apparatus illustrated in Fig. 21 the chemical tank is located above the settling tank, the power to agitate the chemical being derived from the hard water flowing over an overshot water wheel.

This engineer builds a similar type with the exception that the chemicals are mixed upon the ground level and elevated to the upper chemical tank once a day by means of steam ejector or pump. In the type of apparatus illustrated in Fig. 22, the chemical tank is located at the ground level and after the chemicals are proportioned they are diluted with softened water and pumped to the top of the reaction tank by means of a centrifugal pump. In this type of apparatus the power is derived from an outside source, either an electric motor, a line shaft or a small steam engine. The apparatus illustrated in Fig. 23 is similar to the foregoing type with the exception that the chemical is agitated and pumped to the reaction chamber by means of a water wheel located at the top of the settling tank. All of these types are built with either excelsior or quartz filter as individual conditions require.

Softening by use of Permutit. — A recent issue of the *Engineer*, published in London, England, gives this information regarding an effective means of softening hard water, which has recently come into use in Germany. This system is also in use in this country to a small extent, which is, to a certain degree, not surprising, on account of the very high cost, comparatively, of this material over the cost of the chemicals used in the usual softening process by which just as good or better results can be obtained.

The peculiar property of zeolites — which are generally composed of varying quantities of silica, alumina, lime, soda, potash and water — whereby they can exchange their bases for others, enables them to be utilized as softening agents, and when hard water filters slowly through layers of them the lime in the water changes place with the soda in the zeolites. In Germany there is now being produced an artificial zeolite of a uniform composition, the action of which on water is more certain. Permutit, as this substance is called, is prepared by fusing together feldspar, kaolin, clay and soda in fixed proportions, lixiviating the product in hot water and collecting the residue. In use as a softener a period must arrive when all the soda in it has been given up and when, of course, its action ceases. It can then be easily regenerated with common salt simply by washing it thoroughly with soft water and allowing a salt solution of 10 per cent strength to flow through it for 4 or 5 hours; the layer of brine is then kept standing on the surface for another 4 or 5 hours. In the regeneration process the soda of the sodium chloride replaces the lime in the permutit and becomes converted into calcium chloride, which passes away in solution in the regeneration water. Permutit, it is said, is capable of reducing hardness from 53 degrees to 3.7 degrees. It suffers no apparent loss in working and can be kept in use for very long periods with regeneration every four days or so. In appearance, when in a moist condition, it is of a granular, flaky form with a luster resembling mother-of-pearl. It is of very porous texture, and when dry can absorb 50 per cent of water.

Through the courtesy of one of the softener companies the following table, showing the quantities of lime and soda required for each 1000 gallons of water treated, is given:

LIME AND SODA REQUIRED TO SOFTEN 1000 GALLONS OF WATER.

	Pound for each 1000 U. S. gallons.	
	Lime (90 per cent calcium oxide).	Soda (58 per cent sodium oxide).
Calcium carbonate	0.098	.....
Calcium sulphate	.....	0.124
Calcium chloride	.....	0.151
Calcium nitrate	.....	0.104
Magnesium carbonate	0.234	.....
Magnesium sulphate	0.079	0.141
Magnesium chloride	0.103	0.177
Magnesium nitrate	0.067	0.115
Ferrous carbonate	0.169	.....
Ferrous sulphate	0.070	0.110
Ferric sulphate	0.074	0.126
Aluminum sulphate	0.087	0.147
Free sulphuric acid	0.100	0.171
Sodium carbonate	0.093	.....
Free carbon dioxide	0.223	.....
Hydrogen sulphide	0.288	.....

The lime used is supposed to contain 90 per cent calcium oxide and the soda 58 per cent sodium oxide. The quantities shown in the table are approximately 10 per cent in excess of the quantities calculated from the chemical equivalents.

In discussing a paper on the water and sewage works of Columbus, Ohio,* Mr. Samuel Rideal, consulting chemist of London, England, says in part: he understands that the raw water is treated with a considerable quantity of chemicals, comprising solutions of lime, soda ash, and coagulant (sul-

* Trans. Am. Soc. C. E., 1910.

phate of iron or sulphate of alumina), and then settled, as is done in ordinary processes of treatment for industrial purposes, and that finally, "when desired," a small quantity of raw water is added prior to filtration in order to eliminate traces of caustic alkalinity. That some expedient was necessary is shown by the fact that during the first 3 months the caustic alkalinity in the filtered water was often 20 parts per million or more, reaching, in one case, 37 parts. A well-known rule in the trade treatment of water is that the reagents shall be adjusted so that the product will not show any caustic reaction with phenolphthalein, and this appears to be still more important in the case of drinking water; in this case, it is questionable whether the raw water is allowable to obtain the object.

The hardness of the water in the Thames River, England, which varies from 20 to 23 parts per 100,000 after having been stored in Staines reservoir and then pumped, showed 20 per cent less hardness. When filtered from this reservoir and pumped back again several times during a pumping trial it contained only half as much carbonate as the ordinary filtered water.*

One of the largest cold process softeners in this country is at the Carnegie Steel Co.'s plant at Duquesne, Pa., with a capacity of 2500 gallons per minute.

Calcium carbonate and magnesium carbonate in water help to produce foam. Cold process systems for water containing magnesia should be handled very carefully to properly eliminate it. Wehrenfenig says that preheaters are very necessary for water containing bicarbonate of magnesia. A more complete softening is obtained than would be possible in the same time with the cold process system. F. C. Anderson says that hydrate of magnesia is appreciably more

* Eng. Rec., Vol. 55, p. 648.

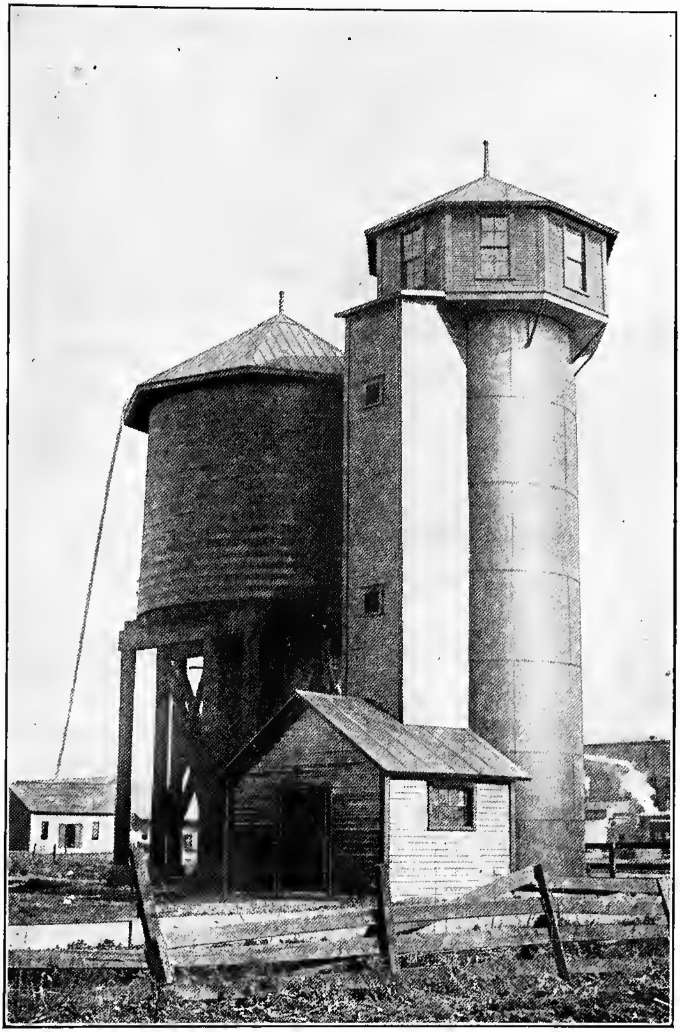


FIG. 24.—Railway Water Softening Plant.

soluble in water containing certain salts, sulphate of soda, for example, than pure water. He says also that it is advisable to treat the lime salts in preference to the magnesia. In the absence of lime salts the magnesia salts have but little scale-forming tendency, but a soft water of 5 degrees of hardness may easily have more scale-forming tendency than a soft water of 10 degrees of hardness.

CHAPTER III.

WATER SOFTENING—HOT PROCESS SYSTEMS.

PROLONGED boiling will alone free a water from magnesium, carbonate, or bicarbonate. Soda ash added to the water hastens the precipitation and renders it more complete. Heat and soda ash can be used with every chemical in water that forms scale. If water contains sodium bicarbonate it should be treated with heat and gypsum water. With some reagents and hot water fairly complete settling takes place in 10 minutes, while with cold water many hours are required, even 12 hours being too little with some waters. A less time than this will give fairly satisfactory results with some waters.

Iron and alum coagulate and take down precipitates that would possibly require 24 hours for settling in cold process systems, more quickly in hot water. Of course the action would be very much more rapid. Only the best fresh-burned lime and lime low in magnesia should be used for cold process treatments or for hot process treatments — 10 per cent of impurities is a high enough amount.

To power plant engineers the feed-water heater and the heater and purifier are an indispensable aid in the operation of the steam plant. The open type heater is the one made use of as a part of the hot process system of purification. While in the closed pressure heater, steam and water do not come in contact, this they do in the heaters of the open type, and if the water temperature does not get to 200° F., a little live steam may be added to bring it up to that point if it is desired. Exhaust steam from steam engines or pumps is used in these heaters and arrangements are made for purification of the water from the entrained oil, removing the sediment, and as far as possible automatic regulation is given to the process.

The closed heater does not remove much of the disturbing elements in the water which form hard scale, as the temperature reached in it is not as high as in the open type heater, but they are seldom, if ever, cleaned or given the care as should be the case with every apparatus in the power plant.

A case of serious damage to two horizontal tubular boilers, in which both suffered from burning out or bulging out of the bottom sheets, was largely due to the fact that the closed type feed-water heater was almost solid with sediment accumulating during months and months, it was part of this the sediment which went over with the water and lodged on sheets which caused the trouble.

Hot Process Systems. — In one of the hot process systems heat from the steam takes the place of the chemical used in cold systems to precipitate the elements of temporary hardness, while the permanent hardness elements are acted on by chemicals much the same as in cold softening processes. They are also similar to the chemicals forming what are known as boiler compounds.

It is a well-known fact to all chemists, at least, that all reactions take place much more rapidly in warm water than in cold water. The open heater provides a place for all drips and returns from steam mains, coils, and after treatment the water is also hot and ready to pass to the boilers direct. To do this requires a pump fitted to handle very hot water, and is a detail which is not always given thorough consideration in the power plant.

Results obtained by the hot process system, in which the reactions of heat and soda are combined, are exhibited in the following table.

SUMMARY OF PURIFYING RESULTS OBTAINED IN ONE OF THE HOT PROCESS SYSTEMS.

Substance in feed water.	Trouble in boiler.	Remedied by
Calcium bicarbonate, $Ca(HCO_3)_2$	Soft scale	Heat
Calcium sulphate, $CaSO_4$	Hard scale	Heat and soda ash
Calcium chloride, $CaCl_2$	Indirectly may cause corrosion	Soda ash
Calcium nitrate, $Ca(NO_3)_2$	Corrosion	Soda ash
Magnesium bicarbonate, $Mg(HCO_3)_2$	Soft scale and foaming	Heat
Magnesium chloride, $MgCl_2$	Corrosion	Soda ash
Magnesium sulphate, $MgSO_4$	Indirectly may cause scale	Heat and soda ash
Iron bicarbonate, $Fe(HCO_3)_2$	Sludge	Contact with air and heat
Silica, SiO_2	Sludge	Filter
Clay, $H_2Al_2Si_2O_8$	Sludge	Filter
Mineral acids	Corrosion	Soda ash
Carbonic acid	Corrosion	Heat
Hydrogen sulphide	Corrosion	Heat
Air	Corrosion	Heat
Organic and oily acids	Corrosion	Soda ash

Hot Purification Process. — One of the makers of a hot process system says: "We rarely have analyses made after treatment, and none have been made for several years, as we are not obliged to analyze the water continuously in order to determine the efficiency of the chemical treatment."

The above refers to a complete chemical analysis of the water. The writer is firmly of the opinion that it is not only wise, but necessary, to analyze all water both before entering and after leaving a purification apparatus often enough to be sure that the effluent is properly purified.

"For final results we rely upon indications given by the boiler, that is, if scale appears in the boilers, we recommend the feeding of more reagent, while if the boilers are clean we have ample proof of the adequateness of the treatment from an engineering and a commercial point of view. In

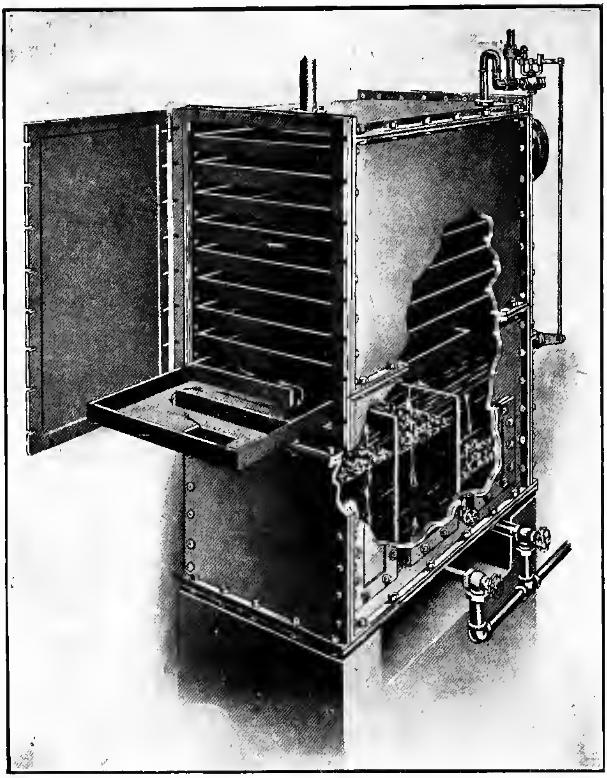


FIG. 25. — Type "D" Heater and Purifier.

View showing heater with single series of trays with door open and one tray partially drawn out, showing the construction of the tray, also the general interior construction of filter and oil-separating device.

any case, analyses made from small samples of water are apt to be misleading, while, on the other hand, the boiler, in effect, analyzes the entire volume of water and gives the net result.

"Where water is heated in a finely divided state, as when sprayed through a steam bath, both carbon dioxide and air are quite completely driven out at a temperature of two hundred (200) degrees F. This is corroborated not only by our own experience, but also by the experiments made by the different investigators as recorded in the various physical and chemical tables that have been published."

In the Type "D" heater and purifier, the water travels a considerable distance over the trays before passing from the upper tray to the one next below it and repeating the operation by means of a large door. These trays can be readily removed.

The tray system is made in three different types; single, double and quadruple series. The double and quadruple series of trays operate entirely independent of each other. The feed water is equally distributed to each series of trays, as shown by the pipe connections at the top of the heater. These trays can either be made of steel or cast iron. After leaving the trays the water passes to the filter chamber at the bottom of the heater. The filter plates are removable and the filtering material can also be taken out through the side openings.

The oil separator is connected to the heater by flange connection and is connected to a water seal taking care of the overflow of the heater and separator and allowing no steam to escape.

In this heater the water is kept practically in a quiet state while being heated, giving, the makers say, better results as to purification than the spray type of heater. The water in the trays, being compelled to follow one fixed course, comes in contact with the steam for a considerable length of time. In this filter the water flows by its own gravity through three separate filter beds, giving both a downward and an upward flow, first filtering downward then upward through the second compartment and over the top of the second partition to the pump.

Type "F" heater and purifier is built, as nearly all of these machines are built, similar to the other machines in principle, the difference being in special details. In these

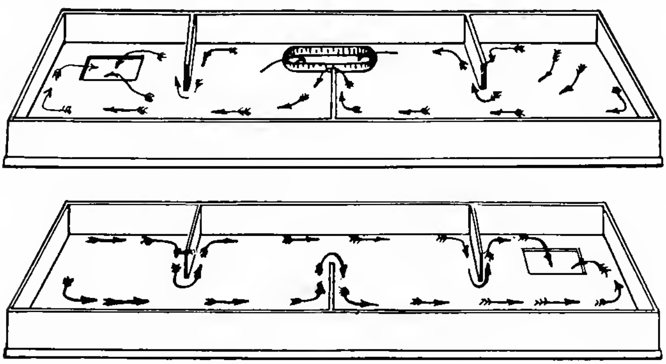


FIG. 26. — Two of the Trays.

machines the oil separator is built into and made part of the inner shell and forms the inlet through which all of the exhaust steam enters. The exhaust, coming at a high velocity, strikes the surface plate bolts at right angles to its line of motion. This surface consists of a sheet metal plate, properly bent and punctured and placed between two cast-iron gratings. Steam rebounds and passes to either side, where the oil, on account of its momentum, is carried through the punctured plate against the back plate of the grating, where it passes to the receiving well and to the

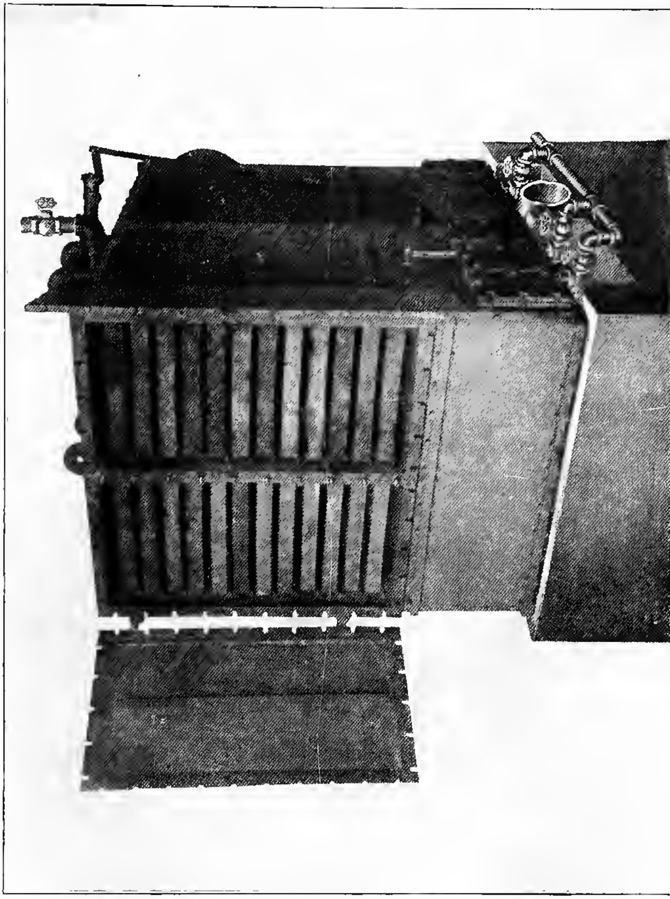


FIG. 27. — Cut showing Quadruple Series of Trays used in construction of the large sizes.

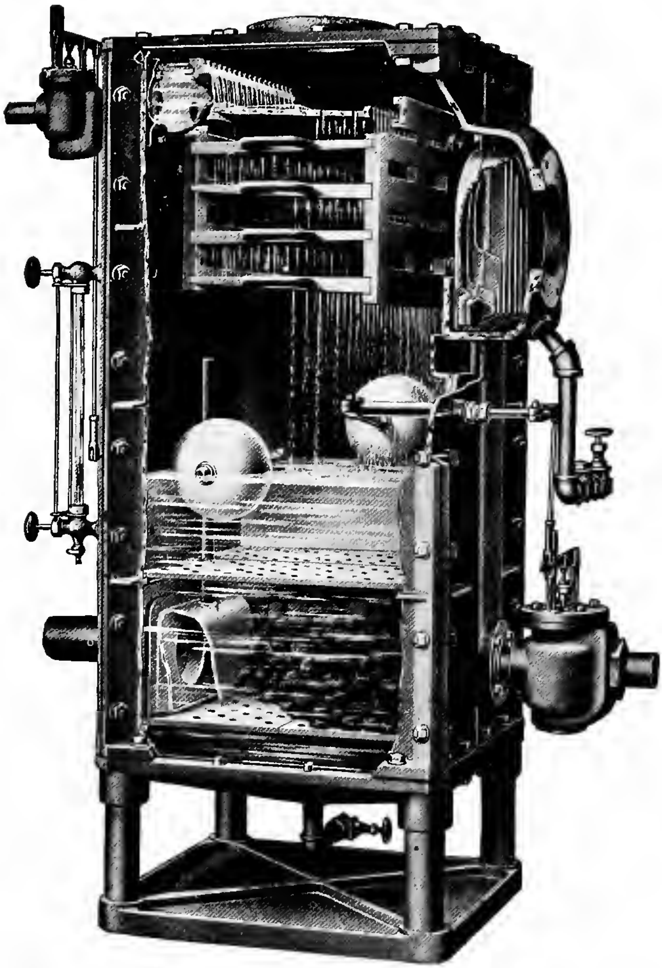


FIG. 28. — Open-Feed Water Heater. (Sectional View. Type 100 to 400 H. P.)

waste and drain pipe. The cold water enters at the top in a distributing trough which extends the full width of the heater, allowing the water to drip on plates which are punctured and the water passes down through from one plate to the other while the steam is all about the same, the plates being placed at a slight incline and so designed that the water passing over the first half of each tray is caused to flow in a thin film and is allowed to trickle down to the next tray through a number of small holes in the second half of the tray; that is, each tray is divided by a slight shoulder extending across its width. The filter is in the lower part of the hot well, and the material — coke, excelsior or similar substance — is placed between perforated cast-iron plates. Around the filter bed is a settling chamber provided with a drain and blow-off connection.

In cases where purification in addition to ordinary feed-water heating is desired a larger machine, provided with storage and settling capacity is made. Any dangerous excess of water in the heater passes out automatically, being controlled by a special float inside the heater which ordinarily holds the valve closed so that no steam can escape. The edge of the overflow opening extends the full width of the heater, and the impurities of the water can be skimmed off by holding the cold water inlet valve open until the heater fills to the overflow point.

Type "B" softener is designed for hot water to be softened under pressure and also for economy of space and quickness of results, for it is said that "the reactions in hot water under pressure are practically instantaneous." This, however, is not true, as it requires some time for the precipitates to settle. After entering a closed steam heater and becoming heated, the water being pumped in from mixing tanks passes through the precipitating tanks where the reagents are introduced, to the filter tanks for the removal of the suspended matter and sludge that may pass over. Quartz is used

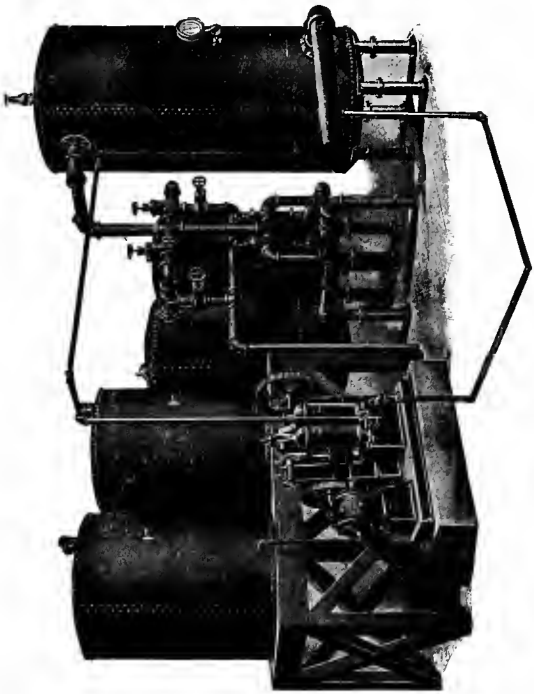


FIG. 29. — Type "B" Hot Process Softener. (Patented.)

as a filtering material. The upper body of water in the precipitating tanks is being continually mixed while the bottom part is quiet, thereby helping along the settling process. After

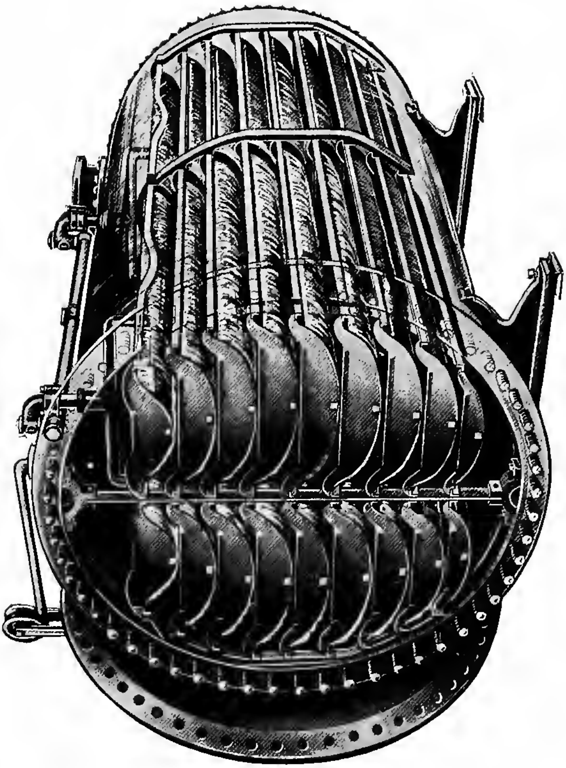


Fig. 30. — Type "H" Live Steam Feed-water Purifier showing Formation of Lime on Under Sides of Pans.

settling, the precipitate is blown out of the bottom of the tanks to the sewer.

There is a wide difference between an open heater, as such, and a hot water purifying system, even if the system has some similarity to the open heater. Slow chemical reactions in cold water systems require much more liberal designs of details than do the instantaneous chemical reactions in the hot water systems. The kind of water treated and the use to which the effluent is to be put vary all details necessary to the softening process and should be given very careful thought and consideration in designing new power plants.

The exhaust steam feed water heaters and purifiers made by this company are of the open type of the cylindrical horizontal form. These are built in four principal classes, "Standard," "Class 'R'," "Class 'H'," and "Class 'T',"' besides several combinations to suit conditions under which they are to operate.

The "Standard" type shown in Fig. 30 has steel shell and steel trough-shaped pans with malleable heads, the pans having a projection on each corner to slide on angle-iron ways in the shell. This type is especially adapted for handling water having a large percentage of carbonates in solution.

Class "R," shown in Fig. 31, has the bottom made of cast iron and the upper part of the shell of steel plate. The pans are also of cast iron and are a multi-trough design.

Class "H" is the same as class "R" with the exception that the entire lower half of the shell is cast iron. Class "T" is also the same with the exception that the entire shell is of cast iron. In all of these lettered classes all parts of the heater with which the water comes in contact are made of cast iron to prevent corrosion.

All of these heaters are equipped with trough-shaped pans, as in using this form the exhaust steam is brought in direct contact with the water while flowing in a thin film along the under sides of the pans. This not only gives the water

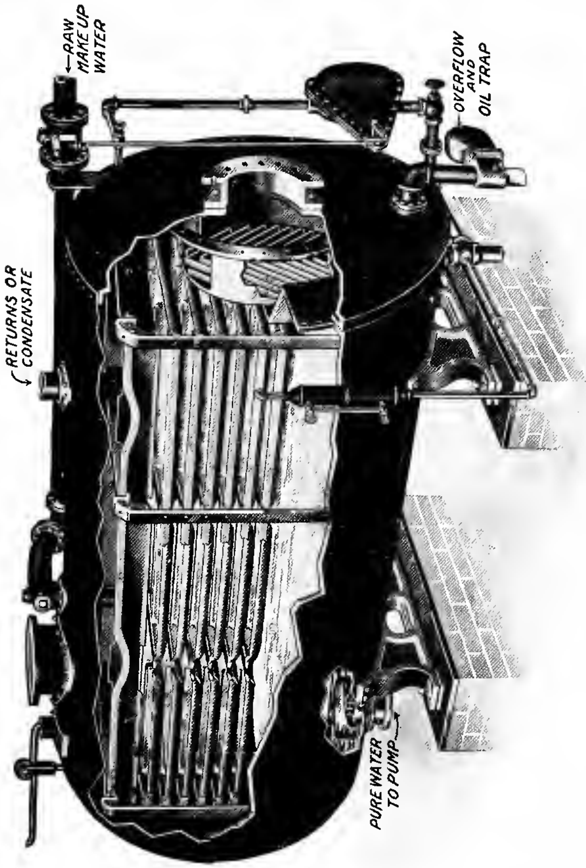


Fig. 31. — Type "H" Feed-water Heater, with Large Storage Capacity.

the highest possible temperature while the pans are clean, but no matter how much scale is formed on the pans the steam still comes into direct contact with the water, so that the maximum efficiency is always maintained.

All heaters are provided with ample oil catchers for purifying the exhaust steam before it mingles with the feed water. Large removable heads permit the pans being easily and quickly removed for cleaning. Any of these heaters may be provided with a chemical feeding apparatus if desired.

This company also manufactures Live Steam Feed-Water Purifiers, as shown in Fig. 32, which work under full boiler pressure, and where the pressure is high enough no chemicals are required, — usually a boiler pressure of 125 pounds is sufficient, depending on the amount of the sulphate of lime present in solution. These machines are cylindrical and horizontal in form. The pans used are of special sheet steel with malleable heads and slide in the shell on angle-iron ways. The pans in this machine are also trough shaped as shown in Fig. 32, and the water flows over the edges and along the under sides. This causes the lime and other solids to form on the under sides of the pans in the same manner as the stalactites form on the roof of natural caves and seems from the efficiency obtained to be Nature's way for removing solids from water. When the purifier is ready to clean the formations are usually about $1\frac{1}{2}$ inch thick on the second pan running down to $\frac{1}{16}$ inch on the bottom pan.

A head, removable by a crane, gives access to the full size of the shell, making the process of cleaning comparatively easy. The purifier is located above the boilers, at least two feet above the water line, and feeds the water pumped to it by gravity to the boilers. Full steam pressure is maintained by a steam connection to the boilers, and circulation to remove the noncondensable gases is maintained by taking the steam pipe for supplying the boiler feed pump from the rear end of the purifier. The only water in the purifier during operation is the water in the pans and a small amount in the bottom of the shell.

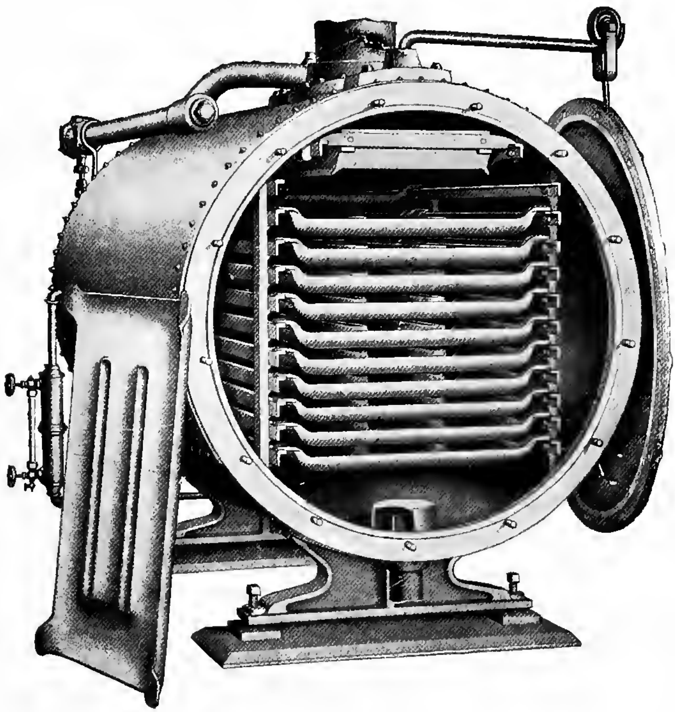


FIG. 32. — Front End View of Heater showing Multi-trough-shaped Pan.

Another make of open heaters and purifiers is known as type "J" machines. The chemical required to purify the water is dissolved in a tank, on the floor or in any other convenient location. The solution is then raised by means of a steam jet to a chemical feed tank which is set above the

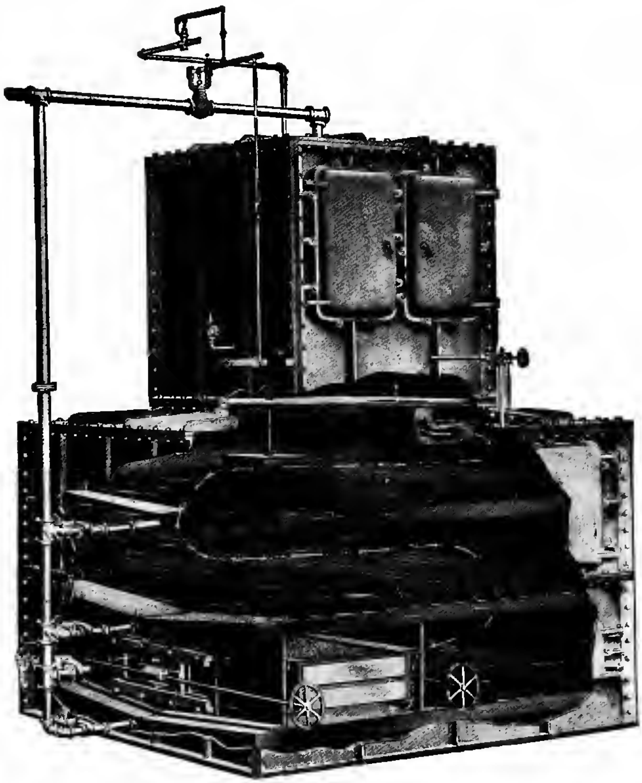


Fig. 33. — Feed-water Heater and Chemical Purifier, Type "J."

heater at such an elevation that the solution will gravitate to the heater.

From the feed tank the chemical flows to an automatic feed valve which is so arranged by means of levers that it will open and shut in direct proportion to the movements of the water inlet regulating valve, and thus permit chemical

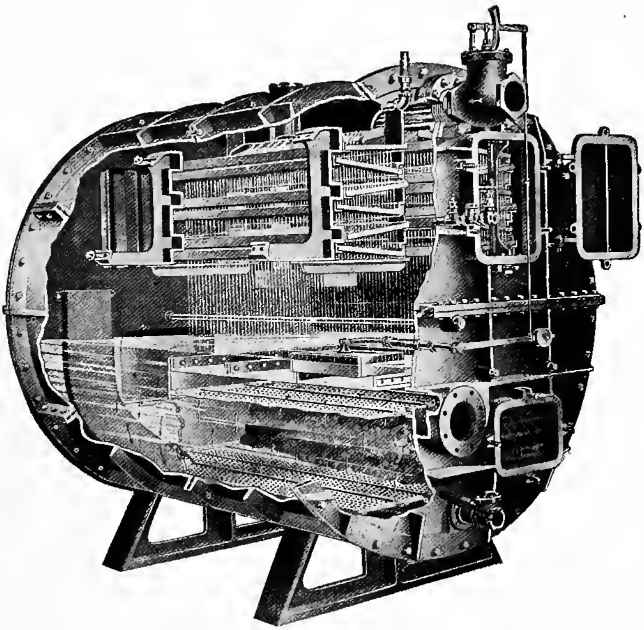


Fig. 34. — Feed-water Heater and Purifier of Large Capacity, Type "J."

to enter upon the copper trays of the heater in exact proportion to the quantity of raw water to be treated within the heater.

The depositing device consists of several rows of cast-iron sedimentation plates with angular wings opposed to the flow of water. The very slow progress of the heated water across the plates allows of maximum sedimentation. The plates are easily cleaned.

As a final treatment, the water passes through quartz filters inclosed in copper cartridges. In this apparatus a universal filter allowing the use of both compartments, or of either when the other is removed for cleaning, is included.

A testing apparatus is furnished with which a quick test may be made by the operator, to determine the proper adjustment of the chemical feed valve to admit the amount of chemical solution necessary for the desired results.

The manufacturers of these heaters make also a large-capacity open heater of cast-iron construction. Besides heating the feed water to within from 2 to 5 degrees of the temperature of the exhaust steam entering the heater, when the heater is kept filled with exhaust steam, a purification approaching that attained by heating water to exhaust steam temperatures is also obtained. These heaters are equipped with oil separators, copper heating trays, copper sink pans, controlling normal water levels and overflow levels by their connections to water-regulating valves, and filter chambers which may be filled with coke, charcoal, straw or other convenient filtering materials. They are of the "vacuum" type because of their action in reducing back pressure.

As illustrated by Figs. 35, 36, 37 and 38, the hot process system of purification, introduced by its makers about ten years ago, is designed primarily for treating water which is to be supplied to steam boilers in order that it shall be hot, nonscale-forming and noncorrosive.

The purifying action of the open feed-water heater affects chiefly the bicarbonates and, to a certain extent, colloidal substances, such as silica, iron and alumina, the action upon the bicarbonate being as follows:

The water, when heated to the boiling point, under atmospheric pressure, expels all gases held in solution, including air and carbon dioxide gas. If the water is heated in a mass, this process necessarily requires more time than if the water is heated while broken up into a fine spray, in which case the air and carbon dioxide gases are expelled almost immediately. In this heater the water is heated to the boiling point by spraying over trays, precipitating the carbonates on the trays and in the settling and filter space of the heater, and in doing this work it serves the same purpose for which lime water is used in the cold process system.

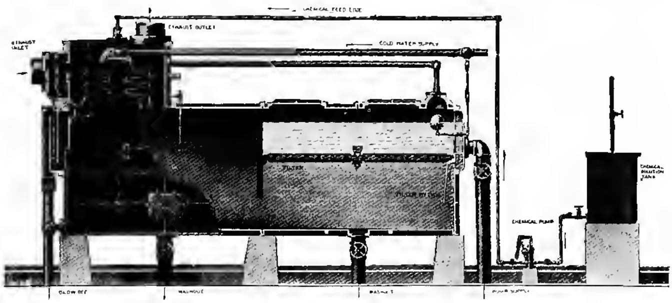


FIG. 35. — Hot Process System Softener.

The makers of this device say that more is accomplished by the heat than would be gained by the treatment of lime water, since air is driven out of the solution along with the carbon dioxide gas, and, as recent investigations have shown that the presence of air is essential to the corrosion of boilers and piping, the water is at the same time rendered noncorrosive and nonrusting.

The next step to be taken up is one which would rid the raw water of the permanent hardness. Soda ash, which has already been used in the cold water process, being very inexpensive, is adapted to this purpose. The soda ash, or sodium carbonate, combines with the calcium sulphate, forming calcium carbonate—which is insoluble — and sodium sulphate —which is highly soluble— and remains in the water as in the cold process treatment. The precipitate is coarser and settles more rapidly in hot water than in cold.

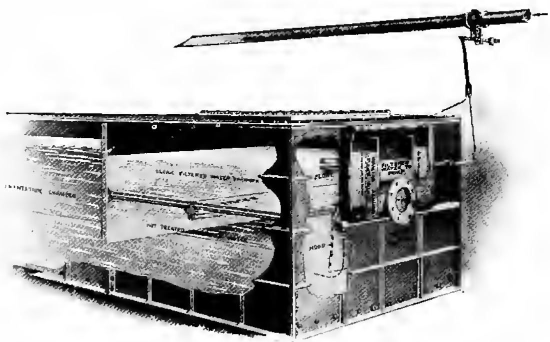


FIG. 36. — Hot Process System Water Control.

This apparatus is provided with convenient and reliable means for feeding the soda ash and such automatic attachments as are required for convenient handling and continuous operation, as, for instance, the automatic by-pass around the filter when the latter is unable to supply or pass the amount of water required by the boiler feed pumps.

The apparatus shown in Fig. 35 is designed to be used in connection with engines or pumps exhausting freely to the atmosphere, that is, without back pressure. Exhaust steam enters the apparatus through an oil separator which is part of the heater. The oil drips discharge into the water seal, through which they are discharged to the waste pipe. This water seal also disposes of any surplus water that may enter the system and also aids in the skimming of the surface of the water in the heater which is accomplished by holding open the cold water regulating valve.

The water supply is introduced into a distributing box in the top of the heating compartment from which it flows upon a series of trays and from thence to the settling chamber.

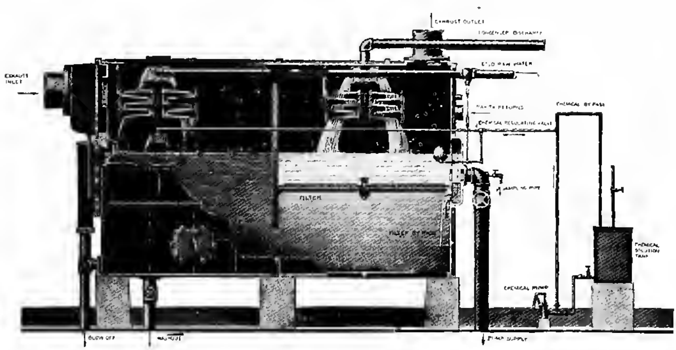


FIG. 37. — Feed-water Heater and Purifier.

The admission of water is controlled by a balanced valve operated by a float in the clear water chamber.

Chemical solution is prepared daily in a separate tank and pumped by a solution pump attached to the boiler feed pump and working in conjunction with it. Most of the sludge settles in the bottom of the settling chamber and is easily removed by washing out through the washout openings indicated. In case the filter becomes clogged between cleaning periods, so that it is unable to pass the required amount of water, the level of the water in the clear water space will fall sufficiently to cause the float therein to hold the cold water valve open until the level of the water in the settling chamber underneath the trays rises to a point where the water begins to overflow through the automatic by-pass directly to the pump suction. The action of automatic by-pass will be readily understood by reference to Fig. 37.

In steam plants where large quantities of water are available for boiler feed purposes and do not require softening, but heating only, while the raw water requires both heating and softening, it is better that the latter be softened before being diluted with the condensed steam. For such purposes the apparatus shown in Fig. 36 is used, the raw water together with the chemical reagent, being delivered into the left-hand end of the apparatus while that which does not require softening is led to a distributing trough and heating trays located in that part of the heater shell directly above the clear water space.

The float controlling the raw water valve also controls a valve in the chemical solution pipe, upon which a constant head is maintained by the use of a chemical pump attached to the boiler feed pump and an elevated overflow.

Where large capacity is required in small space, or where it is desirable to operate the system continuously through twenty-four hours each day, without shutting down for Sundays, the type of apparatus shown by Fig. 38 is generally used.

The difference between this and the horizontal, rectangular form of apparatus is principally in the relative positions of the different chambers. The heating chamber is at the top and discharges the hot and treated water through a vertical down-take pipe, which ends in a funnel near the bottom of the cylindrical settling chamber, forming the base of the apparatus. The water then rises slowly through this chamber and passes out the top into one or both filter compartments, each of

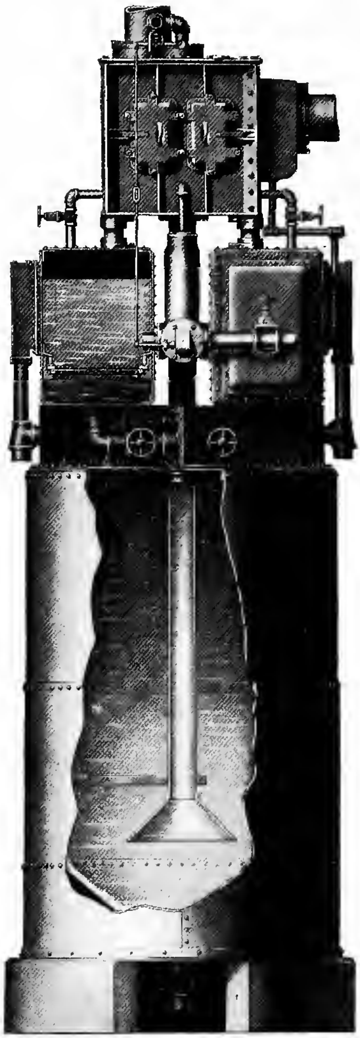


FIG. 38. — Hot Process System of Water-softening Vertical Type.

which contains a horizontal filter and a water seal overflow. Suitable valves may cut off communication between the settling chamber and either of the filtering compartments, and also communication between the clear water space of the filter chamber and the pump supply, thereby enabling one filter compartment to be opened for cleaning and renewal of the filter while the other remains in service.

These systems have been designed primarily for steam plant use, and the makers guarantee that if sufficient exhaust steam is supplied at all times to heat the water to 210° F., and the proper amount of reagent is regularly fed, hard scale will not form in the boilers, and the boilers will be entirely protected against corrosion. The boilers should be blown down at regular intervals to prevent the overconcentration of sodium sulphate, which of course should be done with any boilers using water-softening systems employing soda ash.

In a paper on "Live Steam Feed-water Heating," by A. W. Hamilton, before the Belfast Mechanical and Engineering Association, 1902, after explaining the benefits of heating feed-water by live steam, Mr. Hamilton draws these conclusions:

1. Live steam heaters do save fuel and economizers show a saving that has not been accounted for.

2. Evaporating water absorbs heat more rapidly than water which is being only heated.

3. The rate at which heat passes through a plate depends upon the temperature of both sides of the plate.

4. Evaporation always cools the surface upon which it takes place.

There has been quite a lively discussion in the pages of the *Engineer*, published in England during the year 1911, on the advantages and disadvantages of feed-water heating.

The writer would by all means advise that the general investigation of the problem of treatment of water be made by an independent party not connected with any manufacturer, as any such would be more likely biased toward the output of his own company.

There is one plant which has no trouble with scale or corrosion in boilers; an open feed-water heater is in use for artesian well water; the heater was not intended as a purifier, nor was it bought as such.

Another plant has had no trouble in the boilers from using water whose source was the river. The water being filtered before being fed to the boilers. After a chemical treatment cold process apparatus was installed and water filtered, much trouble was experienced, and water was again taken from the river and filtered by the old method.

One of the objections to both hot and cold water softening has been that sufficient time is not given for the proper clarification of the water and much sludge passes over to the boilers, or the machines using the water. This should not be considered an objection to the system, it being more the result of lack of care in the operation and use of the system.

In an article which was published in the Scientific American Supplement, recently, the purification of water was discussed, and also the methods employed by patentees to get over using large settling tanks, and the subsequent slow and complete filtration.

These methods are given in the paper:

1. Treated waters are mixed with old sediment.

2. They are mechanically stirred.

3. They are stirred by air jets.

4. They are heated.

5. After having settled the nearly clear fluid is treated with carbonic acid, which dissolves the sediment.

Nos. 1 and 2 are fairly satisfactory in results.

No. 3 waters are made more corrosive.

No. 4 reaction is quicker, scale is deposited in heater; if in an economizer the tubes choke up. If in certain purifiers the feed is heated by live steam before treatment, the cylinder oil and all the sediment appear to be removed. There is loss by radiation unless purifier is covered by a nonconductor.

Water analyses taken from actual experiences with a hot water purifying system.

PROBABLE COMBINATIONS

	Grains per U. S. gallon.	
	Raw well water.	Treated water.
Volatile and organic matter	.45	.35
Silica	.30	.25
Iron and alumina oxides	Trace	Trace
Calcium carbonate	6.20	1.20
Magnesium carbonate	1.32	....
Magnesium sulphate	4.69	....
Magnesium chloride	1.60	....
Magnesium hydrate	....	.35
Sodium carbonate	....	.42
Sodium sulphate	....	4.90
Sodium chloride	.99	2.97
Sodium hydrate	....	.32
TOTAL SOLIDS	15.55	10.66
Suspended matter	.15	.15
Free carbonate	.33	None
INCRUSTING SOLIDS	14.56	2.05
NON-INCRUSTING SOLIDS	.99	8.61

PROBABLE COMBINATIONS.

	Grains per U. S. gallon.	
	Raw well water.	Treated water.
Volatile and organic matter	.40	.25
Silica	.45	.45
Iron and alumina oxides	Trace	Trace
Calcium carbonate	9.29	1.25
Magnesium carbonate	.59	.59
Magnesium sulphate	3.06	....
Magnesium chloride	.49	....
Sodium carbonate	....	.60
Sodium sulphate	....	3.05
Sodium chloride	.21	2.64
Sodium nitrate	....	.39
Total Solids	14.49	9.22
Suspended matter	Trace	.15
Free carbonic acid	.22	None
Incrusting Solids	14.28	2.54
Non-Incrusting Solids	.21	6.68

PROBABLE COMBINATIONS.

	Grains per U. S. gallon.	
	Tuscarawas River water.	Treated water.
Volatile and organic matter	1.10	.75
Silica	.25	.20
Iron and alumina oxides	.15	.05
Calcium carbonate	6.55	1.09
Calcium sulphate	5.68	.22
Calcium chloride	7.50	....
Magnesium carbonate	....	1.07
Magnesium chloride	3.21	....
Sodium sulphate	....	3.79
Sodium chloride	21.45	23.60
Total Solids	45.89	30.77
Suspended matter	2.35	5.15
Free carbonic acid	.11	None
Incrusting Solids	24.44	3.38
Non-Incrusting Solids	21.45	27.39

Another method of hot water treatment is shown by the apparatus illustrated by Figs. 39, 40, 41 and 42. Figs. 39

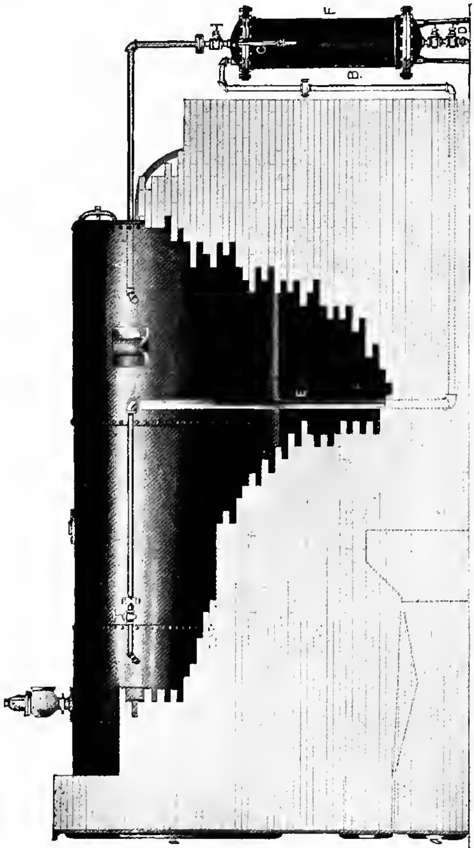


Fig. 39. — Apparatus showing Typical Connections to Horizontal Boiler.

A — Draw-off C — Vent E — Circulating Tube
B — Return D — Blow-off F — Filter

Chemical and Filtration System (patented) attached to return tubular type of boiler and showing filter in rear of setting.

and 42 show two different types of boiler equipped. Fig. 43, a cross section of the filtering device employed.

Soda ash or caustic soda — preferably the latter — is introduced into the boiler with the feed-water in quantities sufficient to neutralize all scale-forming or corrosive properties present. The precipitates resulting from this treatment, together with the temporary hardness and any foreign matter of an organic or earthy nature, are continuously removed from the boiler, while in suspension, and delivered to

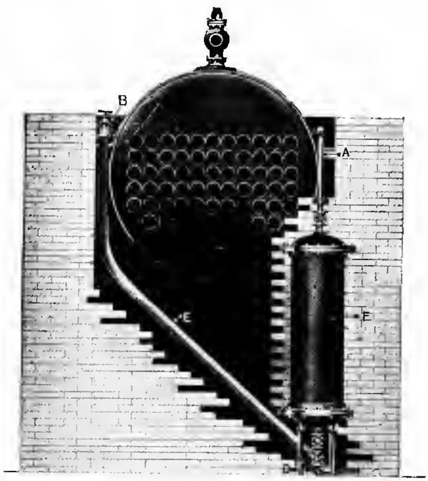


FIG. 40. — Sectional View of Horizontal Boiler Connection.

a filter located at the side or rear of the boiler setting. It will be noted that with this system the reactions take place inside the boiler but the objection to this is overcome by the effective removal of the sludge, which, if left in the boiler might set up a foaming condition or result in mud burns.

The filter "F" is in the nature of an outside mud drum or precipitating chamber with connection to the boiler at such points as the construction and type of same indicate. The point of return "B" is not particularly important providing it is fully submerged at all times, but the draw-off "A" must be from such a point that a constant intake of suspended impurities is assured.

FIG. 41. — Apparatus attached to Stirling Boiler.

A — Draw-off C — Vent E — Circulating Tube
B — Return D — Blow-off F — Filter

An Apparatus attached to Stirling Water Tube Boiler and showing Seamless Steel Bent Circulating Tubes located above Arch in Front Bank of Tubes.

The water containing the foreign matter is removed from the boiler through draw-off pipe "A" and delivered into collecting space in the bottom of the filter. A lower temperature materially assists precipitation, which is completely effected in the upward flow of the water through the filtering medium of crushed granite, the result being that a practically pure supply is being returned to the boiler from

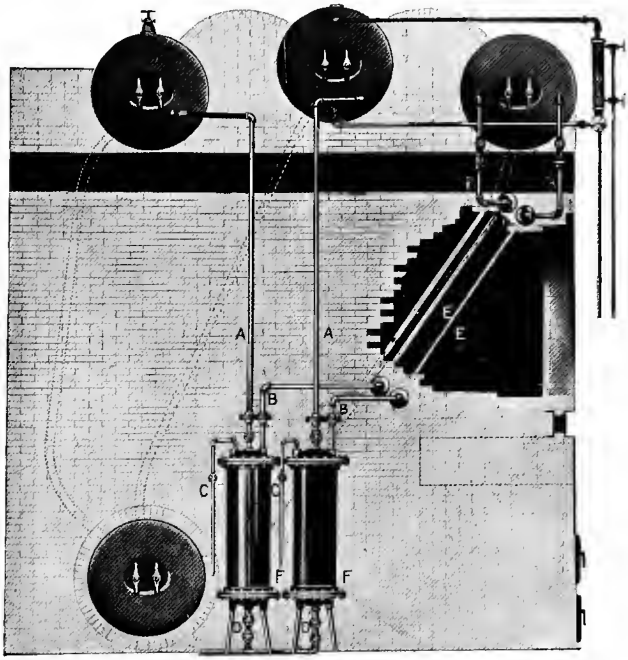


FIG. 42.—Apparatus showing Typical Connections to Stirling Boiler.

the open space in the top of the filter through return line "B."

The circulating tube "E" is the section of return tube "B" which is introduced into the intense heat of the boiler furnace. This tube has a diameter in excess of the other connections and the increased cross-sectional area and cubic contents and the consequent steam generation result in the very rapid circulation. This circulation causes sufficient suction at the point of draw-off to attract to the filter the suspended matter from all parts of the boiler.

At regular intervals the blow-off valves "D" are opened and the valve in the draw-off line at the top of the filter is closed. The boiler pressure thus released through return line "B" removes the sludge from the "collecting space" and thoroughly cleanses the filter bed. The opening of draw-off valve "A" and closing of blow-off valves "D" causes the circulation to recommence, and the continuous filtration, interrupted in the process of blowing down, is resumed. A small valve "C" vents the filter of steam after blowing down.

This is not a skimmer, as no resort is made to floating pans or interior mechanism, and does not depend upon a surface blow for results.

The manufacturer of this device furnishes these analyses of bad mine water from the Middle West, all of which, he assures me, can be and have been made fit for use in steam boilers.

Total solids.	Calcium sulphate.	Magnesium sulphate.	Sodium sulphate.
A — 125.89	52.60	34.56	34.29
B — 227.24	44.44	51.97	110
C — 328.09	37.5	185.6	35
D — 76.85	6.27	61.84	.....
E — 186.60	95.21	66.33	17.25
F — 220.37	81.55	124.68	.....
G — 102.85	Traces	85.88	.....
H — 97.94	14.50	64.10	12.20

(All grains per gallon.)

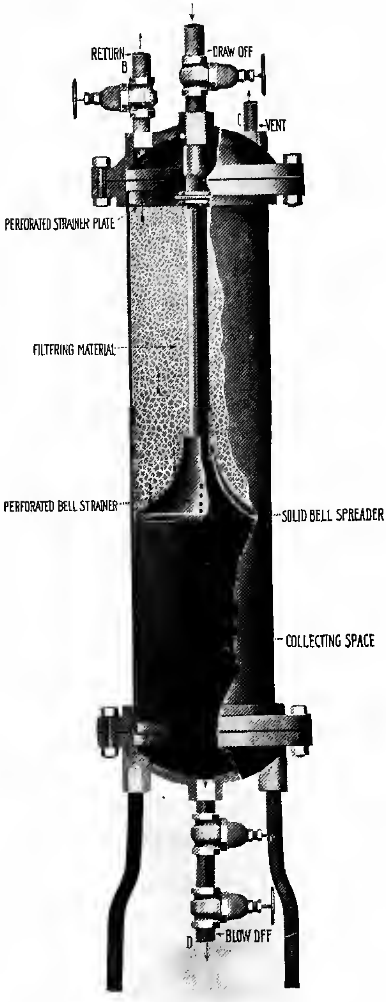


Fig. 43. — Details of Filter Construction.

Another manufacturer says that using this device with the boiler at 40 per cent over-load caused no water troubles, and also that the plant economy over the time when "compound" only was used was about 1000 pounds of coal per 10-hour day.

In a western plant using this method of purifying boiler feed-water it was found that by the use of sal-soda parts of the tubes and shell that showed black iron originally were still clean and black, and the old scale gradually softening and falling off. The raw water at this plant is very bad, as shown by this analysis.

	Grains per gallons.
Silica and silicates	1.050
Iron and alumina	2.277
Sodium and potassium chlorides	1.532
Calcium sulphate	14.817
Calcium carbonate	6.834
Magnesium carbonate	17.169
Loss	.121
Total solids	43.800

CHAPTER IV

RESULTS ACCOMPLISHED BY WATER SOFTENING.

Some idea of what is being accomplished by water softeners is given in the following notes of experience in various parts of the country.

One of the worst boiler waters, that from Chartier's Creek, Pa., is almost impossible of treatment by compounds. It has been satisfactorily softened and has cut the ¼-inch scale in boilers so that it could be easily removed by softening the same.

Water from a canal in Milwaukee, Wis., connecting two rivers is almost black to the eye, has a large amount of suspended matter and a strong offensive odor; varies in hardness as much as 38 per cent in an hour. The bacteria number is as high as 32,000 per cubic centimeter in freezing weather, and higher in summer. After being screened the water is used in a condenser at 68° F. above 32° F., then goes to the softener, which treats about 2,000,000 gallons per day, and the hardness has been reduced to 3.5 grains per gallon. The variation is kept within ½ grain per gallon while endeavoring to maintain 5 grains per gallon — at which the plant is operated.

A previous water cost of $30,000 per annum for raw water has been reduced to 2.5 cents per gallon, the bacteria count reduced to about 150 per cubic centimeter and the treated water is colorless, odorless and remarkably clear.

The city supply of raw water at Terre Haute, Ind., containing

8.42 grains of incrusting solids,
0.19 grains of suspended matter,
1.45 grains of non-incrusting solids,

after treatment in a softener gave

3.79 grains of incrusting solids,
0.11 grains of suspended matter,
6.38 grains of non-incrusting solids,

the calcium sulphate and magnesium sulphate being entirely removed.

At Kansas City, Mo., water at a laundry, having

19.45 grains per gallon of incrusting solids,
1.73 grains per gallon of non-incrusting solids

gave after softening

4.59 grains per gallon of incrusting solids,
10.79 grains per gallon of non-incrusting solids,

the calcium carbonate being reduced from 14.20 to 2.20 grains. It is now fit to drink, and saves the use of distilled water in washroom.

At Columbus, Ohio, water at a laundry having

29.91 grains per gallon of incrusting solids,
2.65 grains per gallon of non-incrusting solids

gave after softening

4.55 grains per gallon of incrusting solids,
16.02 grains per gallon of non-incrusting solids,

the calcium carbonate being reduced from 13.20 to 3.00 grains.

At Lafayette, Ind., at a brewery, the raw water was softened in a 2000-gallon machine at a cost of 2.1 cents per 1000 gallons.

ANALYSIS.

	Grains per U. S. gallon.	
	Raw water.	Treated water.
Calcium carbonate	20.35	1.15
Calcium sulphate	0.48	None
Calcium chloride	None	None
Magnesium carbonate	None	1.93
Magnesium sulphate	8.04	None
Magnesium chloride	3.52	None
Iron and aluminum	0.05	0.05
Silica	0.53	0.54
Suspended matter	Trace	None
Total	32.97	3.67

A textile mill in Michigan reports reducing hardness from 18½ degrees to 5 and 6 degrees hardness at a cost of 1.25 cents per 1000 gallons, and a saving of 50 per cent in soap and alkali.

A woolen mill reports a softer finish on goods and a 50 per cent saving in soap.

A Minnesota laundry saves 40 per cent in soap and soda accounts by softening.

A Michigan laundry using dirty river water varying from 14 to 20 degrees in hardness gives as results of softening 5 degrees hardness, one-third saving of soap and alkali, and no compound required for steam boiler, while the goods are sent out of the laundry whiter than before.

Arlington, S. D., water containing a very high amount of incrusting and non-incrusting solids was treated by a softener with the following results:

	Grains per U. S. gallon.	
	Raw water.	Softened water.
Calcium carbonate	70.50	3.37
Magnesium carbonate	19.38	0.88
Magnesium sulphate	18.60	None
Sodium carbonate	None	4.18
Sodium sulphate	64.00	160.00
Sodium chloride	3.76	3.76
Free carbonic acid	2.61	None
Iron alumina and silica	2.00	0.42
Incrusting solids	110.48	4.67
Non-incrusting solids	67.76	163.76

Lime required to treat the above water was 7.65 pounds per 1000 gallons.

RESULT OF ANNUAL SAVING MADE BY A 500-HORSE-POWER WATER SOFTENER.

52 boilers cleaned (2 men, 1 day each at $2.00)	$208.00
Gaskets ruined and replaced	34.00
Cost of operating turbine cleaner (8 boilers turbined using for each time 75,000 gallons water at 125 pounds' pressure)	18.00
Turbine and hose maintenance	26.00
Coal used to raise steam to service pressure after boiler is cleaned, 104 tons at $1.95	202.80
20 pounds boiler compound a day at 4 cents	240.00
Cleaning heater 12 times a year (each cleaning requires 1 man at $2.00, and 80 cents worth of excelsior)	33.60
Boiler repairs due to scale	48.00
Annual expense before installing water softener	$810.40

Chemicals used in softener		$123.84
15,120 pounds lime at 0.40 per cwt	$60.48	
5,760 pounds soda at $1.10 per cwt	63.36	
	$123.84	

4 boiler washings per year, each costing...		$9.50	$38.00
2 men, 1 day at $2.00	$4.00		
Gaskets replaced	.70		
Pumping wash water...........	.80		
Fuel to put boiler in service.....	4.00		
	$9.50		
Heater cleaned twice			$5.60
Cleaning filter in softener			8.50
Excelsior	$4.50		
Labor	4.00		
	$8.50		

Annual expense after installing softener	$175.94
Net reduction in expense	634.46
Saving in fuel by clean boilers	510.00
Total annual saving after installing softener	$1144.46

A cold process softener at the works of Fried. Krupp of Rheinhausen-Friemersheim, Germany, purifies 24,030 gallons of boiler feed-water per hour at a temperature of 176° F. to 185° F., and the boilers are practically free from scale.

At a mill in Ohio, where a purifier and boiler compound was used, the cost of cleaning boilers, cleaning water purifier and supplying the compound was $689.97 for 244 days' run.

With the softener in use attention, cleaning boilers and supplying chemicals was $121.22 for 244 days' run.

First method, boilers cleaned every 6 weeks.

Second method, boilers cleaned every 17 weeks.

"We are saving 6 tons of coal per day, 1500-horse-power system, and find it necessary to wash out our boilers only once every six months and have practically eliminated boiler repairs. We formerly found it necessary to turbine our boilers regularly and to expend a great deal of money for boiler repairs. The system installed paid for itself in fuel saving and boiler repairs in eleven months' operation.

"We have been operating our 6000-horse-power B. and W. boiler plant for nine years, and during that time we have only lost two boiler tubes. As a result of this record, and the fact that we only found it necessary to wash out our boilers every three months, we have decided to place an order with you for a duplicate of our present system.

"We have operated our boilers for eleven months on a water which formerly gave us a great deal of trouble from an extremely hard scale. All the sludge and scale that we could remove from our boilers at the end of that time was contained in an ordinary water bucket. It required less than a minute to push a turbine through a tube of our boilers, showing that the same were perfectly clear. We did not feel that it was necessary to put the turbine through the boiler, but to be absolutely certain that the tubes were clean, we did so. The result was the small amount of scale just mentioned. Just what our fuel saving is we do not know, but it is certainly an item, and if we effected no other saving than the cost of cleaning our boilers, it would be an item which would pay a good return on the investment in your system."

One of the most gratifying results to the user of softened or chemically purified water is the uniformity and dependability of the effluent especially when the process is carefully watched and controlled by a competent man.

This feature of purification is not only of much value to manufacturers, but of inestimable value to the inhabitants of cities and towns where softening or chemical treatment of drinking-water supplies are necessary.

The results obtained by one of the softening processes where spring water is taken from a pond at a low point in the town and purified for drinking purposes are shown by these analyses:

TABLE OF CHEMICAL ANALYSIS.

Determined.	Parts per million.	
	Raw.	Treated.
Silica, SiO_2	2.40	0.40
Calcium oxide, CaO	101.00	31.00
Magnesium oxide, MgO	8.50	5.80
Sulphuric acid, as sulphates, SO_3	19.32	19.32
Hydrochloric acid, as chlorides, Cl	9.00	9.00
Nitrogen, as nitrates, N	4.16	4.00
Alkalinity in terms of calcium carbonate	158.00	94.00
Turbidity in terms of silica standard	5.00	1.00

TABLE OF HYPOTHETICAL COMBINATIONS OF ACIDS AND BASES.

	Grains per gallon.	
	Raw.	Treated.
Silica, SiO_2	0.140	0.023
Calcium carbonate, $CaCO_3$	9.239	3.233
Magnesium carbonate, $MgCO_3$	.....	0.713
Calcium sulphate, $CaSO_4$	0.777	.....
Magnesium sulphate, $MgSO_4$	0.126	.....
Magnesium chloride, $MgCl_2$	0.704	.....
Magnesium nitrate, $Mg(NO_3)_2$	0.583	.....
Sodium carbonate, Na_2CO_3	.....	0.132
Sodium hydroxide, NaOH	.....	1.029
Sodium sulphate, Na_2SO_4	.....	2.005
Sodium chloride, NaCl	.....	0.868
Sodium nitrate, $NaNO_3$	0.809	1.420

The bacterial test which gave 400 colonies per cubic centimeter in the raw water showed 12 colonies in the treated water. The results of the operation of the plant for six months are shown in the following table, which also gave the

TABLE OF OPERATION RECORDS.

	Average gallons treated daily.	Hardness, raw.	Grains per gallon treated.	Chemicals used per 1000 gallons.		
				Lime.	Soda ash.	Hypochlorite.
May	470,000	10.8	3.54	1.60	0.66	.0084
June	569,400	12.5	3.33	1.27	0.45	.0041
July	597,300	13.3	3.66	1.43	0.43	.0039
August	572,200	13.0	4.61	1.35	0.38	.0058
September	538,200	13.2	3.87	1.60	0.57	.0085
October	472,600	12.2	3.42	1.82	0.60	.0071

amount of chemicals used in the process. Sulphate of iron has been used at intervals only. The cost of operation has varied, due to the different conditions of both the water and the operating force. The average cost per 1000 gallons, including pumping the water, a lift of about 20 feet, is divided as follows: Lime, $0.0049; soda, $0.0050; hypochlorite, $0.0003; superintendence, $0.0038; power, $0.0091; supplies, $0.0005; total, $0.0236.*

* *Engineering Record*, vol. 64, p. 706.

CHAPTER V.

PRESSURE FILTERS.

In a great many industrial plants and in some municipal plants water is purified by mechanical methods through pressure filters, with or without coagulation in open tanks. The general plan is to have a closed tank with a number of strainers spaced equally distant over the bottom of the tank through which the water leaves the filter and by passing downwards through properly graded layers of sand and gravel of the right thickness to properly purify the water passes out through a pipe to the main supply line thoroughly filtered.

Fig. 44. — Strainer.

To clean these filters an interior agitator containing spikes or fingers extends down into the sand or gravel stirring the same by means of mechanical connections outside of the tank, and also by reversing the flow of the water the sediment can be washed out of the tank at the bottom. This method of filtration is used to a great extent when suspended matters abound in the raw water. Often raw water has been treated in softening tanks and still there remain some matters in suspension which can be taken out in the pressure filters. The treatment in the softening tanks may be ahead of the filter or may come after the water is filtered, depending on what the raw water contains.

FIG. 45. — Strainer.

One of the filter builders supplies pressure filters up to 120 inches in diameter, which use machine-crushed sifted quartz for the filter bed, and strainers made of non-corroding bronze, through which the water passes. A strong and well braced agitator provides the means of breaking up the quartz so that it can be readily washed. For residential purposes this filter is made in sizes 24 to 36 inches in diameter.

Another pressure filter uses a different shape strainer as shown in Fig. 45.

Still another strainer is made by another manufacturer, as is shown in Fig. 46.

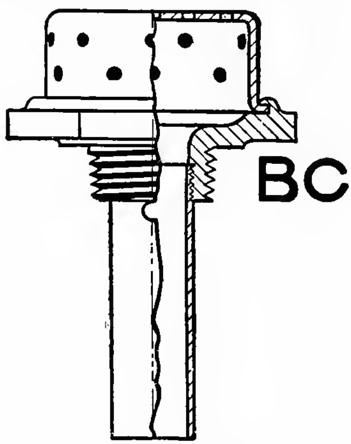


FIG. 46. — Strainer.

The patented sand and charcoal filter, Fig. 47, is a combination filter in which both sand and animal charcoal are used as filtering material. The shell of the filter is of cast iron. The strainer which enables the filter to be washed by reversing the flow, which is accomplished by turning the three-way valve and opening the sewer connection, makes it a simple and easily operated filter.

FIG. 47. — Double Combination Sand and Charcoal Filters for Residences.

This filter is also built as a double combination sand and charcoal filter, the water passing through the first filter, in which the bed is made of sand and crushed quartz, and then through a second filter containing pure animal charcoal. In this type the charcoal never comes in direct

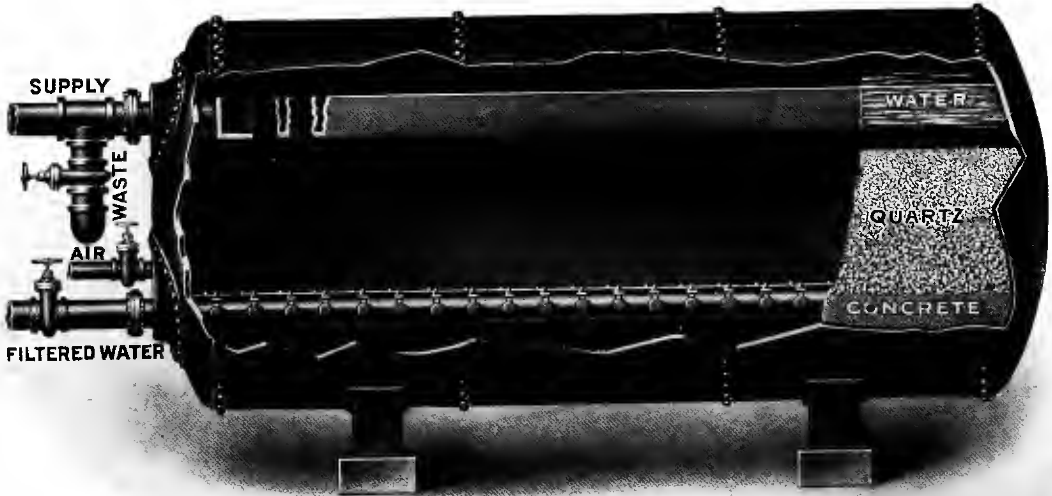


FIG. 48. — Single Horizontal Pressure Filter.

contact with the impure water, but only with the water after it has been filtered through the sand.

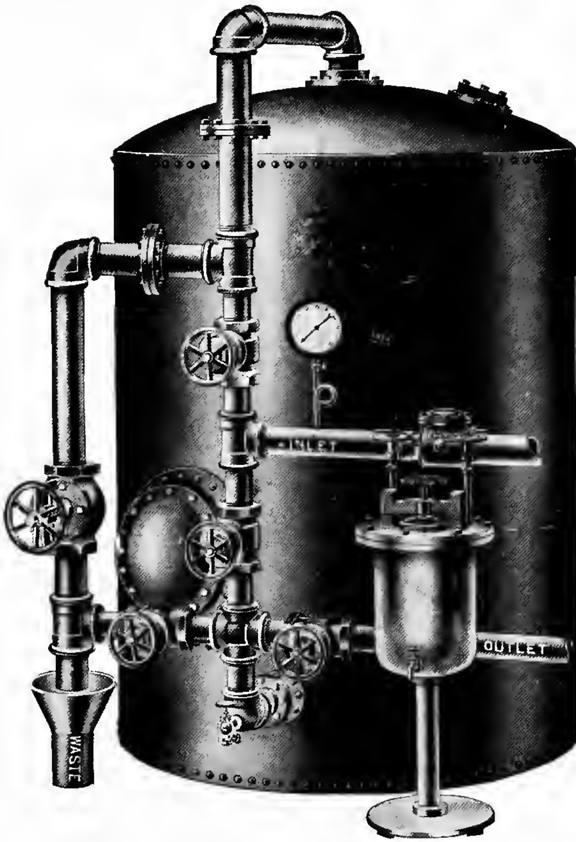


FIG. 49.—Vertical Type, Steel Tank, Pressure Filter.

Fig. 48 shows a larger type pressure filter applicable to either double or single filtration of water. The larger types are usually supplied with air wash in addition to the water wash, and with the strainer shown by Fig. 60. The illustration shows a sectional view of the pressure filter.

The resistance or back pressure, due to delivering water through pressure filters, varies from $1\frac{1}{2}$ to 2 pounds immediately after cleaning, and gradually increases, owing to the accumulation of matters intercepted by the sand bed, to from 10 to 15 pounds, and sometimes more, depending upon the length of run between washings, the turbidity of the

FIG. 50.—Strainer or Sand Valve.

water and the rate of filtration. After each washing operation, however, the resistance falls back to the initial $1\frac{1}{2}$ or 2 pounds, and may be allowed to increase to any desired or convenient pressure.

One of the devices for removing oil from the water of condensation is that shown by Fig. 51, using filters in series.

In this filter or series of filters the water enters at the bottom of one filter, passing upward through a zinc grating and then through a charcoal filter, then passes out through the top and down to the bottom of another filter tank. This is repeated as many times as is necessary, or rather through as many cylinders as is necessary, for the proper

SCHEDULE OF SIZES, CAPACITIES, ETC.

Diameter.	Inlet and outlet pipes.	Waste pipe.	Capacity in U. S. gallons.			Approximate shipping weight in pounds.			Test pressure.
			Minute.	Hour.	24 hours.	Case.	Parts.	Filtering material.	
Ins.	Ins.	Ins.							
24	$1\frac{1}{2}$	2	6–9	360–540	8,640–12,960	850	300	1200	Stock filters made to stand 125-lb. test. Filters to stand 150 or 200 test are special.
30	$1\frac{1}{2}$	2	10–15	600–900	14,400–21,600	1500	300	1650	
36	$1\frac{1}{2}$	2	14–21	840–1260	20,160–30,240	1575	425	2800	
40	2	$2\frac{1}{2}$	17–26	1120–1560	26,880–37,440	1625	650	3400	
42	2	$2\frac{1}{2}$	19–29	1140–1740	27,360–41,760	1700	700	3848	
48	$2\frac{1}{2}$	3	25–37	1500–2220	36,000–53,280	2025	850	5450	
50	$2\frac{1}{2}$	3	27–41	1620–2460	38,880–59,040	2350	875	5700	
60	$2\frac{1}{2}$	3	39–59	2340–3540	56,160–84,960	3300	950	7800	
Ft.									
6	3	4	56–84	3360–5040	80,640–120,960	4000	1300	10,000	Stock filters are made to stand 100-lb. test. Filters to stand 150- or 200-test are special.
$6\frac{1}{2}$	3	4	66–99	3960–5940	95,040–142,560	5000	1300	12,000	
7	4	5	78–115	4680–6900	112,320–165,600	5700	2000	13,600	
8	4	5	100–150	6000–9000	144,000–216,000	9350	2000	17,700	

The above capacities are conservative. Use minimum capacities for muddy waters. Where maximum capacities are exceeded resistance will increase, the filter will require washing more frequently, and the filtered water will not be of as good quality.

cleansing of the water and is a device that has been applied to as large a boiler horse power capacity as 4500.

Charcoal is much used as a filtering medium, both for drinking water and mill supplies and for boiler purposes. The old way of making charcoal was to burn wood under a

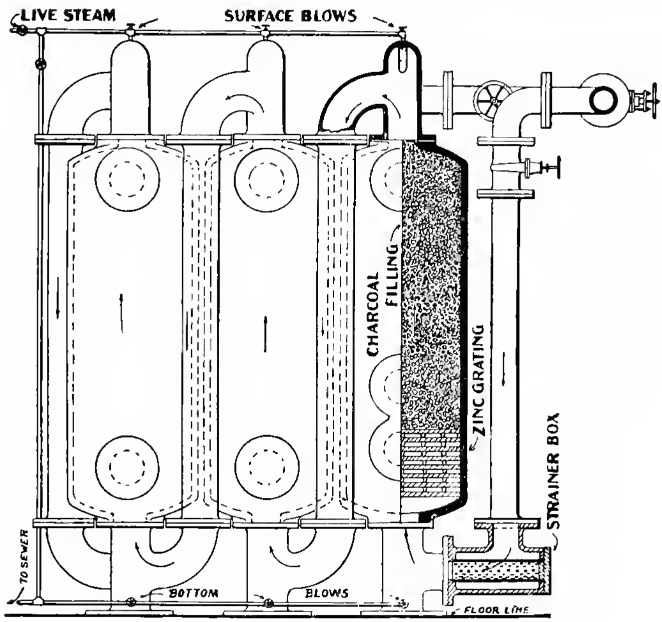


FIG. 51. — Filter for Removing Oil.

covering of sod or turf, allowing the wood to smoke just enough to keep the wood burning without flaming. By this method all of the juices of the wood went to waste either by passing out as vapor to the air, or by allowing them to sink into the ground and be lost beyond recovery, the process lasting at least three weeks.

In the modern method the wood is burned slowly for ten days in large iron retorts. From these retorts pipes are led to receptacles in which the products such as creosote, wood tar, acetic acid, etc., are caught and afterward chemically purified. In 1910 filtering charcoal was quoted at about $25.00 per ton f.o.b. cars.

Mechanical Filtration. — Mechanical filtering plants, complete, including buildings and moderate size clear-water basin, cost, on the average, $12.00 to $15.00 per 1000 gallons per 24 hours.

Crushed quartz, which is also much used as a filtering medium, is sold in accordance with its grade or size of particles. The following table is one which is furnished by a company dealing in crushed quartz, and the prices in 1910 were given as subject to 45 per cent discount from the following list, f.o.b. cars.

Grade.	Weight per cubic foot, pound.	Price per ton.	Grade.	Weight per cubic foot, pound.	Price per ton.
S. M.	88	$14.00	2½	79	$15.00
30	92	14.00	2	78	16.00
25	90	14.00	1½	78	16.00
10	88	14.00	1	77	16.00
6	86	14.00	½	76	16.00
5	84	14.50	0	76	16.00
4½	82	15.00	00	74	16.00
4	81	15.00	000	73	18.00
3½	80	15.00	0000	73	20.00
3	79	15.00			

All material put up in 100-pound sacks.

The filtering apparatus, used by the East Jersey Water Co., at Little Falls, to filter the drinking water, as well as all water for manufacturing purposes which is supplied to the

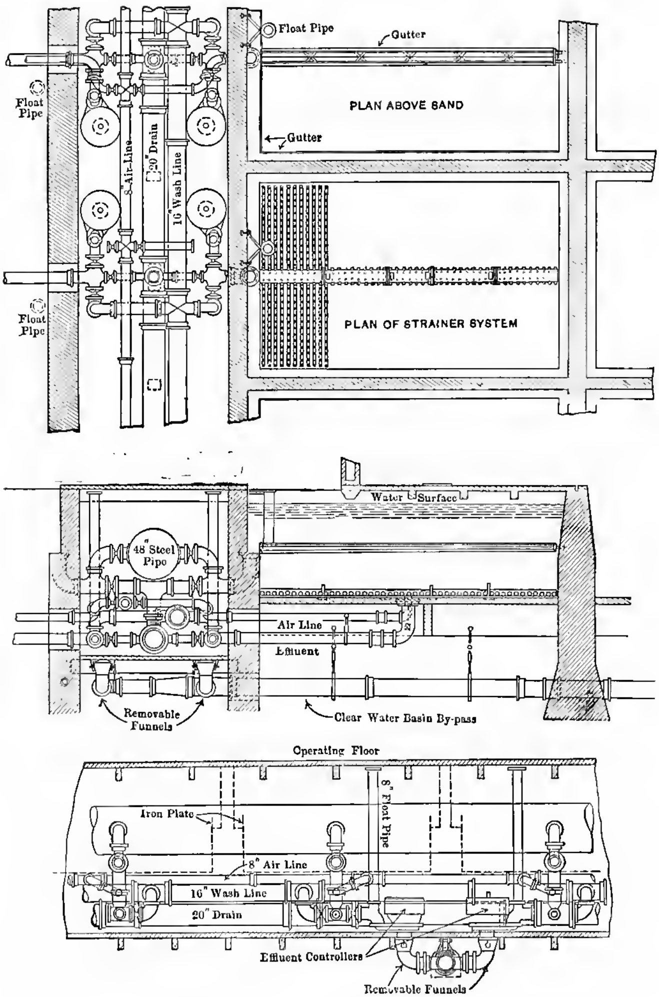


FIG. 52. — East Jersey Filters.

cities of Passaic and Paterson, and a few of the suburbs of these cities, is composed of a raw water coagulation tank where the water is coagulated by alum or other material from whence it is turned into sand filter beds where it is further purified by gravity filtering through sand.

CHAPTER VI.

PURIFICATION OF WATER BY STERILIZATION, DISTILLATION, AËRATION, AND OZONE. ICE IN DRINKING WATER. STORAGE OF WATER.

ONE of the most important contributions to the use of electricity in purifying water through the production of ozone is that of Dr. Th. Weyl, of Charlottenburg, Germany. He writes of the discovery of the ozone method of water purification by Schœnbein about 1849.

One of the best known properties of ozone is its power in exterminating bacteria. Ohlmuller has proved that ozone cannot be used economically in treating water which contains organic matter, owing to the fact that ozone will first act on such organic matter, and only when this has been destroyed will the ozone attack the bacteria.

Dr. Weyl tried three ways of purification as follows:

1. Raw water + air + iron.
2. Raw water + ozone + iron.
3. Raw water + ozone.

Only No. 2 gave a perfect filtrate.

The cost stated by Dr. Weyl would seem to bring the total cost of water purification up to a prohibitive figure. The writer believes that the most expensive part of ozone purification is the renewing of the electrodes and this has been an expensive feature of such plants that cannot be very well overcome or cheapened.

Another authority, W. H. Lindley of Frankfort, in discussing the paper by Dr. Weyl suggests the probable use and future of an ozone filter as an auxiliary to the sand filter.

Should the reader desire to go deeply into the question of the electrical purification of water, he will find in *Engineering News*, vol. 63, p. 488, nine pages of descriptive matter and illustrations under the heading, "The Production and Utilization of Ozone," with a special reference to water purification.

In 1897 an article in "Fire and Water" gave the view of Dr. Heysinger on purification of water for drinking purposes, and among his conclusions was the following — "That sedimentation should always be made use of, then filtration or better purification by ozone."

Sterilization of Water by Ozone. — The *Practical Engineer*, Oct. 26, 1906, gives some information on this point as follows:

Paderborn, Germany — continued ozone operation of $3\frac{1}{2}$ years, result — typhoid fever has entirely disappeared from the town.

Petersburg — sterilization of drinking water.

Astrachan — sterilization of mineral water.

Munich Brewery — sterilization of rinsing water.

In the latter place the plant includes a scrubber-shaped sterilizer tower filled with pebbles, in which the ozone air comes in contact with a back current of water dropping down; a direct current motor being direct-connected to an alternating current machine, and driving at the same time a blower and water pump.

In this plant an automatic cut-off is used to stop the supply of raw water to the tower as soon as the tension of the transformer drops below a given amount.

The Russian Army has a portable plant that was in use in Manchuria and gives from 500 to 600 gallons (imp.) per hour at an expenditure of about 2 horse power.

Ozone sterilization treatment of water by the de Frise-

Siemens type of apparatus is said to cost $6.67 per 1,000,000 gallons treated — based on a daily treatment of 10,000,000 gallons.

Mr. Geo. A. Soper, in a very elaborate article in *Engineering News*, vol. 42, p. 250, says in part:

"The claims made for the ozone treatment of water are as distinct and its functions as clearly defined as are those of filtration and sedimentation. Ozonation aims to eliminate bacteria from water and to destroy unpleasant colors and odors of vegetable origin. It is especially valuable in removing unpleasant odors.

The Saint-Maur, France, de Frise ozone process plant is said to generate the ozone and treat 22,000 imperial gallons (100 cubic meters) of water per hour with an expenditure of 3 kilowatts or 4.8 horse power. The results have been very satisfactory.

The cost of electrical treatment of water for locomotive use at Alamogordo, N. M., was 47.9 cents per 1000 gallons.

Incrusting solids, 3.347 pounds per 1000 gallons.

Non-incrusting solids, 3.347 pounds per 1000 gallons.

Which figures are equal to 23,483 grains per gallon.

The electric current costs three-fourths cent per horse-power hour. The calcium carbonate and sulphate and magnesium sulphate were very much reduced in quantity. The incrusting solids were reduced from 1.065 pounds per 1000 gallons to 7.452 grains per gallon.

A full description of this treatment will be found in the *Engineering News*, vol. 60, p. 166.

Professor Proskauer, 1906, says, with respect to the use of ozone, that this method of treatment furnishes a means of procuring drinking water of unobjectionable quality, and that, according to his own observations, the employment of ozone is a very valuable measure for the sterilization of water.*

Aëration. — Another method of purifying water of certain impurities is by aërating it. This can be accomplished by spraying in the open air where the water can get the benefit of the sunlight or any breeze that is blowing, and this is all that is required where water is used over and over again in condensers for steam engine work, for cylinder jacket water and other like uses.

Fig. 53 shows a cooling spray pond in action. The loss of the water by spraying through nozzle, as shown, is given as ¾ to 1 per cent for a modern well-designed pond.

These three sizes of nozzles are recommended by their maker for spray cooling work.

Diameter of pipe for supplying nozzle.	Diameter of nozzle orifice.	Capacity of nozzle at 10 pounds pressure per square inch.	Gallons per minute at 15 pounds pressure per square inch.
Inches	Inches	Gal. per minute.	
1½	½	21	23
2	¾	44	50
2½	1	93	102
3½	1½	190	210

The method in use in San Francisco, Cal., at the College Hill Reservoir Aëration Plant, which has a capacity of 8,000,000 gallons daily, is to run the raw water through a 30-inch diameter pipe supplying the water to overhead flumes 22 inches deep by 4 feet wide, making together a letter T, the top of the T being the longest part of the flume. In the sides of this wooden flume are about six hundred ¾-inch diameter holes, from which the water flows on dash boards, splashing 3 feet down to another board and repeating the operation several times until the bottom of the apparatus

Inst. Civ. Engrs., vol. 166, p. 452.

Fig. 53. — Spray Cooling Pond.

is reached, when the purified water which has been mixed with the air is run out to the reservoir through a weir, thereby giving an opportunity to measure the water running. This device is illustrated in *Engineering Record*, August 15, 1896.

Aëration. — The Board of Water Supply of the City of New York in the report for 1910 gives some results obtained by Mr. J. Waldo Smith, the chief engineer, in experimenting with different types of nozzles proposed for the aëration at Ashokan and Kensico reservoirs which were made at the Hudson East test shaft, using a 25,000 gallon tank for supplying the necessary water under sufficient head.

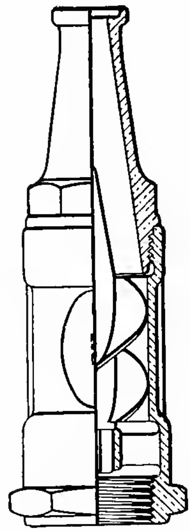


FIG. 54. — Spray Nozzle.

A 6-inch supply pipe led from the tank to a wooden manifold, arranged for the attachment of nozzles, singly, in line or in groups. These experiments, supplementing those made at Coney Island in 1908, fully demonstrated the practicability of casting a thin shell with spiral vanes in one piece, and determined to a certain extent the forms and dimensions of nozzles to be used.

Each nozzle consists of a cylindrical base surmounted by a conical tip. In the base are cast three vanes, equally spaced on the circumference, and projecting nearly to the center of the water way. At the bottom the vanes are parallel to the axis of the nozzle, and above are curved to an inclination of about 60 degrees at the top. Three types of nozzles were used, a short tipped, a long tipped and one without a tip, the base being the same for all types. No advantage in shape, jet or coefficient was shown by the long tipped or the short tipped nozzle over the other. A commercial nozzle gave a symmetrical jet with high coefficient of discharge (0.96), but the spray was not as finely divided as in the jets from the board's nozzles, and for the proposed use the speed was greater than was desired.

The nozzles designed for the first installation at Kensico were $1\frac{3}{8}$ inches in tip diameter. A full equipment of these will discharge in the reservoir flow line not less than 330,000,000 gallons per day.

The coefficient of discharge for the nozzles with long and short tips was about 0.9 and for the nozzle without the tip about 0.6.

Ice. — One of the most prolific sources of danger in drinking is from the use of ice in the water or other beverages. Ice is not always cut from ponds free of pollution, and, indeed, seldom is; likewise, if artificial, the water used in its manufacture may be tainted. Clear ice can be made from pure water if agitation is carried on during freezing to expel the air, but the preferable method is one using distilled water. This may come from exhaust steam, condensed and purified, and reboiled and then often the taste of oil can be noticed in the water.

The best method, according to Mr. Hal Williams, in *The Engineer*, London, "is to employ multiple-effect evaporators, such as have long been used to great advantage in the manufacture of sugar. In the triple-effect evaporator, for instance, exhaust steam is passed through tubes surrounded by water, and the vapor thus produced is passed through similar tubes in a second evaporator, and the vapor in this again through a third evaporator. The final vapor is drawn off into a condenser and removed by an air pump, so that there is a progressive vacuum in each evaporator. The condensed steam from the first effect is returned to the boiler as feed, while that from the second and third and the condenser is filtered and used for freezing. In this way the latent heat given up by the vapor in condensing is utilized to evaporate more water and a high degree of economy is attained. Combinations as high as sextuple effect, on this principle, have been employed. With a triple effect one pound of steam will produce 2½ pounds of distilled water, and a sextuple effect will produce 4½ pounds of water from one pound of steam. It is, of course, desirable to operate an evaporating apparatus with the exhaust steam from the engines, but this involves a certain amount of back pressure, which is sometimes objectionable. Live-steam effects are, therefore, sometimes employed, although they cannot compete in economy with exhaust-steam apparatus, but are applicable in cases where only a small portion of the ice produced is made from distilled water, as then the main engines can be worked condensing, and a corresponding economy secured."

His paper concludes with a cost comparison of the amount of coal required to distill 50 tons of water during 24 hours, coal at 10 *s.* per ton.

Method of distillation.	Cost of coal for 24 hours.		
	£.	*s.*	*d.*
By direct condensation of the exhaust steam from the engines	3	2	6
The triple effect, using exhaust	2	4	0
The triple effect, using live steam	2	18	0
The sextuple effect, using live steam	2	8	0

While the second method is the most economical, it is not very much in excess of the fourth. Given a good water supply, ice made in this manner should be safe and satisfactory to use.

W. Everett Parsons, in 1900, made some tests of a special evaporator in single and triple effect where the evaporation was accomplished by live steam. In the single effect the pounds of water evaporated per pound of steam were 0.83 and 0.86. With a double effect the pounds of water evaporated per pound of steam were 1.48 and 1.50. Triple effect was 1.98, 1.98, 2.00. In another test a triple effect gave 1.98, 1.87, 1.97.

Steam pressure in the first coil was about 73 pounds.

Sterilization. — At a meeting of the American Society of Civil Engineers in London, July, 1900, a discussion on the subject of "The Filtration of Water for Public Use," took place, and Mr. Samuel Rideal of London said in part:

The speaker believes that the question of sterilizing water will soon become prominent, and that the removal of pathogenic organisms can be effected satisfactorily and economically by heat sterilizing. He used the term "heat sterilizing" (a somewhat misleading phrase) purposely, because he wished to accentuate before a body of engineers that it is not a question of heat sterilization at all, but a temperature condition. The organisms are killed when they reach a certain temperature and the maintenance of this condition does not necessarily involve the expenditure of any energy.

The problem of bringing a body of water to a high temperature, and keeping it at that temperature sufficiently long to insure the death of the organisms present, is one of the problems to which he believes it would be worth while for the engineers in this country and the States to pay special attention. The cost of bringing small quantities of water — perhaps 2 or 3 pints of water per head of the population, instead of the 65 or 75 gallons — to a temperature which will insure the killing off of the pathogenic organisms cannot be very large. By a proper system of incoming and out-

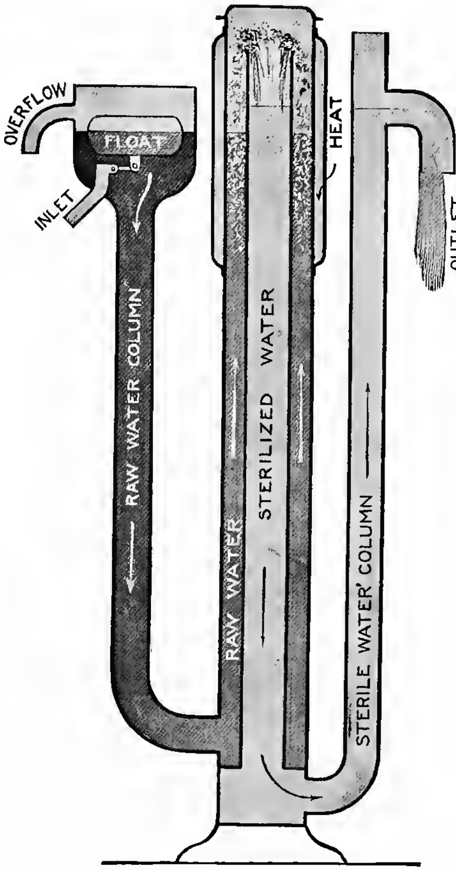


FIG. 55. — Sterilizer, Section.

coming of the water, and possibly by a vacuum jacket such as is used for maintaining a very low temperature, the expenditure of the heat or energy, either gas or electric heating, which would be required for bringing about such local sterilization for potable purposes would be very small indeed. Probably in the States, as well as in this country, legislation could be brought to bear in the same way that we now have by-laws for limiting the quantity of waste in flushing closets. In this way it would be possible for the municipalities to supply to every consumer a machine for producing sufficient sterilized water for potable purposes, while leaving the supplies and mains in their present condition.

By a simple contrivance, arranged by Mr. ——, two vertical currents of water are kept flowing past each other in contiguous passages, so that their heat is equalized by convection. The water upon reaching the top of one column is heated to the boiling point, and then, in descending, gradually imparts its heat to the water rising in the first column, and finally escapes with a temperature only from 2 to 5 degrees higher than the original temperature. The water is thus actually boiled, with a very small expenditure of heat, only enough to raise its temperature from 2 to 5 degrees.

Sterilization of Water by Heat. — Simple sterilization of water by heat, as distinguished from distillation and consisting in merely boiling water, is an ancient custom, but an absolutely sure method of bacterial destruction. Boiling by the ordinary method, however, can only be done on a small scale, is expensive in fuel, is troublesome and, moreover, the finished product is generally flat, insipid and unpalatable.

This method is distinctly not an "applicative" method, as are filtration, ozonization, the ultra-violet ray and the chemical methods already mentioned, and in this basic feature it is, therefore, superior to these other methods. The fundamental principle may be said to be "conditional" and consists in combining two immutable phenomena of nature in such a manner that the sterilization of the water and the act of its passage through the apparatus are inseparable and are effected by one and the same agent or condition,—heat and heat only.

The two natural phenomena used to accomplish this remarkable result are: gravity, which may be interpreted in this case by the statement that water seeks its own level and will not run up hill unless acted upon by some external force or agent, and ebullition, under which condition water will rise above its normal cold level and, therefore, run up hill.

There is a third element which, though vital from the economical standpoint, is not essential to the function of sterilizing, but rather a constructive feature. This element is the heat exchange whereby the heat of the hot outflowing sterilized water is imparted to the cold, raw inflowing water and thereby conserved and used over and over again.

Referring now to Fig. 55, which is purely diagrammatic, and here rendered to show in the most elemental manner the principle of operation, it will be seen that the raw water (dark) enters the float chamber through the raw water inlet. Passing down through the "raw water column" it enters the bottom of the heat exchange and rises in the same on the outside of central tube and stops by the closing of the float valve at a point far below the top of central tube. This float valve is not a function of the sterilization; it is a water economizer and it could be dispensed with entirely by allowing sufficient water to enter the chamber and continually overflow to waste, thus effectually maintaining a supply of raw water at a level below the top of the central tube.

The water is now heated by the jacket at the top of the heat exchange until ebullition takes place. In boiling the water rises and overflows into the central tube, much as a pot on a kitchen range boils over. In descending inside this central tube (light), the heat of the water is absorbed, through the walls of the tube, by the cold, raw water (dark) ascending on the outside, so that the sterilized water leaves the apparatus within a few degrees of the temperature of the cold, raw water entering, and the latter, having absorbed the heat of the outflowing water, reaches the point where ebullition is to take place nearly at the boiling point. The economy of this method is, therefore, evident, as there is but little heat leaving the sterilizer in the effluent water, and, generally speaking, it requires but one-eighth as much fuel as that required for boiling water in the ordinary way.

FIG. 56. — Sterilizer, General View.

Fig. 56 shows a type of sterilizer adapted for capacities up to 500 gallons per hour. The apparatus, as shown, is operated by low-pressure steam, about five pounds gage, though in specially constructed apparatus as low as $\frac{3}{4}$ pound pressure has been successfully used.

This type of apparatus will sterilize about five gallons of water for each pound weight of steam condensed in the heater and it will deliver the sterilized water at an increase in temperature of 12° F. above that of the entering raw water.

It has been found by eminent authorities, among whom may be mentioned Abbott, Reed, Sternberg, Firth, Janowski and others, that it is not necessary to actually boil water to destroy all the so-called water-borne pathogenic micro-organisms and that a temperature very much below the boiling point (212° F.) is sufficient to render the water absolutely safe. A momentary exposure of water to a temperature of 162° F. will invariably destroy all the water-borne pathogenic microörganisms and very much lower temperatures for longer periods of time will effect the same results.

For capacities of 1000 gallons per hour, and over, a somewhat different type of sterilizer is used.

In these larger sterilizers the phenomenon of expansion instead of ebullition is made use of to cause the water to rise and overflow the central tube; hence the apparatus requires considerable height in order to gain a satisfactory range of expansion.

Fig. 57 shows the general arrangement of a battery of two water sterilizers, expansion type. Each of these units has a capacity of about 250,000 gallons per day or a combined capacity of about half a million gallons. In this type of apparatus the heat consumption is very low and, roughly speaking, where the water is pumped the exhaust steam from the pump is sufficient to sterilize all the water being pumped.

In this type of apparatus the absolute certainty of steriliza-

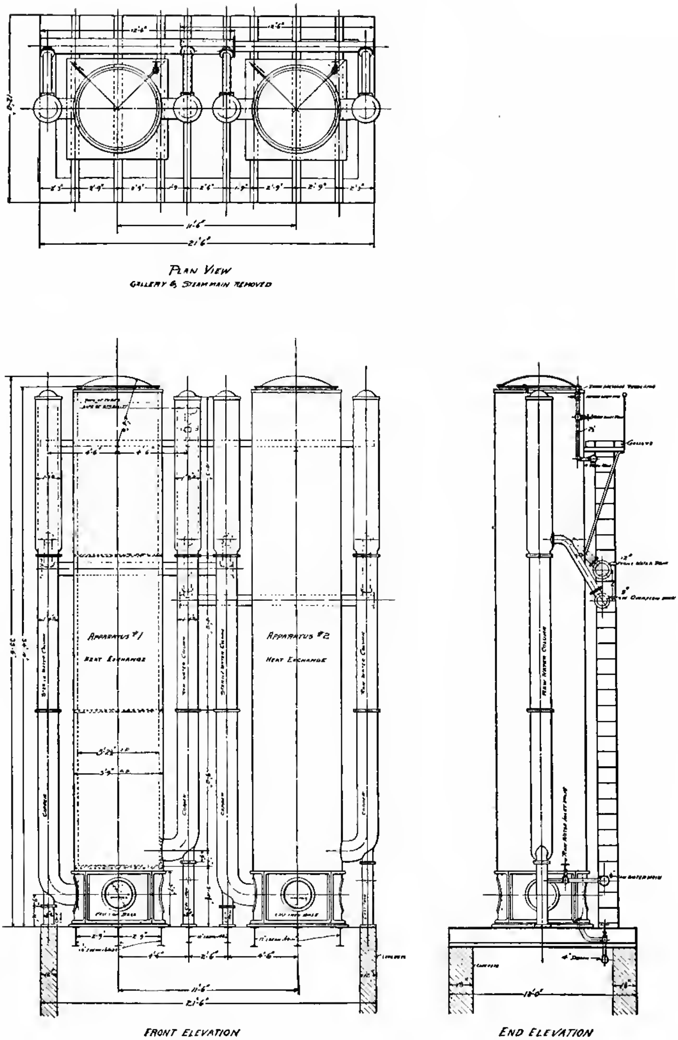


FIG. 57. — Sterilizer Arrangement, of Large Size.

tion is as positive as in the boiling type above described, for the tall column of water must necessarily attain a predetermined temperature in order to increase in length, by expansion, sufficiently to overflow the central tube or tubes. This type has the advantage of great economy in fuel, for there is no ebullition and consequently no steam is generated and therefore there is no loss in latent heat. Moreover, the thermal range being less than in the boiling type sterilizer, relatively less heat exchange surface is required, so that the proportional initial cost is less.

A surprising fact in connection with all these sterilizers is their freedom from scaling even with so-called extremely "hard" waters.

The sterilizer is so constructed that water has to run up hill to pass through the apparatus, and this can only be accomplished by the action of heat boiling the water.

Samuel Rideal, London, says: "Sand and mechanical filters in good condition, and under favorable circumstances, occasionally yield a sterile effluent; but such a result cannot be depended upon. At this date it is hardly necessary to refer to the large variety of filters formerly trusted, which have been proved by Plagge, Sims, Woodhead, Guinochet, Johnston and others to be quite inefficient in preventing the passage of bacteria, though they may render the water bright in appearance."

These filters are really worse than useless, as they form a cultivation bed for organisms of all kinds, including pathogenic forms, and sometimes actually increase their number. In verification of this it is only necessary to mention the fact that since the inauguration of such modern and up-to-date municipal filtration plants as those at Washington and Philadelphia more typhoid fever has prevailed in these cities than before.

Distilled water is conceded by many to be a very depleting agent of the human system — it cannot perform as much work as sterilized water.

Distilled Water. — One method of producing pure distilled water is that in which the apparatus introduces live steam into a closed tubular condenser at a pressure of from 50 to 100 pounds per square inch by gage, preferably the

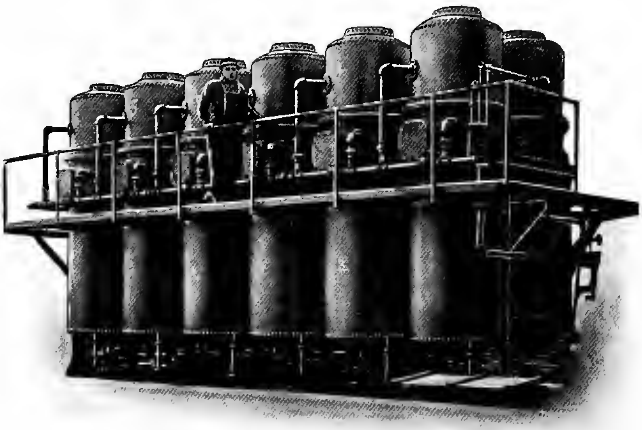


FIG. 58. — Ten-effect Water Distilling Apparatus.

higher pressure. The steam is condensed by means of a water jacket at a lower pressure than is maintained in the condenser itself — this condensation generates some steam in the jacket water. This steam is carried into the condenser of the next effect, and the process is again repeated and continued — a certain drop in pressure is automatically maintained between each pair of effects, by reinforcing heat to compensate for that lost by radiation, resulting in a high degree of economy.

The distilled water is drawn from the several condensers. With this device it is said to be possible to obtain as high as 10 gallons of water with one pound of coal burned. Water thus prepared is said to taste like spring water. The gases

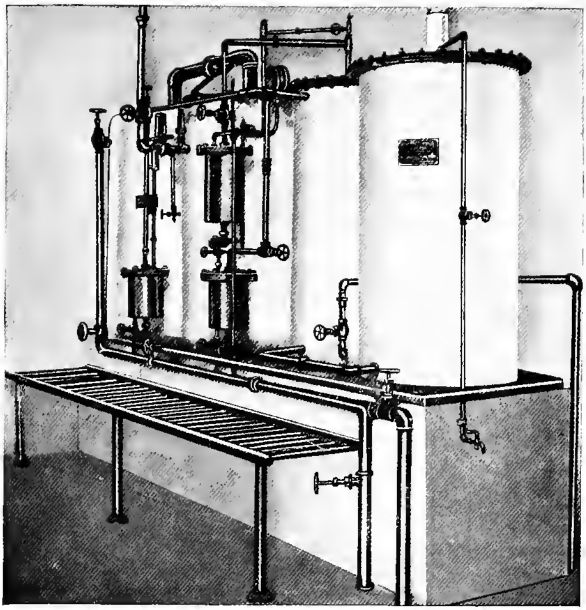


FIG. 59. — Two-effect Water Distilling Apparatus.

generated and contained in the steam not coming in contact with the water, the insipid or boiled water flavor is absent.

The remaining steam from the last condenser may be used at its reduced pressure to run engines, or for heating, cooking, laundry purposes, absorption ice machine, etc.

Equally good results are obtained from sea or alkaline waters.

Storage of Water. — Water when stored in closed tanks does not diminish perceptibly in quantity either by evaporation or sweating of the tank, or leakage, if the tank is taken care of, but when stored in open reservoirs, such as tanks formed on the tops of roofs as is done on some mills, in foreign countries at least, the loss by evaporation may amount to considerable.

The sunshine, as well as the wind velocity, is a very important factor in surface evaporation, as is also the blanket of invisible vapor which lies over water when the air is quiet and which in some cases is 30 feet thick.

Prof. F. H. Bigelow in writing of the Salton Sink and the rate of evaporation from the surface of the water, which some thought amounted to 8 feet in depth of water annually, says it may not be more than from 4 to 5 feet, based upon experiment. Other tests made later gave 6.70 feet.

Professor Bigelow gives five factors which are to be taken into account in studying surface evaporation. These are:

1. The diffusion factor — a function of the height above the surface of the water.

2. The temperature of the water and its capacity to deliver vapor — a function of its vapor pressure.

3. The capacity of the air to receive vapor — a function of the difference between the dry air and the dew point.

4. The velocity of the wind, the function being the square of the velocity.

5. The wind coefficient, being a function of the height above the ground.

The Loss of Water by Evaporation. Experiments conducted for 18 months in California, ending in June and July, 1904, gave a total evaporation from water surfaces at Tulare of 74.68 inches; at Pomona, of 66.92 inches; at Calexico, of 108.23 inches.

The following summary, which gives in brief the average results, confirms the records obtained from different parts of California, viz., that the amount of water evaporation is largely dependent on the temperature of the water.

WATER TEMPERATURE.

Fahr.	55.5°	62.0°	69.2°	80.1°	89.2°
Weekly evap.	0.42 in.	0.77 in.	1.54 in.	3.08 in.	3.92 in.

In connection with irrigation, these experiments have brought out the fact that surface flooding is most wasteful and the deep furrows conserve more water than do the shallow ones.

Observations made at Lee Bridge, England, with an average air temperature of 50.3° F., gave an annual evaporation of 20.75 inches.

Observations made at Chestnut Hill Reservoir, Boston, Mass., with an average temperature of 49° F., gave an annual surface evaporation of 39.12 inches.

The United States Geological Survey records the annual surface evaporation at Amarillo, Texas, 55.4 inches, and at Albuquerque, New Mexico, the average for 2 years was 82.9 inches per year.

CHAPTER VII.

DRINKING WATER — OPEN FILTERS — ALUM — CHLORIDE OF LIME — TANNIN.

DRINKING water, or water which enters into compounds afterward to be taken into the human system, comes to the individual in different ways and under different conditions of purity.

G. C. Whipple has given the qualities of a public water supply which most affect the ordinary consumer as:

1. Its sanitary quality; that is, its liability of infection with disease germs or substances deleterious to health.

2. Its attractiveness or lack of attractiveness, as a drinking water.

3. Its hardness, so far as this relates to the use of soap in the household.

4. Its temperature, so far as this relates to drinking.

Nature's way of treating water is either to send it as rain or to purify it by filtration, passing it through a portion of the earth's crust or over the sand and gravel of river courses.

Sand filters, as an engineering construction, were built, under the direction of Mr. James Kirkwood, as early as 1874, at Poughkeepsie and at Hudson, N. Y.

There are many forms of filters, probably no two being exactly alike in relative proportions or method of use. There are also two general methods of filtering water:

Slow sand filtration which has particular advantages for waters that are low in color and non-clay-bearing.

Rapid sand filtration which has advantages for waters highly colored and highly charged with particles of clay.

The cost of filtration by one method is about the same as by the other. In slow sand filtration the thickness of the sand bed should never be less than 12 inches, and usually be many feet in depth.

Good American practice for this type of filter is 3,000,000 gallons per acre per day of 24 hours.

With a mechanical filter of a rapid type, 120,000,000 gallons per acre per day has been accomplished in American practice, but this requires coarse sand.

Cost of Filtration. — At Albany, N. Y., slow sand filtration (1908–1909) costs $7.63 per million gallons. This includes washing the sand and returning it at an extra cost of $0.77 per million gallons.

At St. Louis, Mo. (1909–1910), the cost was $4.84 per 1,000,000 gallons, for clarification with iron sulphate and lime.

At Cincinnati, O., the cost of operating the filter plant for the first six months of 1909 was as follows:

Average cost of chemicals per million gallons of effluent, $1.99; average cost of coagulating and filtering per million gallons, $4.62.

0.9 grains of lime 1.95 grains sulphate of iron	per gallon or
2.06 ounces of lime 4.46 ounces sulphate of iron	per 1000 gallons.

Average amount of water filtered daily 41,258,440 gallons.

The cases of typhoid in the years 1904, 1905 and 1906 were respectively 872, 674 and 610, or a total of 2156; the deaths resulting therefrom were respectively 225, 126 and 112, or a total of 463, making (2156 : 463) 4.65 cases to one death.

At St. Louis, Mo., the costs of water treatment for the years 1904–1907 were as given in the following table:

	1904–05.	1905–06.	1906–07.
Average daily water consumption, gallon	79,052,000	69,000,000	70,109,000
Average quantities of iron and lime per gallon.			
Iron sulphate, grains	1.50	2.20	2.13
Lime, grains	6.00	6.28	7.39
Average cost of treatment per million gallons of water:			
Lime	$1.89	$1.74	$2.45
Iron sulphate	1.07	1.53	1.44
Labor	0.57	0.62	0.58
Power	0.07	0.09	0.07
Repairs	....	0.01	0.08
Total cost	$3.60	$3.99	$4.62

Slow sand filtering systems are used mainly for the supply of cities and towns of considerable size, while the rapid systems are the more readily adapted to factory and mill uses. The cost of installing mechanical filters is about 44 per cent of the cost of slow sand filters, and the cost of maintenance is given in one case as $8.50 per million gallons treated.

Sand Filtration of Water. — Water filtration at Harrisburg, Pa., where the Susquehanna River water is purified by mechanical filters, costs as follows: Chemicals, aluminum sulphate and calcium hypochlorite, per million gallons delivered to the pump, $1.06 for 1910; chemicals, $1.81 for 1908. The 1910 expenses per million gallons were: Coagulation, $1.06; supplies, 28 cents; repairs, 38 cents; coal, 63 cents; oil and waste, 7 cents; laboratory, 37 cents; and labor, $2.52 — the total operating expense per million gallons being $5.13. The bacterial efficiency was 99.94 per cent for the year, the raw water count averaging 78.42 per cubic centimeter, and filtered water 5. Turbidity was 29 parts per million.

The Belmont filters at Philadelphia operated during 1909 at an average rate of 2,790,000 gallons per acre daily at a cost of $3.23 per million gallons, which included 60 cents per million gallons for preliminary filtration and 31.6 cents for laboratory expenses. The preliminary filters reduced the turbidity nearly 53 per cent and the bacteria 60 per cent. The average length of runs using the Brooklyn method of cleaning was 40 days. Comparing the effluent from the Belmont filters with the Schuylkill River water the reduction in turbidity was 99.24 per cent and in bacteria 99.76 per cent.

The Upper Roxborough Filtration Plant at Philadelphia, comprising a sedimentation reservoir, 8 covered filter beds, and 8,000,000-gallon clear water basin, during 1909 purified an average of 2,437,000 gallons of water per acre daily at a cost of $3.18 per million gallons, including laboratory charges of 44 cents per million. Turbidity reduction from raw water was 99.74 per cent, bacteria reduction 99.92 per cent. Raw water from the Schuylkill River.

Cleanings were on an average of 8 per each filter per each year. Average time between scrapings 45 days. Three methods of washing were used: the scraping and ejecting method cost 49 cents per million gallons filtered; the Brooklyn method 28 cents; and the Nichols sand separator method cost 61 cents.

Engineer "Z" designs and builds gravity filters, open tanks, shown by Fig. 61, where the water inlet to the filter is controlled by means of a float, the valve to regulate the supply maintaining a uniform pressure above the water filter bed. Filtering material is graded and selected to meet the requirements of each individual case. The strainers are of the type shown by Fig. 60, described hereafter, and are screwed into manifolds in the bottom of the filter, which are so designed and arranged that each square foot of the filter carries the proper amount of water. When it is necessary to absolutely control the rate of filtration, the effluent is controlled by a regulating device which can be adjusted to any rate of flow required. These filters are built in units with a capacity ranging from 500 to 25,000 gallons per hour.

FIG. 60. — Filter Strainer. (Patented.)

The patented double cone brass strainer shown by Fig. 60 is considered by the makers a novelty, and to differ from all other strainers in the market in that it brings about an even distribution of the wash water in all parts of the filter. It is made up of an outer and inner cone and when in operation all of the openings in the outer and inner cone permit the water to flow through the strainer to its full capacity. In washing the filter the inner cone moves up, closing a certain number of openings to get a full pressure evenly distributed throughout the filter bed with a use of minimum quantity of wash water.

Straıners give no trouble in the ordinary operation of the filter, — that is, in allowing the filtered water to flow down through it, — but in the washing process a perfect distribution of the wash water at the proper pressure over all parts of the filter bed is essential for good results, though oftentimes it cannot be obtained.

This strainer was designed to overcome this difficulty, and stirring devices, slotted plates, wire screens and other devices are said to be unnecessary.

With the open type of filters, as well as with the pressure type, coagulation is often advisable and necessary.

FIG. 61. — Mechanical Gravity Filter.

Engineer "Z" has patented a valveless coagulant feed apparatus for either aluminum sulphate or iron sulphate, in which one adjustment provides the proper flow of coagulant solution for any variation in the rate of the flow of water into the coagulating basin. This device also starts and stops the flow of the solution as the flow of the raw

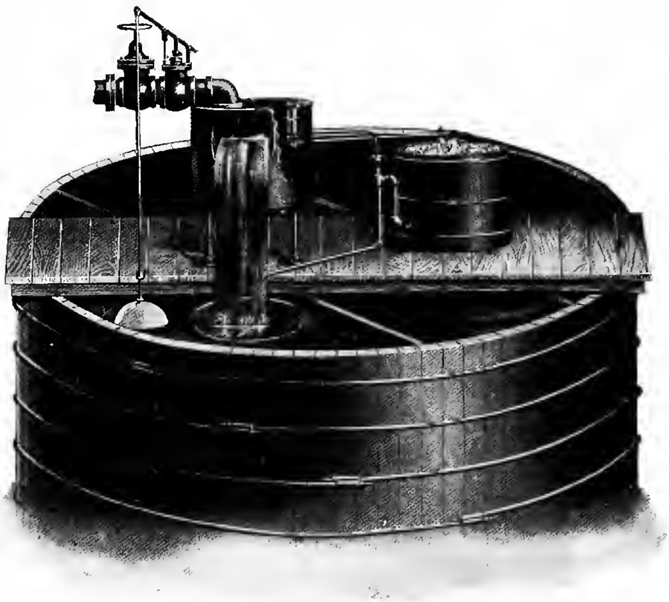


Fig. 62. — Coagulant Feeder. (Patented.)

water starts and stops. With this device the lump aluminum sulphate or commercial iron sulphate is placed directly into the feeding device without being previously dissolved. The device is shown in prospective by Fig. 62.

Another engineer builds a gravity filter which is clearly shown by Fig. 63, and which is also covered by patents. The tanks are made of wood, steel, concrete or masonry.

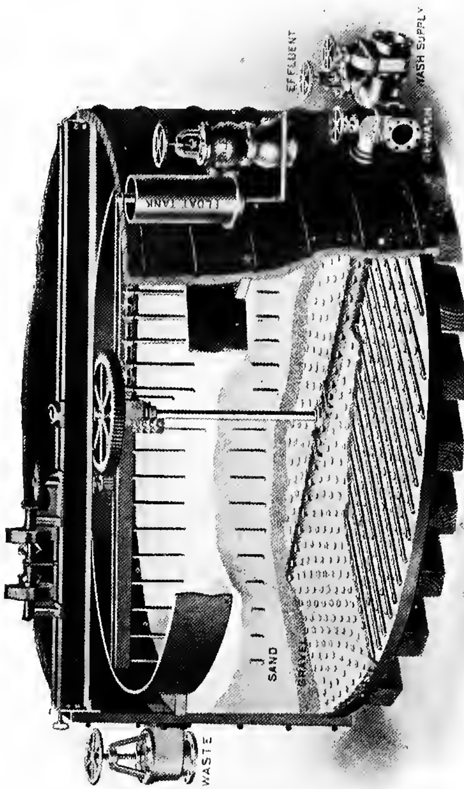


Fig. 63. — Open Tank Gravity Filter.

The agitating apparatus is so constructed that the rake bars automatically assume a perpendicular position by the action of the sand bed upon them during the washing process, so that they penetrate and break up the sand bed. During the filtering process these rake bars are automatically withdrawn so that their extremities rest upon the surface of the sand layer or filter bed. This automatic change in position of the bars is brought about by causing the agitating device to travel in one direction and then in the reverse direction. If the bars were allowed to remain perpendicularly within the sand layer during the filtering process, there would be a tendency for the filtered water to follow them through the sand bed and cause the formation of large channels through which the bulk of the water would flow and be improperly or only partially filtered.

This filter can also be built for washing the sand with or without mechanical agitation and with or without air agitation. It can also be arranged for cleaning in sections.

The following table will give some idea of the sizes and capacities in which open filters are built, more especially where wooden tanks are used.

Diameter.	Height.	Inlet and outlet pipes.	Waste pipes.	Capacity in U. S. gallons per			Approximate shipping weight in pounds.			Area, square feet.
				Minute.	Hour.	24 hours.	Tank.	Parts.	Filter bed.	
Ft.	Ft.	In.	In.							
6	7	3	6	57	3,420	82,000	1350	1,200	11,300	28.27
8	7	4	6	102	6,120	147,000	1750	2,250	20,000	50.26
10	7	4	8	160	9,600	230,000	2250	3,300	31,200	78.54
12	7	5	10	230	13,800	331,000	2800	5,500	45,200	113.10
14	7	6	10	314	18,840	452,000	3450	6,500	61,200	153.94
15	7	6	10	360	21,600	518,000	4000	8,300	70,400	176.71
17	7	8	12	463	27,780	667,000	4600	11,000	90,400	226.98

Capacities given are minimum for turbid waters and will be exceeded from 50 to 100 per cent in filtering waters carrying small quantities of sediment.

This engineer, as do also many other manufacturers, furnishes a variety of devices to be used in connection with filtration and purification. One of these is used for applying chemicals in predetermined quantities and in direct proportion to the volume of water delivered to and through the filters. Where reciprocating steam pumps are used for supplying the raw water to and through the filters, a pipe is led from the front and rear head from one water end of the pump to the top and bottom, respectively, of the motor end of the chemical pump, so that each stroke or revolution of the steam pump delivering water to the filter will cause a stroke of the chemical pump, the two working in unison at all times. To change the quantity of solution delivered, it is only necessary to increase or diminish the stroke of the chemical pump. Fig. 64 shows one of these pumps.

Fig. 64. — Chemical Pump.

In one instance, two of these pumps were installed — one for feeding sulphate of alumina as a coagulant and the other for soda ash. The raw water was so low in alkalinity that it would not decompose the quantity of sulphate of alumina required to clarify the water. It was therefore necessary to apply artificial alkalinity.

In other instances, the two pumps were installed for the two chemicals mentioned, so that the mineral contents of the water might be altered as little as possible by the application of sulphate of alumina and that any possibility of undecomposed coagulant being found in the filter might be avoided. Where purified water is used for dyeing and bleaching purposes the most careful regulation of the chemicals used is very important.

Filtration of Water. — Isaac Roberts, Proc. Liverpool Geol. Soc., 1868–9, gives these results of tests made on the flow of water, or rather filtration of water:

"The flow of water through a block of sandstone $10\frac{1}{2}$ inches thick was,

Under a pressure of......	10 lbs.	20 lbs.	46 lbs.
Imperial gallons per hour	4.50	7.50	19.00
Pounds of water..........	45	75	190.00
Through 4 in. of chalk under head of..........	2 ft.	6 ft. of water	
Imperial gal. per hr.......	0.428	1.138	
Pounds of water..........	4.28	11.38	

The water taken from the Bruges Canal at Schoore-Crugge is first filtered through beds of different kinds of sand and finally pumped through sterilizers, being there subjected to the influence of an electric current of 1000 volts.

The result of filtering Merrimac River water through ashes 48 inches deep gives an effluent which is clear and odorless, and the removal of organic matter equal to that accomplished with sand filters.

The advantages of slow sand filtration therefore are:

1. Great bacterial efficiency; 2, no chemical or other

agent is added to the water before or during the filtering process.

The disadvantages are:

(1) The very large space needed for the construction of the filter; (2) the cost of constructing these beds apart from the cost of ground on which they are built; (3) the fact that the turbidity is only partially removed and that stained or tinged waters are not improved in appearance; (4) the liability to breakage or disturbance of the "Schumtzdecke" or active filtering agency in the process; (5) the possibility that even with an undisturbed "Schmutzdecke" the cleaning of the filters will be too long delayed, and that the water will come from the effluent with a larger bacterial content than the affluent; (6) the inclination to force the beds beyond their capacity in time of scarcity or unusual consumption of water; (7) the certainty that if the "Schmutzdecke" is broken or cracked in a given filter bed the water from the bed will be contaminated and, if not removed at once, that the whole content of the storage reservoirs will be contaminated from the admixture.

Slow sand filtration for large municipal water supplies is always designed especially for the conditions which exist in those cities where they are placed. They are built both open to the outer air and with the reservoirs for the filtered water covered. Any number of examples could be given and illustrated, but they do not seem to the writer to come within the purpose for which this book was prepared.

In manufacturing plants frequent use is made of open gravity type filters which are properly equipped with hand-operated valves, where the water filters through the bed composed of fine pebbles, different grades of sand or crushed stone.

In tests made at Louisville, Ky.; Cincinnati, O.; Pittsburg, Pa.; Providence, R. I., and other places, the rapid or

American filters demonstrated conclusively that the rate of filtration to obtain the best results should not exceed 125,000,000 gallons per acre for 24 hours, which is equivalent to about 2 gallons per minute per square foot of affected filtration area. If this rate is exceeded, the quality of the filtered water will deteriorate and the filter will require cleansing at more frequent intervals; will also be more expensive in the consumption of wash water.

Cost Data of Sand Filtration Plants. — Cost data of Power-Plant Installation and Operation by W. H. Weston, in the *Engineering Magazine*, Jan., 1912:

The cost of open sand filtering plants approximates $0.85 to $1.25 per square foot of sand area.

Groined arch covering for filter costs from 27 to 40 cents, averaging 30 cents per square foot of sand area (including columns). The ordinary rate of filtration is 2,500,000 to 5,000,000 gallons per acre of sand area per 24 hours, according to the quality of the water. The average cost of scraping filtering sand per million gallons filtered is $1.50. The average cost of washing sand per cubic yard is 40 cents.

Sand. — One manufacturer in writing about the grade and quality of sand in both pressure and gravity filters says: "Filter sand should be practically pure quartz, containing not more than about 1½ per cent of calcium oxide, magnesium oxide, mica, slate, coal or other foreign mineral compounds measured collectively, nor more than ½ of 1 per cent of loam, clay or dust. The effective size of the sand should be from about 0.35 to 0.40 mm. and the uniformity coefficient not more than about 1.50. Filter sand weighs approximately 100 pounds per cubic foot."

Alum as a Disinfectant. — Prof. W. S. Mason, who opposed for a time the use of bleaching powder as a disinfectant in the purification of water, now favors its use.

He found that three one-hundredths of a grain of bleaching powder per United States gallon, measured as available chlorine, was sufficient to do good work, and to reduce the bacteria from a high figure to nearly zero.

Sterilized water has been badly affected by algæ. Copper sulphate is a good algicide, but is not considered a safe or efficient germicide, while lime serves the purpose much better.

In discussing the filtration of water supplies, *The Surveyor* (London) says: "It is obvious that well waters free from suspended matter and other waters of similar quality are often bacterially impure and therefore require sterilization without filtration, the filtration in such cases being practically useless. We have often urged the importance of removing the matters in suspension from water, and even from sewage effluents, before applying the sterilizing agent which otherwise is wasted in dealing with the organic matter. There can be no question as to the relative values of filtration and sterilization. There is no comparison. One might as well compare the relative value of pumping and filtration. Matters in suspension must be removed by sedimentation or filtration and cannot be removed by sterilization; to suggest such a process is absurd, but, on the other hand, if the filters are used for their legitimate purpose, viz., for the removal of suspended matters and not for the removal of bacteria, their rate of working may be greatly increased and the bacterial purification can then be best effected by sterilization.

"Coagulation by means of alum, in mechanical filtration, causes some of the carbonate of lime to change to sulphate of lime, setting free carbonic acid which causes corrosion of the metal of boilers, though it can be obviated by the use of a good protective coating on the metal. The sulphate of lime in steam boilers results in a scale which attaches itself to the shell and boiler surfaces much more firmly than does calcium carbonate."

The Journal of the American Medical Association, Jan. 19, 1901, says:

"The efficiency of the sand bed depends on a slow and regulated filtration; that of the mechanical filter on the addition of alum to the water to clarify it. Carbonates in the water decompose the alum, precipitating the gelatinous aluminum hydrate which entangles the clay and other particles constituting the turbidity, together with any bacteria which may be present. These are strained off by the passage of the water through the mechanical filter. It is the alum — not the filtration — which is actively concerned in the removal of the bacteria. Experiments of the engineer department on turbid Potomac River water have shown that purification without alum can be accomplished with slow sand bed filtration."

From a government report on filtration of water for Washington, D. C., it will be seen from the record of the work of the mechanical filter that the essential to its efficiency is the addition of alum to the water prior to its passage through the filtering medium. Without the alum or other coagulant the mechanical filter would have been merely a coarse strainer. The amount of alum to be added varied with the condition of the river water. Alum, when added in proper quantities to a turbid surface water, is decomposed. A white gelatinous hydrate of alumina is precipitated, which in subsiding carries with it the clay and other suspended particles constituting the turbidity. The ability of alum to clarify turbid waters was known for many years before it was applied commercially in connection with rapid filtration. The gelatinous aluminum hydrate with the particulate substances (bacteria included) present in the water was removed by the subsequent filtration. The soluble sulphates formed during the decomposition of the alum in the water do not interfere with the potability of the latter, although they may detract from its softness. An excess of alum remaining in the water would be exceedingly injurious but the addition in actual practice could, under expert supervision, easily be regulated.

In the fall of 1908 George A. Johnson introduced the chloride of lime or hydrochlorite treatment at the water works in the Chicago Stock Yards, where the cost of 1⅓ cents per pound — a merely nominal figure — permits increasing rate of filtration and reduces clogging of filter beds.

Johnson says: "It is a fact that there has been no chemical test yet devised which is capable of identifying the presence of free chlorine in an alkaline solution, such as water is."

The action of the chloride of lime is germicidal, common solution is ½ per cent strength, that is, one pound of bleaching powder, which is chloride of lime, to 200 pounds of water, but 4 or 5 per cent solutions may be made and be effective. The above causes a sludge where hypochlorite of soda produced by electrolysis does not do so.

Concrete tanks are to be preferred to iron tanks for storage of such water after treatment. Calcium hypochlorite does not remove all bacteria, turbidity, color, swamp tastes, or odors. It hardens the water a little but at the same time it is a valuable adjunct to filtration.

Use of Tannin in Boilers. — In April, 1886, there appeared a note in the Journal of Railway Appliances regarding the use of tannin, speaking of it as a vegetable astringent found in greatest strength in the sap or juice of an East India tree and in our sumac. The leaves of many trees and plants contain considerable tannin, but the bark of hemlock and oak is the main reliance where cost is to be considered.

The correspondent's observation of the working of compatible compounds of tannin is that no corrosion of the iron, brass, or packing results, and its action on the skin, mouth or eye of a person is simply astringent. He has observed in repeated instances that, after a week or two from its introduction into a badly scaled boiler, the quantity of scale reduced to a soft or mud state was so great as to induce foam, but never until the strength of the tannin was expanded in reducing the scale.

In 1910, in *The Engineer*, London, there appeared a note on corrosion of iron, from a brewer, who gave these facts:

1. Iron tanks in which spent hops had been boiled for two or three hours are rendered immune to rust, owing to the tannic acid of the hops combining with the iron and forming an impermeable coating of ferric tannate.

2. Iron spanners and fittings used in connection with pumps situated near the hop boilers and constantly damp with steam seemed also to be more or less immune, though whether this be due to the constant handling or to the cleaning is not very clear.

3. Steel joists situated in the fermenting rooms where CO_2 is constantly present are certainly more prone to corrosion than those in other parts of a brewery, which fact seems to support the theory that carbonic acid has some connection with the trouble.

Tannin is obtained from such vegetable sources as sumac, gallnuts, tan bark, leather scraps, etc. The objection to it in boilers has been that it attacks iron and is somewhat expensive compared with the cost of soda or lime.

The action of tannin is that the tannate of lime and magnesia form a light flocculent and amorphous precipitant which remains in suspension in the water, or is deposited as a loose mushy mass in that part of the boiler where the circulation is the weakest.

CHAPTER VIII.

MEASUREMENT OF WATER.

Measurement of Water. — We are all accustomed more or less to the use of water meters for measuring the flow of water. At least we are acquainted with the type in which a disk or wheel is located in the water and is revolved by the water when it moves through the pipe, indicating the quantity on dials much in the same manner as the ordinary gas meter registers.

These meters are used in large numbers for measurement of cold water in city supply systems. They are also used for hot water, when constructed for high temperature measurement, but they have not proved as successful or reliable for hot water as for cold, though by careful calibration they may be and are so used with a minimum amount of error.

For the weighing of large volumes of water or other liquids besides water, which would give trouble in the disk meters, there have been devised machines in which automatic weighing, disposing, refilling and registering are accomplished with any degree of temperature of the water, and, as before suggested, for any other liquid than water, these machines have found a field all their own which they fill with satisfaction.

Another type of machine which generally weighs, but has not been built for a definite amount of water in the machine has been used with considerable success, for example, automatic weighing devices have been built having a weighing scale for water which is self-recording and self-testing in accuracy, for it is not necessary to draw off the water to weigh it, as it can be weighed in the usual way if such a check is desired.

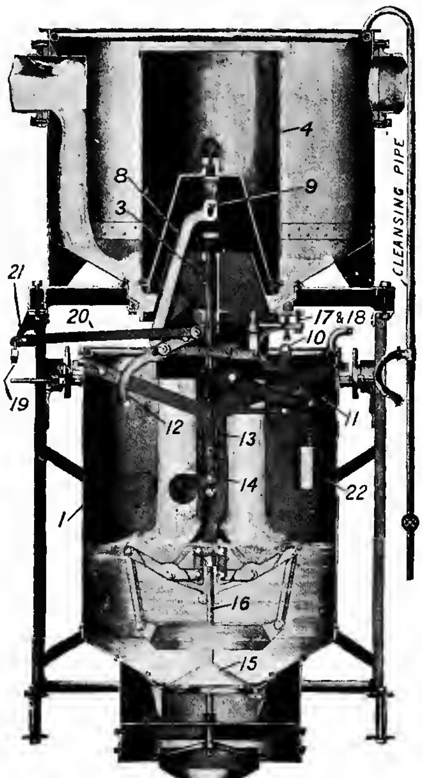


FIG. 65.—Automatic Liquid Scale.

This machine, illustrated by Fig. 65, will accurately weigh not only water, but other hot juices, oils and practically all liquids. The machine consists of braced angle iron framework supporting a galvanized-iron feed tank which receives the water to be weighed.

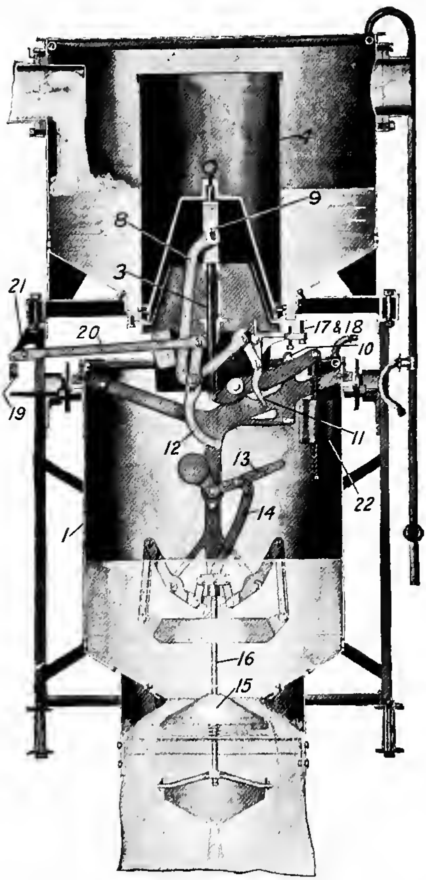


FIG. 66. — Automatic Liquid Scale.

An equal-armed cast-steel weigh beam is carried on steel bearings bolted to the upright channels of the framework.

This beam, which is scientifically constructed and very sensitive to weights, supports on one arm a tank and on the other the weights to balance the amount of liquid to be weighed. When they balance correctly one is loaded with the proper amount of water or other liquid and the other with the amount of weight to be recorded. It is continuously reliable no matter what the density of the liquid may be.

The valve joints are made of billiard cushion rubber reinforced with canvas. The actual feed valve is of cast iron and bell-shaped, and has its seat on a rubber ring. The discharge valve is a circular cone made of brass, and is self-sealing.

The working levers are all made of cast phosphor bronze which is proof against rust. All bolts and cotters are made of brass. No springs are used except as shock absorbers. All motions are positive, being entirely operated by weight. The reciprocating register counts and indicates every discharge of the scale.

The operation of the scale is as follows: As the tank fills, it gradually descends, and when about seven-eighths full its further descent is arrested by a trigger linkage. When the scale has received a load equal to the weights in the weight box, the tank end of the beam once more descends and, on reaching the balance position, cuts off the supply. In doing so, through special mechanism, the pressure of the liquid comes on the cone valve and, a dead center connection of lever being broken, the outlet valve opens. After the liquid has run out, the lower valve closes and is locked in place, which locking again upsets the dead centers and allows the inlet valve to open.

The mechanism of this scale really consists of two combinations of dead centers by which it is evident that at no time are the supply and discharge valve open together.

It is also possible to complete a weighing without discharging it, the scale remaining balancing, so that its accuracy can readily be seen.

Another device for weighing water is that shown by Fig. 67, which is constructed on the even-armed beam principle, with a weight box at one end of the beam in which

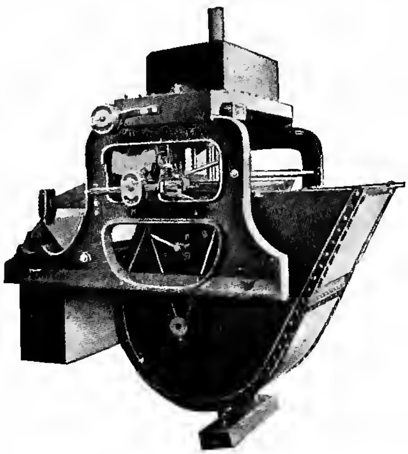


FIG. 67.—A Tipping Weigher for Water.

standard United States weights are placed, and a weight hopper at the other end for receiving the water which is to be weighed. When the box and hopper are empty one exactly balances the other, so that it will be obvious that if the weight hopper end of the beam balances the weight box, when same has the desired quantity of dead weights in the weight box, that the exact amount of water is in the weight box. The weight hopper is built on the tipping principle, doing away with the necessity of a valve to release the water. The passage of the water to the weight hopper is controlled with a suitable valve with the necessary operating mechanism. The valve in the present instance is of the balanced type, built for taking care of water at a high pressure — as high as 125 pounds per square inch — and also as high a temperature as 220° F. While the balanced valve is opened and delivering water to the weight hopper, the same is prevented from discharging by means of a suitable trigger, which is released when the exact amount of water is in the hopper, and drops, causing a toggle joint to lock while a projection on the end of one of the toggle joints releases the trigger, which has prevented the hopper from discharging, and the same tips over. While the weight hopper is discharging, the above-mentioned toggle joints, which have become locked, prevent the inlet valve from being opened. As soon as the water is out of the weight hopper, a weight returns the same to its original position, and in its travel a peg on the hopper liberates the toggle joint which has been keeping the inlet valve closed. This allows a spring, which has been compressed by means of the dead weights in the weight box, to open itself and, by means of suitable levers, to open up the inlet valve. The machine will keep on repeating its operation as long as desired and will regulate itself to the rate at which the water is to be fed up to its rated capacity. The scale can be stopped at any moment, to ascertain whether it is weighing correctly, by simply pushing in a bolt.

Another machine, called the water weigher, which operates by weighing or measuring and then automatically releasing each measured charge by means of a water column of standard height, is built. It is not affected by air in the water, nor temperature of the same.

The only removable part of this apparatus is the standpipe shown in Fig. 68. Water comes in through the inlet pipe, when the standpipe is down on its seat, and fills the upper compartment until it flows over the standpipe and down the inside of it to the bottom edge of the bell-float, which it seals, when it rises, allowing the water to pour down to the

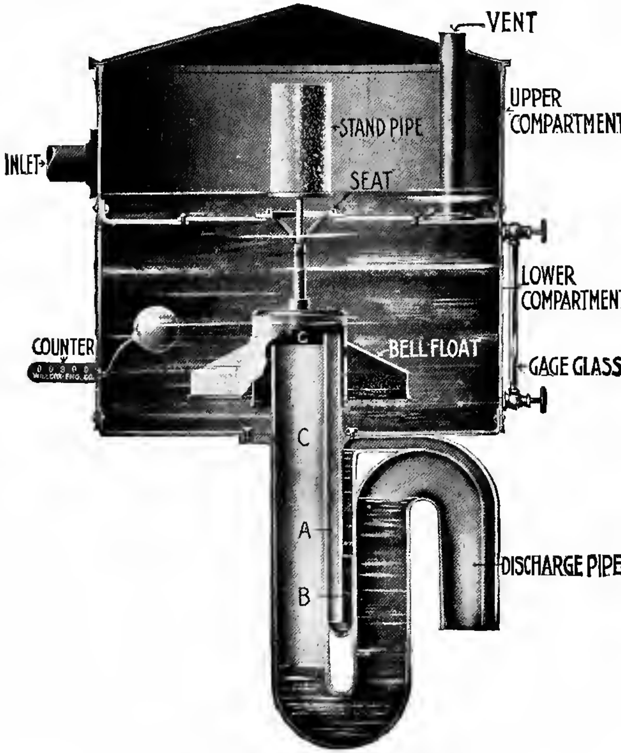


FIG. 68. — Automatic Water Weigher.

lower compartment, filling it until the proper measure of water is reached, when it is again released and pours down to the goose-neck discharge pipe.

A counter is provided for registering the number of trips

made by the weigher. There is also a gage glass and air vent. The last release of the water is accomplished by means of air compressure in the last compartments of the water and a "trip pipe" U-tube, normally water sealed, but automatically unsealing itself.

These machines are built to measure as large an amount of water as 500,000 pounds per hour, and one machine, in constant use for four months, and tested frequently, showed an error of less than one-fourth of one per cent.

Another type of weigher is that shown by the colored plate facing this page. It will be seen that this weigher comprises a tank divided into two compartments by means of a partition. A siphon in each compartment discharges the water when the full unit charge has been received. A small portion of the water leaving the inlet is stored in a tipping box just above the compartments, while the greater portion passes to one of the compartments below. When the compartment receives the desired quantity of water, a float automatically tilts the tipping box, spilling the previously stored water into the compartment, thereby completing the charge and flushing the siphon which discharges the unit charge. At the same time the supply is instantly shifted to the opposite compartment, where a similar operation is repeated.

A mechanically operated counter registers each double charge and is so arranged that it cannot be meddled with during the operation of weighing, or by anyone not authorized to do so.

These machines may be built up to a capacity of 1,000,000 pounds of water per hour. In the smaller sizes they are built of copper or galvanized iron, and in the larger sizes of steel plate and cast iron.

Another device which is shown by Fig. 69, and which is used for the measurement of water or other liquids, takes advantage of the reliability of weir measurements, using the V notch for passing the water over and, by means of a spindle and float fitted with a proper recording drum and apparatus, the flow of water is determined. This instrument will not measure a definite amount of water and discharge it, but is used for measuring water in motion.

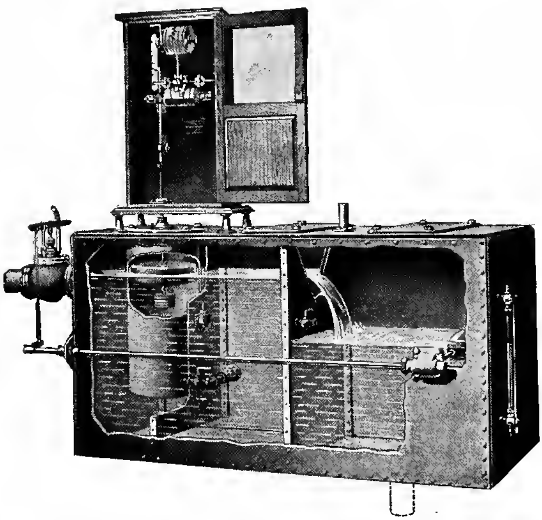


FIG. 69. — Water Weir Measuring Device.

This apparatus has been found of use in measuring corrosive liquids. No doubt the reliability of the apparatus will continue with use, but the notch should be kept perfectly clean. This would have to be specially guarded against when handling corrosive liquids, and in the case of water the notch should be made of non-corrosive metal.

To give an idea of the capacity of the notches we give here a table of flow through 90-degree V notches. This table is deduced from Thomson's Formula: Cubic feet per minute = $0.305\ H^2 \sqrt{H}$ where H = depth in inches.

Depth in notch.	Flow per hour.	Depth in notch.	Flow per hour.
Inches.	Pounds.	Inches.	Pounds.
1	1,140	9	277,960
2	6,480	10	361,740
3	17,830	11	459,030
4	36,610	12	568,720
5	63,940	13	694,710
6	100,860	14	836,110
7	148,290	15	993,510
8	207,060		

One of the uses to which a tilting steam trap can be put is the measurement of water and metering hot water, a condition which has been most difficult to meet satisfactorily. This trap provided with a counter to record the number of trips and a proper weighing of the water discharged at one tipping gives all the information necessary with a reasonable degree of clearness. This amount is measured and recorded by the maker and can be checked by the user.

The trap shown in Fig. 70 measures the condensation from 1208 square feet of radiation and discharges the water into the main return line to the boiler room.

A meter which contains no moving parts to come in contact with the flowing water is the Venturi meter designed and patented by Mr. Clemens Herschel, in 1887, and further improved by the present makers.

This meter, shown by Figs. 71, 72, and 73, consists of the combination of a peculiar tapering contracting pipe and an instrument with three dials for showing the total gallons which have flowed and the instantaneous rate of flow and for

FIG. 70.—Tilt Trap.

recording the previous rate of flow upon chart paper. Sometimes a simpler recording instrument having one or two dials is used instead of the above.

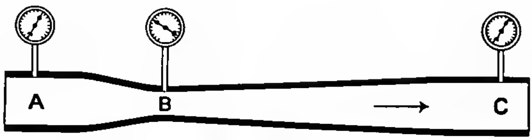


FIG. 71. — The Principle.

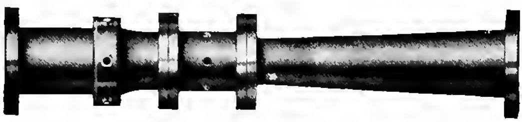


FIG. 72. — The Meter Tube.

The operation of this meter depends upon the fact that the difference between the throat pressure and the inlet pressure in a contracting pipe like the Venturi meter varies almost exactly as the square of the velocity.

The absence of all mechanism adapts these meters to the measurement of hot water, sewage, brine, etc., as well as to the measurement of the entire supplies to cities. They are also used extensively for measuring hot feed-water to boilers. The usual sizes for this service range from 2 inches to 12 inches in diameter.

This type of meter, not being specially susceptible to cold, can be used in very many localities where meters having moving parts refuse to work. In 1909 the largest meters of this type in the world were two 120-inch diameter tubes, registering up to 625 cubic feet per minute or 404,000,000 gallons in 24 hours, at the Divi Island Pumping Plant, Madras, India. These have been in use for four years for measuring irrigation water.*

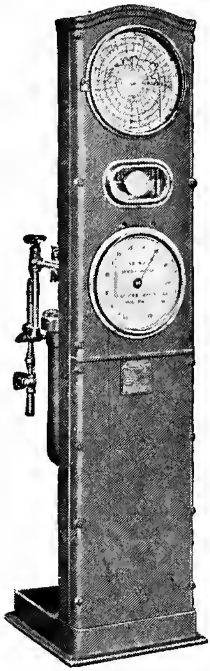


Fig. 73. — Venturi Recording Apparatus.

Three meters as large as 17 feet 6 inches in diameter have been installed on the new Catskill Aqueduct for New York City.†

* *Engineering News*, Nov. 25, 1909.
† *Engineering Record*, January, 20, 1912.

CHAPTER IX.

OIL IN BOILER WATER

Mr. D. B. Morrison,* in a paper on "Boiler Furnaces and the Effect of Oil on Their Ultimate Strength," read before the North-East Coast Institution of Engineers and Shipbuilders of England, said: "If the surface in the furnace of a boiler for, say, 200 pounds pressure, were clean, the temperature of the metal would never reach the point at which the original tensile strength would be appreciably reduced, even under very high rates of evaporation. If, however, the surface were simply rubbed over with a thin coating of heavy oil, the temperature would at once rise to over 650 degrees, even with a moderate rate of evaporation." Herein lies a fact which would help to explain the mysterious collapse of apparently clean boilers, and also the collapse of boilers which are not quite clean.

The furnaces of a passenger steamer which collapsed in mid-ocean show where any boilers, which were apparently clean, with no appreciable amount of scale on any part of them had trouble, which was caused by the use of a very inferior oil for swabbing the rods and lubricating the pistons and valve rods of the auxiliary engines. The oil was emulsified with the feed-water and therefore unfilterable, passed into the boilers and was deposited on the metal.

The use of oil in boilers to loosen scale is a positive detriment. If oil must be used in a boiler a mineral oil should always be used as an animal oil will start corrosion by the production of fatty acids in the boiler water.

* *Electrical World and Engineer,* May 13, 1905.

There have been a number of devices built for removing oil from water and keeping oil out of boilers, some of which are here described.

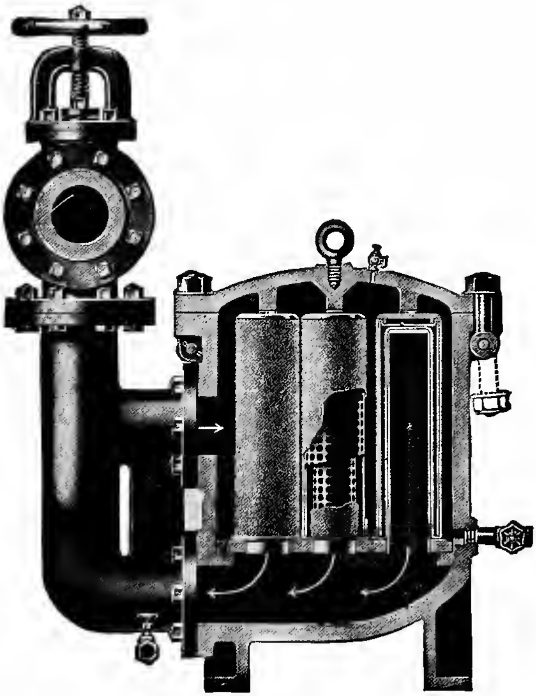


FIG. 74. — Oil Filter.

Another apparatus known as a feed-water filter and grease extractor employs double filtration by passing the water through two separate thicknesses of linen terry or other cloth. The water surrounds the double cartridges and runs through the perforation to the inside of them and then into the discharge pipe.

A by-pass arrangement provides for the flow of the water while new cartridges are being placed in position. Pressure gages show, by the difference in their readings, when the cloths are too heavily saturated or coated with sediment to be continued in use, while a water relief-valve prevents an excessive pressure in the discharge line from pump.

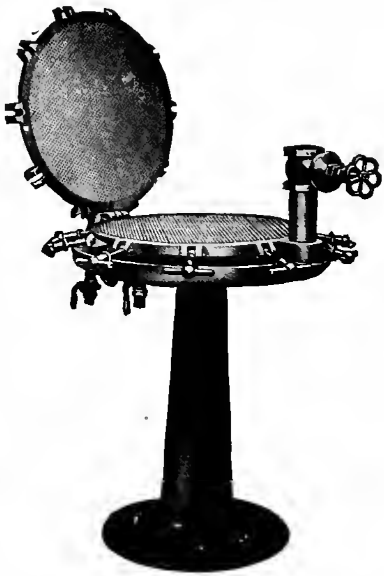


Fig. 75. — Oil Filter.

Fig. 75 shows a filter which consists of two shells bolted together, hinged and fastened with swivel bolts. Outside of these shells is a rim or gutter to catch any leakage or overflow on opening the case. The filtering medium laid over the frame between these two shells is compressed pure cloth fiber, free from chemicals, which, when it becomes clogged to the point of uselessness, can be thrown away and a new cloth put in its place. These filters are built from $\frac{3}{4}$-inch pipe sizes up to and including 3-inch pipe connections.

In order that filters may not be too large and cumbersome, especially for marine work, some filters have been designed to take the place of the large boxes filled with hay,

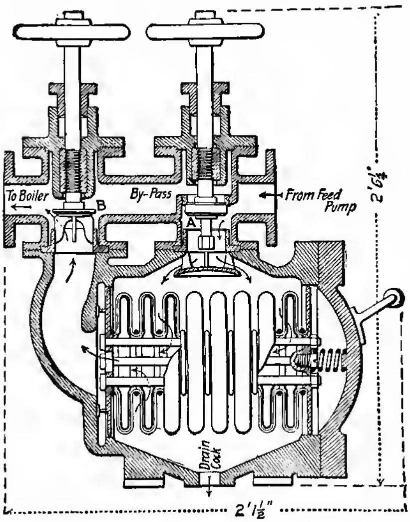


Fig. 76. — Oil Filter.

straw, or excelsior with baffle plates in them, as is the custom in marine work even to-day.

Fig. 76 shows a filter of Terry cloth placed over a number of spiders, which gives a large area of filtering surface. To put new cloths in place, the valves are turned so that the water does not enter the filter compartment, while the head is removed and a spider previously prepared is put in place of the clogged one. Then the head is replaced and the valves turned so that the water passes through the filter cloths again. While it is running with a new spider, the one that has just been taken out can be cleaned for use at any time.

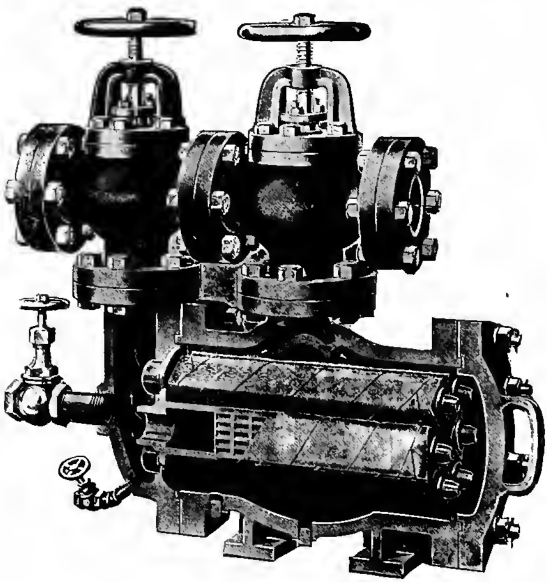


Fig. 77. — Oil Filter.

Fig. 77 shows a filter valve in which we have a filtering compartment containing more than one cloth or spider. Pressure gages on inlet and outlet of these filters show by their increasing difference in pressure just when the filtering medium is becoming too much clogged to be used any further, unless we desire to do so at a great expense of pumping.

Anderson gives the following approximate analyses of the deposit from the cloths of a marine feed-water filter:

	Per cent.
Mineral oil	62
Free fatty acid	22
Combined fatty acid	12
Mineral matter, etc	4
Total	100

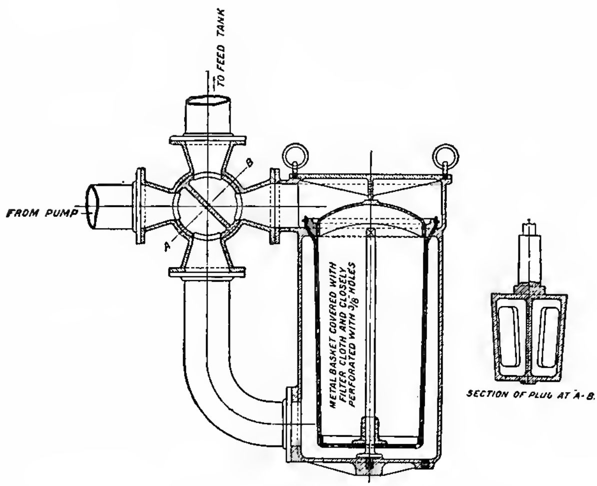


Fig. 78. — Strainer.

A. B. Willets, U. S. N., says that the most rational order of procedure for preventing oil accumulations in boilers is as follows:

To minimize the oil used in the cylinders and on the piston rods at the stuffing boxes; to extract as much oil as possible from the exhaust steam before it reaches the condensers; to extract oil from the condensed water passing from the condensers to the feed tanks; to extract it from the water in the feed tanks by passing it through filtering materials, and to extract it from the feed-water passing from the tanks to the boilers.

A strainer used in the navy consists of a 4-way valve, a metal basket covered with filter cloth, the basket punched full of $\frac{3}{8}$-inch holes, and made so as to be easily removable and have a surface thirty times the area of the delivery pipe. This is shown by Fig. 78.

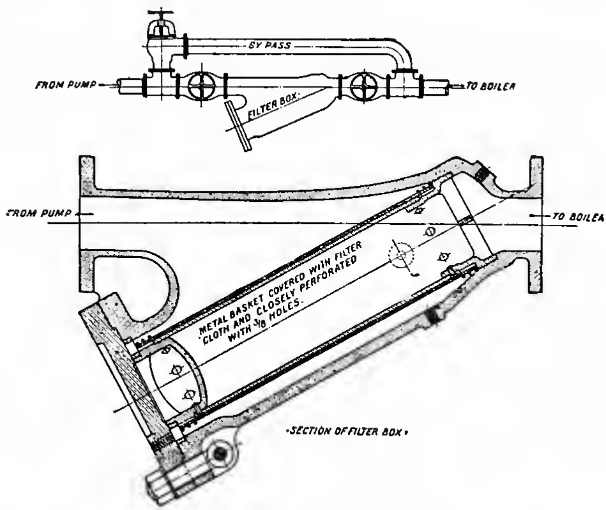


FIG. 79. — Oil Extractor.

By turning the valve $\frac{1}{4}$ or 90 degrees the water is by-passed and the strainer can be removed and a clean basket inserted. One of the principal troubles of the open filter box, filled with excelsior, hay or straw, is that the proper attention is not given it to keep it clean, and, of course, the oil goes over to the boilers, making trouble.

Another oil extractor is that shown by Fig. 79. This, however, requires three valves to by-pass the water. A metal shell covered with filter cloth and punched full of $\frac{3}{8}$-inch holes does the work, the water from pumps being outside of the shell and, after filtering to the inside, goes to the boilers or other uses.

Chemical methods are supposed to be the only absolute ways of removing the oil and are not nearly as flexible as the mechanical methods.

Do not allow any oil to get in your boilers. Oil should not be fed to boilers for boiler troubles, as is done by many at the present time. Animal oils are particularly bad, and are often found as an adulterant in mineral cylinder lubricating oil.

An experience with a tramp steamer may profitably be recalled. Mr. William Henderson, its second engineer, writes of an accident attributed to oil, which seemed strange, as free oil had never been found below the water line in the boilers. Oil has been found absorbed by carbonate of lime and settled as a loose sludge. The oil used was of a poor quality, and caused the high pressure piston rings to be ground away. Impure residues were found in comparatively large quantities in the cylinders and valve casings, so that but little could have gone in the boilers. The accident would never have happened if the surface condenser had not had so many leaky tubes.

Paraffin oil rubbed into the clean metals of the boiler resulted in any scale formations being readily lifted from the shell in sheets. The above suggests for steamship boiler managers these rules for preventing scale:

1. Filtering all water. 2. Evaporator should be fitted. 3. Heating of feed-water. 4. Adoption of a water circulating device. 5. Moderate use of soda. 6. Use of zinc plates.

A coaster between London and Goode took boiler water from the Thames, containing lime and organic matter, which we would expect to form a hard scale. In London boiler and tank were filled up, and after one month $\frac{1}{8}$ inch of hard scale which was difficult to remove was found. Both carbonate of soda and sal-ammoniac were used with good results. The latter at temperatures of boiling water readily dissolves carbonate of lime, and the soluble carbonic acid should decompose the sulphate of lime present.

Result: Water surface was kept clear, while precipitate then found gave a soft scale which could easily be removed.

Never feed water to the boiler at a low temperature, for it strains all of the seams in the neighborhood of its entrance, and, by coming in on old scale formation, it has been known to cause foaming. There is also an economy in heating the feed-water, which amounts to 1 per cent for approximately every 10 degrees of temperature the feed-water is raised. This, of course, will be a much larger saving in winter than in summer, if the natural supply is from the earth, pond or river.

In some steam plants boilers are fed with water from varying sources, which is very bad practice and precludes and prevents any satisfactory diagnosis being made of boiler troubles, their causes or a satisfactory remedy. Sometimes a raw river water is more satisfactory for boiler feeding than the filtered water, as with the river water at Pittsburg, Pa., but here is a case just the reverse.

The water of the Rio Grande River at Laredo, Texas, is filtered in a special manner by passing water over and through sand and gravel, and through a rock tunnel under the river to the receiving basin at the pumping station.

Various analyses have given about 36 grains of solids per United States gallon.

Analysis of the filtered water gave:

	Grains per gallon.
Incrusting solids	21.74
Non-incrusting solids	14.39
Total	36.13
Calcium carbonate	7.17
Calcium sulphate	6.25
Sodium sulphate	3.32
Sodium chloride	11.07
Magnesium sulphate	5.41

In steam boilers the filtered water was more satisfactory than the raw river water, which for a considerable part of the year contains about 555 grains per United States gallon of sand, clay and silt.

Some waters when treated for city or town supplies are hardened and made more corrosive, while they are made perfect for drinking purposes. Then they are not only more unfit for steam-making purposes, but they likewise require the use of much more soap in the work of the laundry, and cause a much shorter life of plumbing and heating iron and steel material.

Steam Boiler Waters. — In order that the life of steam boilers may be lengthened as much as possible and the economy of coal be kept at a maximum, it is necessary that pure water be supplied to them. Pure in the sense of having little or no incrusting solids in the water that will crystallize out by the heat from the furnace, and as little as possible of the non-incrusting solids or such as would form sludge on the bottom surfaces or by their concentration later cause foaming.

The higher the pressure carried in the steam boiler, the more difficult will this water problem become, and the more will be the trouble caused by scale and corrosion.

At the higher temperatures corresponding to the higher steam pressures the hardest scale-forming substances will crystallize out and form a hard scale on the metal of the boiler, while at the lower temperatures corresponding to the lower steam pressures some of these same substances will remain in solution and cause no trouble.

Booth says "priming" is apt to be more severe with low-pressure than with high-pressure boilers. Incrusting or scaling of boilers and tubes is troublesome, because the heat transmission is lessened and rate of evaporation also reduced, and the scale is liable to cause burning or bagging of the sheets. These scale formations are of various thicknesses and likely to be the hardest and thickest where the greatest heat strikes the metal.

Removing incrusting solids by softening or changing the compounds in which they occur and breaking up the scale by heat and chemical action combined are the usual methods of overcoming the difficulties, but one of the troubles of the softening process is that the non-incrusting solids are materially increased and may cause foaming, a dangerous condition in the boilers. Where the softening process is given ample time for sedimentation this condition will not exist.

In connection with the use of softened water in locomotive boilers, Mr. B. A. Ludgate, Pittsburg and Lake Erie railroad, gives the following notes concerning foaming in locomotive boilers and the use of the whole or part of the recommended formula for softening:

Water treated with 100 per cent of formula..	Much foaming. Not so much from raw as from treated water.
Water treated with 25 per cent of formula...	In 3 weeks much trouble — leaky tubes in fire box — no foaming.
Water treated with 50 per cent of formula...	For 5 months, less leaks, no foaming.

In some plants there is much trouble from corrosion. This water trouble is a very serious one, for it can work its way in concealment and often proves disastrous before one is aware of its operations.

This can be caused by the water being too pure, as, for example, condensed steam purified of oil and filtered and refed to the boiler, and neglecting to blow off the boiler at short enough intervals.

Magnesium chloride and magnesium sulphate with sodium chloride are corrosive agents and are not to be allowed in boiler feed-waters, if there is any way to keep them out.

The treatment of boiler water may be accomplished before use, as in a softener or by chemicals put in before the water is fed to the boiler, but where chemicals are put in before feeding to the boiler all of the sedimentation is deposited in the boiler, or the most in an open feed-water heater and purifier if one is used. If this feed-water heater is of sufficient capacity it will retain the greatest part of the chemicals and send the water in very good shape to the boilers. The use of more than one kind of water mixes up matters, for then we have conditions which are always changing.

In one plant having a hard scale to contend with the owner desired at irregular intervals to make a change in the chemicals used, but was advised to persevere with the original recommendation, and in the end the result was entirely satisfactory.

In another case after recommendations were carried out for one month, a new "compound" was used the second month, still another the third and another the fourth. The result was, of course, not satisfactory. In this plant also one boiler was used for one month and then put out of service for a month, and then was used for another month.

In regard to boiler corrosion an example will be found in

Engineering News, March 28, 1812, p. 613, which is as follows:

"The report presents a paper prepared for the committee by J. F. Francis, describing a serious case of pitting and corrosion in a locomotive boiler using water treated by a softening process. The trouble arose from the use of hard (untreated) water at stations where no softening plant was installed, but until this was determined, it led to the softening process being regarded with some suspicion. The remedy was to maintain the water in the boiler slightly caustic and to control the causticity by continuous chemical examination of samples drawn from the boiler."

From this we see that the corrosion was due, not to the water which was supplied by the softening or purifying apparatus on the line, but to the use in the boilers of untreated hard water from stations on the line where there was no purification plant.

The writer in his book, "Boiler Waters; Scale, Corrosion and Foaming," has treated the various boiler water troubles and their remedies, and the reader is referred to that book for information along this line.

Boiler scale, as a rule, is a very evident indicator of the condition of the interior of a steam boiler, and if one desires to know the condition of the boiler plant about all he has to do is use his eyes and see what scale there is and where, and test its hardness or softness, to know whether he is feeding good or bad water.

Corrosion is a decidedly different matter, for its work is carried on in many places that cannot readily be gotten at for examination, and the results are often worse than the results of scaling.

Anderson says that the boiling method, or hot process, of treating feed-water has some advantages in cases where the nature of the water and other circumstances are favorable. For example, it answers well with most of the London waters and with waters from the chalk strata, where hardness is mainly due to carbonate of lime. It has a distinct advantage in being independent of variations in the amount of bicarbonate of lime present. When, however, bicarbonate of magnesia is present in any amount, the boiling process removes but little of it. The same applies to sulphate of lime and other salts of lime and magnesia, which are very little, if at all, effected by boiling at atmospheric pressure.

Soda ash and its use in boiler feed-waters is very fully discussed and illustrated in the *Locomotive*, of October, 1908, published by the Hartford Steam Boiler Inspection and Insurance Co.

Soda ash was first recommended in the columns of the *Times* (England), March 17, 1864, by Peter Spence, of the Manchester Alum Works.

Nicolas De Derschau, 1882, employed Porter's principle, using magnesium instead of lime, which with calcium sulphate waters, produces magnesium sulphate, which remains in solution.

Though some may think that trisodium phosphate is a new remedy for water troubles we know that "tripsa," tribasic sodium phosphate, was recommended by G. E. Davis in England in 1879.

Mr. M. E. Wells, boiler inspector of the Burlington and Missouri Railroad, deprecates the use of soda ash for softening water to be used in locomotives and shows the increase in alkalies by the use of sodium carbonate in a water, and obtained from a well 70 feet deep at Council Bluffs, Iowa, used by the Chicago and North Western Railway.

Here we have an example of a hard incrusting water changed to a foaming water by softening.

	Parts per million.
Incrustants:	
Before treatment	813
After treatment	66
Non-incrustants:	
Before treatment	106
After treatment	472

Mr. Wells, for locomotive practice, much prefers incrusting water to foaming water.

A very singular point, to which much attention has been given in recent years, and which is now well established, is that carbonate of soda, under boiler conditions may, to some extent, become converted into caustic soda. The exact way in which this occurs is still obscure.

Among those who have investigated the question may be mentioned Messrs. Tatlock & Thompson, of Glasgow, who published the results of a case they had studied in the Journal of the Society of Chemical Industry, April 30, 1904. The following passage, taken from the above paper, is of special interest:

"It has been stated that waters containing carbonate of sodium are apt to cause priming in a boiler, but we are assured that there has not been the slighest tendency in this direction with the water under consideration. It has also been stated more recently that waters containing sulphate of sodium have also the same objectionable quality, but although we have no less than 776 grains per gallon of this compound in the concentrated water, it is absolutely devoid of the property assigned to it. From our experience the subject of priming is a very obscure one, and the most contradictory statements have been obtained by us on this subject. It is our opinion that in the positive statements about priming all the conditions have not been taken into account, but that probably because carbonate of sodium or sulphate of sodium happened to be present in excessive proportion when priming took place, these were credited with the defect. These facts show clearly that at present no definite conclusion can be drawn from an analysis of water as to whether it is likely to cause priming or otherwise. It will be observed in this case that 1000 gallons of water have been concentrated to 20 gallons or to exactly one-fiftieth of their original bulk, and at the same time 15 per cent of the total carbonate of sodium has been converted into hydroxide. This transformation is not altogether unknown, but has been referred to by Mr. Arthur E. Leighton in his 'Note on Boiler Water Containing Sodium Carbonate,' which appeared in the *Chemical News* of February 6, 1903, but he does not state any theory as to the origin of the caustic alkali. From consideration of the whole matter we think it probable that the magnesia produced from the carbonate of magnesium acts slowly as a causticizing agent at the high temperature inside the boiler."

The following analysis of a very bad boiler water, both scale-forming and corrosive, comes from Orman, South Dakota, from an artesian well 1417 feet deep, temperature of water 94 + deg. F.

	Grains per gallon.
Silica	.747
Oxides of iron and aluminum	.163
Carbonate of lime	trace
Sulphate of lime	36.176
Carbonate of magnesia	10.049
Sulphate of magnesia	2.002
Sodium and potassium sulphates	15.203
Sodium and potassium chlorides	.340
Loss, etc	.027
Total	64.707

Total incrusting solids .... 47.135 grains per gallon.
Total non-incrusting solids .... 17.572 grains per gallon.

Here are two bad waters:

A.		B.
Grains per U.S. gallon.		Grains per U. S. gallon.
1.050	Insoluble siliceous matter.......	2.2
2.277	Iron and alumina...............	.582
6.834	Calcium carbonate.............	32.98
14.817	Calcium sulphate..............	11.67
......	Magnesium sulphate............	30.31
17.169	Magnesium carbonate..........	12.28
1.532	Chlorides of soda and potash...	2.20
.121	Unaccounted for...............	1.99
43.800	..........Total solids..........	94.212
January, 1908		May, 1909

A — Nordyke & Marmon Co., Indianapolis, Ind.
B — Indianapolis Gas Company.

Mr. George H. Seyms, chemist of the Hartford Steam Boiler Inspection & Insurance Co., has made an extensive study of the waters of Connecticut, and, taking into account the average proportion of the different constituents in the normal waters of the state and assuming that one-half of the total solids in any water is incrusting matter, concludes:

Water containing less than 250 parts per million of solid matters is good for boiler use;

Between 250 and 500 is fair for boiler use;

Over 500 parts unfit for general boiler purposes.

He recommends as available supplies for boiler purposes:

1. River waters, uncontaminated by factory wastes;
2. Ponded reservoirs;
3. Small streams, as compared with rivers;
4. Springs and shallow wells, 30 to 50 feet deep;
5. Deep wells.

This analysis is of an artesian well water which is used in a steam boiler as feed-water.

	Grains per U. S. gallon.
Organic and volatile matter	3.246
Sodium chloride	0.2000
Calcium carbonate	5.597
Calcium sulphate	2.157
Magnesium carbonate	0.816
Magnesium chloride	1.859
Free carbonic acid	1.866

The above water will cause a very hard incrustation. Another scale from Oklahoma gives:

	Per cent.
Calcium sulphate	65.95
Calcium carbonate	17.15
Silica	7.75
Magnesium oxide	6.80
Oxide of iron and alumina	1.25
Moisture and organic matter	1.10
Total	100.00

Boilers in Leavenworth, Kansas, using raw water from the city supply, which was probably obtained from the Missouri River-produced scale with this analysis:

	Per cent.
Calcium carbonate	17.73
Calcium sulphate	61.58
Magnesium oxide	7.59
Iron and alumina	3.25
Moisture and organic matter	1.85
Silica	8.00
Total	100.00

It is frequently of interest to know what kind of scale is obtained in boilers even though we do not know the analysis of the water causing the scale.

A sample of boiler scale from marine practice (the boiler, however, in this case received its water from the land) gave:

	Per cent.
Silica and insoluble matter	7.12
Alumina	0.26
Iron oxide	3.34
Lime	37.40
Magnesia	3.57
Sulphuric anhydride	35.38
Loss by ignition (water, carbonic acid and organic matter)	12.72

Another scale from a boiler using softened water was:

	Per cent.
Calcium carbonate	91.45
Calcium sulphate	3.50
Magnesium oxide	2.10
Iron and alumina	0.50
Moisture and organic matter	1.95
	100.00

Cost of Pumping Water. — Some information regarding the cost of pumping water should prove of interest to water users. The writer has collected a number of figures from different sources, and gives them here, trusting they will be of service to some.

The Chestnut Hill High Service Steam Pump in five different tests gave five different results. Cost per million gallons raised one foot: $0.023, $0.031, $0.049, $0.098, $0.100. Average dynamic head in feet: 125.3, 123.3, 52.1, 125.1, 48.7. These costs are based on an average price of the coal, $4.00 per gross ton.

With coal at $4.50 per gross ton, we have cost per million gallons raised one foot: $0.032, average dynamic head in feet 51.8. This was at the Chestnut Hill Low Service Pumping Station.

The Spot Pond Pumping Station two tests gave these figures: $0.042, 126.5 feet; $0.045, 122.5 feet. Cost of coal $4.72 per gross ton.

With a Triple Nordberg Corliss pumping engine working at full speed, $\frac{3}{4}$ speed, $\frac{1}{2}$ speed, we have $0.0179, $0.0198, $0.0254, as the cost per million gallons raised one foot.

A 15-inch triplex piston pump, 7-inch cylinder in deep well, 11-horse-power Foos gasolene engine, 38 revolutions per minute, pumping 180 gallons of water per minute, uses California distillate costing $7\frac{1}{2}$ cents per gallon, with water at 70-foot depth. Test made on the A. T. & Sante Fé Railroad, San Bernadino, Cal. The cost, not including that of attendance, and with an average dynamic head of 130 feet gave a cost of $0.0693 per million gallons raised one foot.

The following table gives cost per 1,000,000 gallons pumped 100 feet high.

City.	Capacity of station, gallons per day.	Cost per 1,000,000 gallons pumped 100 feet high.				
		Labor.	Fuel.	Oil, etc.	Repairs.	Total.
Chicago..........	99,000,000	$1.97	$3.61	$0.12	$0.12	$5.82
Mankato, Minn....	3,100,000	2.48	3.37	0 16	0.60	6.61
Newark, N. J.....	26,000,000	1.72	1.86	0.35	0.27	4.20
Milwaukee........	35,000,000	1.44	1.00	0.12	0.08	2.64
Milwaukee........	9,000,000	5.39	2.53	1.05	0 47	9.44

The operating cost of three mine water-hoisting plants give, lifting 1000 gallons, 1000 feet vertical, a total cost, including labor, supplies, repairs, and steam: $0.032, $0.029, $0.028, making a total per horse-power year, 24 hours per day, for lifting the water, $65.91, $60.71, $58.97, which is much less, as compared with the average cost of pumping at the collieries of the Lykens Valley Coal Co., which is \$0.05333, \$0.0390 and \$98.11, \$81.47 respectively for the years 1901 and 1902.

In the United States Steamship *Minneapolis* the consumption of steam has been given as ranging from 75.74 pounds, in a circulating pump doing 4.1 horse power, one cylinder alone taking steam, to 318.68 pounds for a small pump developing 0.78 horse power, which was used for flushing purposes — the average of 12 pump tests included in Mr. White's tables, from which these figures were taken, being 161.61 pounds of steam per indicated horse power.

The efficiency or economy of steam-using devices may be given as follows: Injectors and inspirators, about 100 pounds coal per horse-power hour; pulsometers, about 67 pounds; steam pumps, small, 25 pounds; steam pump, large, 13 pounds; power pumps, with steam engines operating them, $1\frac{1}{2}$ to 6 pounds.

Some of these figures are evidently quite low, but, comparatively, they probably give a fair idea of the relative economy of the different methods or powers used in pumping water.

The effect of leaking pistons in pumping engines or steam engines is well illustrated by some tests made on the United States Steamship *Minneapolis*, where 123 pounds of steam per horse-power hour with pistons badly fitted, cylinders bored rough and fitted, was reduced from 88 to 68 pounds when new pistons, new packing rings had been in use 10 days.

Another case, cylinder bores rough, water-packed pistons, required from 84 to 108 pounds of steam per horse-power hour. With new pistons, new packing rings in use 9 days, steam consumption was reduced from 65 to 56 pounds.

Another case, water-packed pistons closely fitted to cylinders, cylinders in good condition, required from 75 to 97 pounds of steam per horse-power hour. While with new pistons and packing rings in use 4 days, the steam consumption was dropped from 81 to 72 pounds of steam per horse-power hour.

In one of the power plants designed by the writer in 1904, he used an electric motor driven two-stage centrifugal pump to remove the water of condensation from a surface condenser, and by so doing not only enjoyed the benefits of direct connection and low friction of the small apparatus required, but also the economy of the original generation of electricity in the power plant, which in this case was by a steam turbine working under high vacuum.

CHAPTER X.

USEFUL INFORMATION.

One million U. S. gallons in 24 hours is equal to:

	24 hours.	1 hour.	1 minute.	1 second.
Gallons......	1,000,000	41,666.66	694.44	11.574
Cubic feet...	133,680	5,570	92.833	1.547
Cubic inches.	231,000,000	9,624,960	160,416	2673.6
Pounds......	8,331,110	347,498	5,791.63	96.527

Water Horse Power, or useful work done in pumping, equals capacity in gallons per minute multiplied by total head in feet, and divided by 3960. For sea water add 2.6 per cent to result.

Water Horse Power. — The effective work accomplished in raising average discharge capacity through the total lift. This equals the product of the two quantities reduced to foot-pounds per minute, divided by 33,000.

Duty. — This term, applied to centrifugal pumps, indicates the number of foot-pounds per hour of effective work accomplished by the pump for each thousand pounds of steam consumed by the engine furnishing the power. This equals the total efficiency of the pump and its driving engine $\left(= \frac{\text{water horse power}}{\text{indicated horse power}}\right)$, multiplied by 1,980,000,000 and divided by the steam consumption of the driving engine per indicated horse power per hour.

The duty of a pumping engine equals foot-pounds of work done, divided by total number of heat units consumed, this quotient multiplied by 1,000,000.

Pounds of coal and feed-water consumed per hour, per horse power, for various duties:

Duty in foot-pounds.	30 Million.	40 Million.	50 Million.	60 Million.
a. Lbs. of feed-water per pump H.P. per hour	66.0	49.5	39.6	33.0
**b*. Lbs. of feed-water per I.H.P. per hour	58.0	43.5	34.8	29.0
†*c*. Lbs. of coal per I.H.P.	5.8	4.35	3.5	2.9

	70 Million.	80 Million.	90 Million.	100 Million.	110 Million.	120 Million.	130 Million.	140 Million.	150 Million.
a.	28.28	24.75	22.0	19.8	18.0	16.5	15.2	14.1	13.2
b.	24.9	21.8	19.4	17.4	15.8	14.5	13.4	12.4	11.6
c.	2.5	2.2	1.94	1.74	1.58	1.45	1.34	1.24	1.16

* 14 per cent friction of machine is assumed.

† At 10 pounds of water evaporated per pound of coal.

Gallons in a Cylinder or Tank. — To find the capacity of a cylinder or tank in gallons, this formula, by adding 2 per cent, is almost exact.

d = diam. in inches, L = length in feet:

$$\frac{d^2 \times L \times 4}{100} = \text{gallons.}$$

If L is in inches; $\frac{d^2L}{294.12}$ = gallons capacity. (*Power.*)

If L and d are both feet; gallons $= \frac{d^2L}{0.17}$. *

LIQUID MEASURE.

	Gallons.
A barrel holds	31.5
A hogshead holds	63
A tierce holds	42
A puncheon holds	84
A tun holds	252

* J. F. Ward in *Eng. News*, July, 1886.

Gallon. — The standard gallon measures 231 cubic inches, and contains 8.3388822 pounds avoirdupois = 58372.1757 grains Troy of distilled water, at maximum density 39.83° F., and 30 inches barometer.

LIQUID MEASURE.

Gallons.	Quarts.	Pints.	Gills.	Cubic inches.
1	4	8	32	231
0.25	1	2	8	57.75
0.125	0.5	1	4	28.875
0.03125	0.125	0.25	1	7.21875
0.004329	0.17315	0.03463	0.13858	1

1 cubic foot per second for 12 hours equals.	43,200 cubic feet.
Approximately	one acre foot
1 cubic foot of water equals	62.5 pounds
1 cubic foot contains	7.48 gallons
1 cubic foot contains	1728 cubic inches
1 cubic inch weighs	.03617 pounds.
1 pound pressure per square inch equals	2.31 feet head of water.
1 ounce pressure per square inch equals	0.144 foot head of water

The *friction* of water in *pipes* increases with the square of its velocity.

The *capacity* of *pipes* increases with the square of their diameter; thus, doubling the diameter increases the capacity four times.

To find the *pressure* in pounds per *square inch* of a column of water, multiply the height of the column in feet by 0.433.

To find *quantity* of *water* elevated in one minute running at 100 feet of piston lift per minute, square the diameter of the water cylinder in inches and multiply by 4.08. Allowance must be made for slippage.

The area of the steam piston multiplied by the steam pressure gives the total amount of pressure exerted. The area of water piston multiplied by the pressure of water per square inch gives the resistance. To move the pistons at the required speed a margin must be made between the power and the resistance.

Use air chamber on long supply pipes, also on discharge pipe for lifts or long delivery.

Water Power. —

Let Q = cubic feet per second flow.

Let H = head in feet.

Then the theoretical horse power is:

$$\text{Horse power} = \frac{62.4283\,QH}{550} = 0.1135\,QH.$$

Allowing 20 per cent loss, the available horse power $= 0.80 \times 0.1135\,QH$ = approximately $\frac{QH}{11}$, while $0.09\ QH$ makes an allowance for about 21 per cent loss.

Bushels. — The United States standard bushel is $18\frac{1}{2}$ inches in diameter by 8 inches deep, as used by the American Gas Light Association, and contains 2150.42 cubic inches.

A heaped bushel is the same plus a cone $19\frac{1}{2}$ inches in diameter, 6 inches high = 2747.7 cubic inches.

An ordinary bushel = $1\frac{1}{4}$ struck bushels = 2688 cubic inches = 10 gallons, dry measure.

Discharge of Pipes. — In a paper in the "Proceedings of the Royal Society," vol. xiv, "On the Maximum Discharge through a Pipe of Circular Section when the Effective Head is due only to the Pipe's Inclination," Mr. Henry Hennessy, F. R. S., says: "The maximum discharge will be when the pipe is filled up to the segment of 308° 10′. The supplemental arc being 51° 50′, the maximum discharge would occur when the liquid falls below the summit of the inner surface of the pipe by about one twentieth of the diameter.

This result might be called a hydraulic paradox, or the condition of a pipe carrying liquid at a small inclination giving a greater discharge when filled up to nineteen-twentieths of its diameter than when completely full. The hydraulic paradox here referred to as a deduction from the expression for hydraulic mean depth is not so practically important as the question of velocity of the liquid passing through the section of greatest hydraulic mean depth. The maximum hydraulic mean depth for the pipe was found to be 0.6086r, while it is 0.5r, for a full pipe. As the velocities may be taken as very approximately proportional to the square roots of the hydraulic mean depths, we shall have for v^1, the maximum velocity,

$$v^1 = v\sqrt{\frac{6086}{5000}} = 1.1033\,v.$$

Or the velocity for the maximum hydraulic depth exceeds the velocity for a full pipe under the conditions specified by $10\frac{1}{3}$ per cent. This result may possibly be utilized in circular drain pipes liable to be coated with deposits.

Flow of Water through Curved Pipes. — Tests at University of Birmingham, Eng., 1901–2, by C. W. L. Alexander and published by the Institute of Civil Engineers in 1905, after giving equations for:

Varnished wood pipes, Drawn brass pipes,
12-inch, 16-inch, 30-inch cast-iron asphalted pipes,

give, as the principal conclusion, that a curve whose radius is $2\frac{1}{2}$ diameters offers a smaller resistance than any other curve, and that this resistance is equivalent to that offered by a length of straight pipe equal to 3.38 times the curved portion of the band measured along its center line.

[E. R., Vol. 52, 221.]

TEMPERATURE OF BOILING, BAROMETER, ALTITUDE.

Boiling-point in deg. Fah.	Barometer, inches.	Altitude above sea-level, feet.	Boiling-point in deg. Fah.	Barometer, inches.	Altitude above sea-level, feet.	Boiling-point in deg. Fah.	Barometer, inches	Altitude above sea-level, feet.
184	16.79	15,221	196	21.71	8481	208.0	27.73	2063
185	17.16	14,649	197	22.17	7932	208.5	28.00	1809
186	17.54	14,075	198	22.64	7381	209	28.29	1539
187	17.93	13,498	199	23.11	6843	209.5	28.56	1290
188	18.32	12,934	200	23.59	6304	210	28.85	1025
189	18.72	12,367	201	24.08	5764	210.5	29.15	754
190	19.13	11,799	202	24.58	5225	211	29.42	512
191	19.54	11,243	203	25.08	4697	211.5	29.71	255
192	19.96	10,685	204	25.59	4169	212	30.00	S.L.=0
193	20.39	10,127	205	26.11	3642	212.5	30.50	−261
194	20.82	9,579	206	26.64	3115	213	30.39	−511
195	21.26	9,031	207	27.18	2589			

Corrections for Temperature.

Mean temp. F. in shade..	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
Multiply by............	.933	.954	.975	.996	1.016	1.036	1.058	1.079	1.100	1.121	1.142

At the level of the sea, water boils and steam is made at 212° F., and the higher the altitude above sea-level the more easily water boils and steam is made; the lower down in the earth we descend the more difficult it is to make steam.

HEAD IN FEET WITH EQUIVALENT IN POUNDS PRESSURE PER SQUARE INCH.

Head.	Pressure.	Head.	Pressure.	Head.	Pressure.	Head.	Pressure.	Head.	Pressure.
1	.434	29	12.58	57	24.73	85	36.89	165	71.61
2	.868	30	13.02	58	25.17	86	37.32	170	73.78
3	1.30	31	13.45	59	25.60	87	37.75	175	76.90
4	1.73	32	13.88	60	26.04	88	38.29	180	78.12
5	2.17	33	14.32	61	26.47	89	38.62	185	80.29
6	2.50	34	14.75	62	26.90	90	39.06	190	82.46
7	3.03	35	15.19	63	27.34	91	39.49	195	84.63
8	3.47	36	15.62	64	27.76	92	39.92	200	86.80
9	3.90	37	16.05	65	28.21	93	40.36	210	91.14
10	4.34	38	16.49	66	28.64	94	40.79	220	95.48
11	4.77	39	16.92	67	29.07	95	41.23	230	99.85
12	5.20	40	17.36	68	29.51	96	41.66	240	104.16
13	5.65	41	17.79	69	29.94	97	42.09	250	108.50
14	6.07	42	18.22	70	30.38	98	42.53	260	112.84
15	6.51	43	18.66	71	30.81	99	42.96	270	117.66
16	6.94	44	19.09	72	31.24	100	43.40	280	121.52
17	7.37	45	19.53	73	31.68	105	45.57	290	125.86
18	7.81	46	19.94	74	32.11	110	47.74	300	130.50
19	8.24	47	20.39	75	32.55	115	50.91	350	152.20
20	8.68	48	20.83	76	32.98	120	52.08	400	173.60
21	9.11	49	21.26	77	33.41	125	54.25	450	195.30
22	9.54	50	21.70	78	33.85	130	56.45	500	217.00
23	9.88	51	22.17	79	34.28	135	58.62	600	260.40
24	10.41	52	22.56	80	34.72	140	60.76	700	303.80
25	10.85	53	22.30	81	35.15	145	63.93	800	347.20
26	11.06	54	23.43	82	35.58	150	65.10	900	390.60
27	11.71	55	23.87	83	36.02	155	67.27	1000	434.00
28	12.15	56	24.30	84	36.45	160	69.44	1500	651.00

PRESSURE PER SQUARE INCH IN POUNDS WITH EQUIVALENT WATER HEAD IN FEET.

Pressure.	Head.	Pressure.	Head.	Pressure.	Head.	Pressure.	Head.	Pressure.	Head.
1	2.3	21	48.3	41	94.3	61	140.3	81	186.3
2	4.6	22	50.6	42	96.6	62	142.6	82	188.6
3	6.9	23	52.9	43	98.9	63	144.9	83	190.9
4	9.2	24	55.2	44	101.2	64	147.2	84	193.2
5	11.5	25	57.5	45	103.5	65	149.5	85	195.5
6	13.8	26	59.8	46	105.8	66	151.8	86	197.8
7	16.1	27	62.1	47	108.1	67	154.1	87	200.1
8	18.4	28	64.4	48	110.4	68	156.4	88	202.4
9	20.7	29	66.7	49	112.7	69	158.7	89	204.7
10	23.0	30	69.0	50	115.0	70	161.0	90	207.0
11	25.3	31	71.3	51	117.3	71	163.3	91	209.3
12	27.6	32	73.6	52	119.6	72	165.6	92	211.6
13	29.9	33	75.9	53	121.9	73	167.9	93	213.9
14	32.2	34	78.2	54	124.2	74	170.2	94	215.2
15	34.5	35	80.5	55	126.5	75	172.5	95	217.5
16	36.8	36	82.8	56	128.8	76	174.8	96	219.8
17	39.1	37	85.1	57	131.1	77	177.1	97	223.1
18	41.4	38	87.4	58	133.4	78	179.4	98	225.4
19	43.7	39	89.7	59	135.7	79	181.7	99	227.7
20	46.0	40	92.0	60	138.0	80	184.0	100	230.0

CAPACITY IN GALLONS PER MINUTE AT VELOCITIES IN FEET PER SECOND, 1 TO 15 FEET; ALSO FRICTION HEAD IN FEET PER 100 FEET LENGTH OF PIPE.

Velocity.	¾-inch pipe.		1-inch pipe.		1¼-inch pipe.		1½-inch pipe.		2-inch pipe.		2½-inch pipe.		3-inch pipe.		4-inch pipe.		5-inch pipe.		Velocity.
	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	
1	1.50	1.19	2.90	1.04	4.50	.74	6.0	.54	11.0	.43	17.4	.31	24	.21	40	.12	68	.10	1
2	3.00	3.66	5.00	2.43	7.5	1.76	11.6	1.65	20.0	1.08	31.0	.76	47	.70	80	.48	128	.39	2
3	4.03	5.98	7.31	4.08	11.6	3.91	16.5	2.7	29.4	2.04	47.2	1.71	66	1.36	117	1.02	184	.82	3
4	5.50	10.49	9.82	6.83	15.1	5.79	22.0	4.5	39.2	3.4	61.0	2.6	81	2.28	156	1.71	245	1.67	4
5	6.89	13.64	12.24	10.25	19.4	8.32	27.4	6.8	48.9	5.1	76.5	4.1	110	3.4	196	2.56	306	2.05	5
6	8.25	19.12	14.68	14.33	23.2	12.34	32.9	9.5	58.7	7.2	91.8	5.7	132	4.7	236	3.6	367	2.87	6
7	9.65	25.44	17.13	19.08	26.8	16.56	34.4	12.7	68.5	9.5	107	7.6	154	6.3	275	4.8	428	3.8	7
8	11.01	32.64	19.58	24.50	30.3	20.82	43.8	16.3	78.3	12.2	122	9.8	176	8.1	314	6.1	490	4.9	8
8½	11.70	36.60	20.80	27.46	32.5	23.65	46.6	18.3	83.2	13.7	130	10.9	187	9.1	334	6.9	521	5.5	8½
9	12.39	40.40	22.03	30.58	34.5	25.51	49.4	20.4	88.1	15.2	138	12.2	198	10.1	352	7.6	551	6.1	9
9½	13.08	44.80	23.25	33.88	36.3	28.34	52.2	22.5	93.6	16.9	145	13.5	209	11.2	372	8.5	581	6.7	9½
10	13.79	49.68	24.48	37.33	38.3	30.53	55.3	24.9	97.9	18.6	153	14.9	220	12.4	391	9.3	612	7.5	10
10½	14.45	54.40	25.70	40.06	40.1	33.56	57.7	27.3	103	20.4	161	16.3	231	13.6	411	10.2	642	8.2	10½
11	15.15	59.60	26.92	44.75	42.6	36.41	60.5	29.8	108	22.3	168	17.9	242	14.9	431	11.1	673	8.9	11
11½	15.85	64.80	28.15	48.71	44.6	40.12	63.2	32.5	113	24.3	176	19.5	253	16.2	450	12.1	704	9.7	11½
12	16.52	70.40	29.37	52.83	46.8	43.73	66.6	35.2	117	26.4	184	21.0	264	17.6	471	13.2	735	10.6	12
13	17.94	82.00	31.82	61.58	49.5	49.91	71.5	41.0	127	30.7	199	24.6	286	20.5	510	15.3	796	12.3	13
14	19.30	94.80	34.27	71.00	53.5	57.25	77.8	47.3	139	35.5	214	28.4	308	23.7	549	17.7	857	14.2	14
15	20.75	108.00	36.72	81.08	57.4	64.82	82.5	54.0	149	40.5	230	32.4	330	27.0	587	20.3	918	16.2	15

CAPACITY IN GALLONS PER MINUTE AT VELOCITIES IN FEET PER SECOND, 1 TO 15 FEET; ALSO FRICTION HEAD IN FEET PER 100 FEET LENGTH OF PIPE.

Velocity.	6-inch pipe.		7-inch pipe.		8-inch pipe.		10-inch pipe.		12-inch pipe.		15-inch pipe.		18-inch pipe.		20-inch pipe.		24-inch pipe.		Velocity.
	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	
1	98	.09	118	.06	156	.05	248	.04	351	.03	551	.02	794	.03	963	.02	1,412	.02	1
2	176	.32	235	.28	312	.21	493	.18	704	.13	1101	.12	1,587	.11	1,956	.08	2,825	.07	2
3	264	.68	360	.58	470	.51	734	.41	1058	.34	1652	.27	2,379	.23	2,938	.20	4,230	.17	3
4	353	1.14	470	.98	627	.85	979	.68	1410	.57	2203	.46	3,173	.38	3,917	.34	5,640	.28	4
5	440	1.70	600	1.46	783	1.28	1224	1.02	1763	.87	2755	.68	3,965	.57	4,896	.51	7,051	.43	5
6	528	2.38	720	2.05	940	1.79	1468	1.43	2115	1.21	3304	.96	4,758	.80	5,875	.72	8,461	.60	6
7	617	3.18	840	2.72	1097	2.38	1713	1.90	2468	1.62	3855	1.27	5,552	1.06	6,854	.95	9,870	.79	7
8	706	4.08	959	3.49	1253	3.06	1958	2.45	2820	2.08	4407	1.63	6,345	1.36	7,833	1.22	11,280	1.01	8
8½	749	4.57	1019	3.92	1331	3.43	2081	2.74	2996	2.33	4688	1.82	6,742	1.52	8,323	1.37	11,985	1.14	8½
9	794	5.09	1079	4.36	1410	3.82	2203	3.05	3173	2.60	4958	2.04	7,138	1.70	8,812	1.53	12,690	1.27	9
9½	837	5.61	1139	4.83	1488	4.23	2326	3.38	3349	2.88	5232	2.25	7,535	1.88	9,302	1.69	13,395	1.40	9½
10	882	6.21	1199	5.33	1567	4.66	2448	3.73	3525	3.17	5508	2.50	7,931	2.07	9,792	1.87	14,100	1.55	10
10½	925	6.82	1259	5.84	1646	5.22	2571	4.09	3701	3.48	5783	2.73	8,329	2.27	10,281	2.05	14,805	1.70	10½
11	970	7.45	1319	6.39	1723	5.59	2693	4.47	3878	3.80	6058	2.98	8,725	2.48	10,771	2.24	15,510	1.86	11
11½	1013	8.11	1379	6.95	1801	6.08	2815	4.87	4054	4.14	6335	3.25	9,122	2.70	11,258	2.43	16,215	2.03	11½
12	1058	8.80	1439	7.54	1880	6.60	2938	5.28	4230	4.49	6610	3.52	9,518	2.93	11,750	2.64	16,920	2.20	12
13	1145	10.26	1559	8.74	2037	7.90	3182	6.15	4583	5.23	7161	4.10	10,310	3.42	12,729	3.08	18,330	2.56	13
14	1233	11.83	1679	10.14	2193	8.87	3472	7.10	4935	6.03	7711	4.73	11,104	3.93	13,708	3.55	19,740	2.95	14
15	1321	13.51	1799	11.58	2350	10.01	3672	8.10	5288	6.89	8262	5.40	11,897	4.50	14,688	4.05	21,150	3.37	15

CAPACITY IN GALLONS PER MINUTE AT VELOCITIES IN FEET PER SECOND, 1 TO 15 FEET; ALSO FRICTION HEAD IN FEET PER 100 FEET LENGTH OF PIPE.

Velocity.	30-inch pipe.		32-inch pipe.		36-inch pipe.		42-inch pipe.		45-inch pipe.		48-inch pipe.		54-inch pipe.		60-inch pipe.		72-inch pipe.		Velocity.
	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	
1	2,200	.013	2,507	.013	3,120	.012	4,319	.010	4,958	.009	5,700	.008	7,138	.006	8,800	.005	12,690	.004	1
2	4,400	.051	5,014	.048	6,240	.043	8,637	.039	9,915	.035	11,280	.031	14,277	.028	17,600	.025	25,381	.021	2
3	6,610	.136	7,520	.128	9,518	.113	12,955	.097	14,872	.091	16,921	.085	21,415	.076	26,438	.068	38,071	.057	3
4	8,813	.228	10,027	.214	12,690	.190	17,273	.163	19,829	.152	22,561	.145	28,553	.127	35,251	.114	50,762	.095	4
5	11,015	.341	12,534	.320	15,863	.284	21,591	.244	24,786	.228	28,201	.214	35,692	.190	44,064	.171	63,452	.142	5
6	13,218	.478	15,040	.448	19,036	.397	25,910	.341	29,743	.319	33,845	.299	42,830	.265	52,877	.239	76,142	.199	6
7	15,421	.636	17,547	.596	22,208	.528	30,228	.454	34,700	.424	39,481	.398	49,968	.353	61,689	.318	88,833	.265	7
8	17,624	.816	20,054	.765	25,381	.679	34,546	.583	39,657	.544	45,121	.510	57,107	.454	70,502	.408	101,523	.340	8
8½	18,725	.915	21,307	.858	26,967	.760	36,705	.654	42,136	.610	47,941	.572	60,676	.508	74,909	.458	107,868	.381	8½
9	19,827	1.01	22,561	.956	28,554	.847	38,864	.728	44,615	.680	50,762	.637	64,245	.566	79,315	.510	114,214	.425	9
9½	20,928	1.12	23,814	1.06	30,140	.938	41,023	.807	47,093	.753	53,582	.706	67,814	.627	83,721	.565	120,559	.470	9½
10	22,030	1.22	25,067	1.17	31,726	1.03	43,183	.899	49,572	.830	56,402	.778	71,383	.691	88,128	.622	126,904	.519	10
10½	23,131	1.34	26,321	1.28	33,313	1.13	45,342	.975	52,050	.910	59,222	.853	74,953	.758	92,534	.683	133,249	.569	10½
11	24,233	1.49	27,574	1.40	34,899	1.16	47,501	1.07	54,529	.994	62,042	.932	78,522	.829	96,941	.746	139,594	.622	11
11½	25,338	1.62	28,828	1.52	36,485	1.35	49,660	1.16	57,208	1.08	64,862	1.02	82,091	.902	101,347	.812	145,940	.677	11½
12	26,436	1.76	30,081	1.65	38,072	1.46	51,819	1.26	59,486	1.17	67,682	1.10	85,660	.978	105,753	.881	152,285	.734	12
13	28,639	2.05	32,588	1.92	41,214	1.70	56,137	1.47	64,443	1.37	73,322	1.28	92,798	1.14	114,566	1.03	164,975	.855	13
14	30,842	2.37	35,094	2.22	44,417	1.97	60,456	1.69	69,408	1.58	78,962	1.48	99,037	1.32	123,379	1.18	177,666	.986	14
15	33,045	2.70	37,601	2.53	46,590	2.24	64,774	1.93	74,358	1.80	84,603	1.69	107,075	1.50	132,192	1.35	190,356	1.23	15

TABLE SHOWING FLOW OF WATER PER SECOND THROUGH CLEAN IRON PIPES.

Fall, in feet, per 100 ft. of pipe.	Diameter.								
	1 in., cu. ft.	2 in., cu. ft.	3 in., cu. ft.	4 in., cu. ft.	6 in., cu. ft.	8 in., cu. ft.	10 in., cu. ft.	11 in., cu. ft.	12 in., cu. ft.
.10	......	......	......	......	......	......	......	......	1.265
.12	......	......	......	......	......	......	.878	1.120	1.402
.14	......	......	......	......	......	......	.960	1.221	1.489
.16	......	......	......	......	......	.573	1.047	1.320	1.634
.18	......	......	......	......	......	.611	1.110	1.394	1.728
.20	......	......	......	......	.298	.639	1.194	1.490	1.846
.22	......	......	......	......	.314	.659	1.265	1.580	1.940
.24	......	......	......	......	.330	.703	1.325	1.653	2.026
.26	......	......	......	.1235	.346	.737	1.377	1.722	2.117
.28	......	......	......	.1298	.359	.768	1.423	1.788	2.207
.30	......	......	.0630	.1335	.377	.808	1.470	1.854	2.297
.35	......	......	.0692	.1465	.395	.876	1.587	1.996	2.466
.40	......	.02584	.0749	.1562	.444	.931	1.683	2.136	2.662
.50	......	.02924	.0839	.1771	.496	1.045	1.865	2.397	3.020
.60	......	.03274	.0915	.1923	.548	1.175	2.059	2.636	3.310
.70	......	.03492	.0992	.2146	.589	1.262	2.222	2.858	3.601
.80	.00567	.03776	.1060	.2339	.631	1.344	2.383	3.062	3.856
.90	.00617	.04081	.1119	.2460	.672	1.424	2.514	3.232	4.072
1.00	.00677	.04321	.1190	.2582	.721	1.496	2.662	3.419	4.305
1.20	.00781	.04843	.1313	.2893	.784	1.644	2.932	3.760	4.728
1.40	.00841	.05150	.1413	.3036	.858	1.782	3.210	4.016	5.094
1.60	.00886	.05456	.1507	.3237	.922	1.916	3.450	4.390	5.482
1.80	.00961	.05740	.1590	.3412	.975	2.033	3.679	4.679	5.839
2.00	.00990	.06111	.1717	.3607	1.022	2.155	3.856	5.251	6.160
3.00	.01245	.07399	.2081	.4503	1.263	2.667	4.762	6.086	7.630
4.00	.01492	.08734	.2469	.5331	1.484	3.145	5.563	7.022	8.860
5.00	.01666	.1095	.2785	.5954	1.665	3.513	6.704	8.244	9.967
6.00	01857	.1200	.3049	.6390	1.929	3.847	......	......	......
7.00	.01988	.1288	.3331	.6967	1.976	4.196	......	......	......
8.00	02141	.1375	.3559	.7506	2.144	......	......	......	......
9.00	.02283	.1442	.3816	.7960	2.274	......	......	......	......
10.00	.02424	.1523	.4043	.9464	2.399	......	......	......	......
12.00	.02676	.1634	.4440	.9270	......	......	......	......	......
14.00	.02890	.1748	.4977	1.0060	......	......	......	......	......
15.98	.03081	.1855	.5131	1.0810	......	......	......	......	......
18.00	.03276	.1955	.5436	......	......	......	......	......	......
20.00	.03458	.2047	.5832	......	......	......	......	......	......
25.00	.03897	.2276	.6523	......	......	......	......	......	......
30.00	.04316	.2483	......	......	......	......	......	......	......
40.00	.04987	.2833	......	......	......	......	......	......	......
50 00	.05648	......	......	......	......	......	......	......	......
60.00	.06320	......	......	......	......	......	......	......	......
70.00	.06943	......	......	......	......	......	......	......	......

TABLE SHOWING FLOW OF WATER PER SECOND THROUGH CLEAN IRON PIPES.

Fall, in feet, per 100 feet of pipe.	Diameter.											
	14 in., cu. ft.	15 in., cu. ft.	16 in., cu. ft.	18 in., cu. ft.	20 in., cu. ft.	22 in., cu. ft.	24 in., cu. ft.	26 in., cu. ft.	30 in., cu. ft.	36 in., cu. ft.	40 in., cu. ft.	48 in., cu. ft.
.02	.....	.....	.....	.....	.....	.....	.....	.....	.....	10.29	13.88	22.98
.03	.....	.....	.....	.....	.....	.....	.....	.....	7.78	12.70	17.00	27.89
.04	.....	.....	.....	.....	.....	.....	.....	.....	8.99	14.56	19.68	32.93
.05	.....	.....	.....	.....	.....	.....	.....	7.48	10.24	16.35	22.08	37.00
.06	.....	.....	.....	.....	3.61	4.61	6.10	7.61	10.97	18.02	24 43	40.21
.07	.....	.....	2.25	3.10	4.07	5.25	6.64	8.27	11.90	19.76	26.27	43.67
.08	1.71	2.05	2.43	3.27	4.35	5.62	7.13	8.70	12.84	20.85	28.14	46.81
.09	1.83	2.19	2.59	3.49	4.68	6.01	7.56	9.36	13.48	22.30	29.80	49.06
.10	1.91	2.30	2.72	3.66	4.92	6.32	7.95	9.81	14.21	23.47	31.46	52.15
.11	2.02	2.43	2.88	3.88	5.15	6.62	8.34	10.44	15.05	24.91	33.25	54.95
.12	2.11	2.54	3.02	4.06	5.40	6.94	8.75	10.87	15.81	26.12	34.68	57.36
.13	2.18	2.65	3.18	4.23	5.62	7.24	9.14	11.41	16.47	27.20	36.21	60.07
.14	2.27	2.75	3.28	4.40	5.82	7.51	9.47	11.80	17.18	28.24	37.57	62.02
.15	2.35	2.84	3.39	4.61	6.05	7.78	9.80	12.26	17.94	29.19	39.18	64.47
.16	2.44	2.94	3.49	4.75	6.27	8.03	10.13	12.70	18.58	30.29	40.54	66.53
.17	2.54	2.98	3.62	4.90	6.48	8.36	10.57	13.13	19.21	31.42	41.88	68.50
.18	2.59	3.11	3.69	5.03	6.65	8.55	10.77	13.46	19.66	32.48	43.07	70.62
.19	2.67	3.21	3.81	5.17	6.92	8.85	11.10	13.84	20.32	33.40	44.28	72.75
.20	2.72	3.29	3.92	5.30	7.05	9.07	11.43	14.23	20.79	34.49	45.20	74.44
.22	2.88	3.47	4.12	5.63	7.42	9.55	12.05	14.98	21.80	36.15	48.12	78.29
.24	3.02	3.63	4.32	5.87	7.79	10.01	12.61	15.69	22.83	37.74	50.48	81.68
.26	3.15	3.79	4.51	6.18	8.14	10.48	13.23	16.42	23.93	39.40	52.67	85.20
.28	3.29	3.95	4.68	6.38	8.48	10.91	13.79	17.07	24.86	40.86	55.04	88.46
.30	3.42	4.11	4.87	6.64	8.77	11.29	14.25	17.75	25.87	42.28	56.33	91.73
.35	3.62	4.46	5.31	7.17	9.49	12.25	15.50	19.25	27.96	45.95	61.09	100.40
.40	3.99	4.78	5.67	7.65	10.16	13.12	16.62	20.62	29.84	48.83	65.41	105.89
.50	4.46	5.37	6.39	8.66	11.43	14.78	18.71	23.13	33.55	54.89	73.09	119.34
.60	4.91	5.91	7.02	9.54	12.59	16.20	20.42	25.30	36.79	59.95	80.32	130.88
.70	5.37	6.45	7.66	10.33	13.66	17.53	22.05	27.12	39.66	65.17	86.70	148.09
.80	5.77	6.90	8.16	11.09	14.66	18.78	23.61	29.20	42.39	69.80	92.58	153.49
.90	6.11	7.31	8.64	11.71	15.54	19.93	25.07	31.00	45.23	74.33	98.00	......
1.00	6.44	7.70	9.10	12.37	16.47	21.06	26.42	32.73	47.71	78.46	103.99	......
1.20	7.00	8.39	9.95	13.65	17.99	23.07	29.03	36.18	52.91	82.84	......	......
1.40	7.60	9.15	10.87	14.75	19.49	24.68	31.49	39.31	57.65	......	......	......
1.60	8.17	9.81	11.63	15.84	21.03	26.97	33.90	42.35	......	......	......	......
1 80	8.93	10.47	12.43	16.90	22.45	29.70	36.18	44.10	......	......	......	......
2.00	9.26	11.09	13.14	17.85	23.56	31.15	38.45	......	......	......	......	......
3.00	11.39	13.66	16.17	21.86	28.86	......	......	......	......	......	......	......
4.00	13.22	15.84	18.77	......	......	......	......	......	......	......	......	......

Loss of Head by Friction.

The following tables give the friction head in pipe 1 to 12 inches diameter, per 100 feet length, with velocities from 2 to 7 feet per second.

INSIDE DIAMETER OF PIPE IN INCHES.

Velocity in feet per sec.	1		2		3		4		5		6	
	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.
2.0	2.37	.65	1.185	2.62	.791	5.89	.593	10.4	.474	16.3	.395	23.5
2.2	2.80	.73	1.404	2.88	.936	6.48	.702	11.5	.561	18.	.468	25.9
2.4	3.27	.79	1.639	3.14	1.093	7.07	.819	12.5	.650	19.6	.547	28.2
2.6	3.78	.86	1.891	3.40	1.26	7.65	.945	13.6	.757	21.3	.631	30.6
2.8	4.32	.92	2.16	3.66	1.44	8.24	1.08	14.6	.864	22.9	.720	32.9
3.0	4.89	.99	2.44	3.92	1.62	8.83	1.22	15.7	.978	24.5	.815	35.3
3.2	5.47	1.06	2.73	4.18	1.82	9.42	1.37	16.7	1.098	26.2	.915	37.7
3.4	6.09	1.12	3.05	4.45	2.04	10.00	1.52	17.8	1.22	27.8	1.021	40
3.6	6.76	1.19	3.38	4.71	2.26	10.60	1.69	18.8	1.35	29.4	1.131	42.4
3.8	7.48	1.26	3.74	4.97	2.49	11.20	1.87	19.9	1.49	31	1.25	44.7
4.0	8.20	1.32	4.10	5.23	2.73	11.80	2.05	20.9	1.64	32.7	1.37	47.1
4.2	8.97	1.39	4.49	5.49	2.98	12.30	2.24	22.0	1.79	34.3	1.49	49.5
4.4	9.77	1.45	4.89	5.76	3.25	12.90	2.43	23.0	1.95	36.0	1.62	51.8
4.6	10.60	1.52	5.30	6.02	3.53	13.50	2.64	24.0	2.11	37.6	1.76	54.1
4.8	11.45	1.58	5.72	6.28	3.81	14.10	2.85	25.1	2.27	39.2	1.90	56.5
5.0	12.33	1.65	6.17	6.54	4.11	14.70	3.08	26.2	2.46	40.9	2.05	58.9
5.2	13.24	1.72	6.62	6.80	4.41	15.30	3.31	27.2	2.65	42.5	2.21	61.2
5.4	14.20	1.78	7.10	7.06	4.73	15.90	3.55	28.2	2.84	44.2	2.37	63.6
5.6	15.16	1.85	7.58	7.32	5.06	16.50	3.79	29.3	3.03	45.8	2.53	65.9
5.8	16.17	1.91	8.09	7.58	5.40	17.10	4.04	30.3	3.24	47.4	2.70	68.3
6.0	17.23	1.98	8.61	7.85	5.74	17.70	4.31	31.4	3.45	49.1	2.87	70.7
7.0	22.89	2.31	11.45	9.16	7.62	20.60	5.72	36.6	4.57	57.2	3.81	82.4

	7		8		9		10		11		12	
2.0	.338	32.0	.96	41.9	.264	53	.237	65.4	.216	79.2	.198	94
2.2	.401	35.3	.351	46.1	.312	58.3	.281	72	.255	87.1	.234	103
2.4	.468	38.5	.410	50.2	.365	63.6	.327	78.5	.297	95.0	.273	113
2.6	.540	41.7	.473	54.4	.420	68.9	.378	85.1	.344	103	.315	122
2.8	.617	44.9	.540	58.6	.480	74.2	.432	91.6	.392	111	.360	132
3.0	.698	48.1	.611	62.8	.544	79.5	.488	98.2	.444	119	.407	141
3.2	.785	51.3	.686	67	.609	84.8	.549	105	.499	127	.457	151
3.4	.875	54.5	.765	71.2	.680	90.1	.612	111	.557	134	.510	160
3.6	.969	57.7	.848	75.4	.755	95.4	.679	118	.617	142	.566	169
3.8	1.070	60.9	.936	79.6	.831	101	.749	124	.680	150	.624	179
4.0	1.175	64.1	1.027	83.7	.913	106	.822	131	.747	158	.685	188
4.2	1.28	67.3	1.122	87.9	.998	111	.897	137	.816	166	.749	198
4.4	1.39	70.5	1.22	92.1	1.086	116	.977	144	.888	174	.815	207
4.6	1.51	73.7	1.32	96.3	1.177	122	1.059	150	.963	182	.883	217
4.8	1.63	76.9	1.43	100.0	1.27	127	1.145	157	1.040	190	.954	226
5.0	1.76	80.2	1.54	105	1.37	132	1.23	163	1.122	198	1.028	235
5.2	1.89	83.3	1.65	109	1.47	138	1.32	170	1.20	206	1.104	245
5.4	2.03	86.6	1.77	113	1.57	143	1.41	177	1.28	214	1.183	254
5.6	2.17	89.8	1.89	117	1.68	148	1.51	183	1.37	222	1.26	264
5.8	2.31	93.0	2.01	121	1.80	154	1.61	190	1.46	229	1.34	273
6.0	2.46	96.2	2.15	125	1.92	159	1.71	196	1.56	237	1.43	283
7.0	3.26	112.0	2.85	146	2.52	185	2.28	229	2.07	277	1.91	330

Loss of Head by Friction.

The following tables give the friction head in pipe 13 to 36 inches diameter, per 100 feet length, with velocities of water from 2 to 7 feet per second.

INSIDE DIAMETER OF PIPE IN INCHES.

Velocity in feet per sec.	13		14		15		16		18		20	
	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in ft.	Cubic feet per min.
2.0	.183	110	.169	128	.158	147	.147	167	.132	212	.119	262
2.2	.216	121	.200	141	.187	162	.175	184	.156	233	.140	288
2.4	.252	133	.234	154	.218	176	.205	201	.182	254	.164	314
2.6	.290	144	.270	167	.252	191	.236	218	.210	275	.189	340
2.8	.332	156	.308	179	.288	206	.270	234	.240	297	.216	366
3.0	.375	166	.349	192	.325	221	.306	251	.271	318	.245	393
3.2	.422	177	.392	205	.366	235	.343	268	.305	339	.275	419
3.4	.471	188	.438	218	.408	250	.383	284	.339	360	.306	445
3.6	.522	199	.485	231	.452	265	.425	301	.377	382	.339	471
3.8	.576	210	.535	243	.499	280	.468	318	.416	403	.374	497
4.0	.632	221	.587	256	.548	294	.513	335	.456	424	.410	523
4.2	.691	232	.641	269	.598	309	.561	352	.499	445	.449	550
4.4	.751	243	.698	282	.651	324	.611	368	.542	466	.488	576
4.6	.815	254	.757	295	.707	339	.662	385	.588	488	.529	602
4.8	.881	265	.818	308	.763	353	.715	402	.636	509	.572	628
5.0	.949	276	.881	321	.822	368	.770	419	.685	530	.617	654
5.2	1.020	287	.947	333	.883	383	.828	435	.736	551	.662	680
5.4	1.092	298	1.014	346	.947	397	.888	452	.788	572	.710	707
5.6	1.167	309	1.083	359	1.011	412	.949	469	.843	594	.758	733
5.8	1.245	321	1.155	372	1.078	427	1.011	486	.899	615	.809	759
6.0	1.325	332	1.229	385	1.148	442	1.076	502	.957	636	.861	785
7.0	1.75	387	1.630	449	1.520	515	1.430	586	1.270	742	1.143	916

Velocity in feet per sec.	22		24		26		28		30		36	
2.0	.108	316	.098	377	.091	442	.084	513	.079	589	.066	848
2.2	.127	348	.116	414	.108	486	.099	564	.093	648	.078	933
2.4	.149	380	.136	452	.126	531	.116	616	.109	707	.091	1018
2.6	.171	412	.157	490	.145	575	.134	667	.126	766	.104	1100
2.8	.195	443	.180	528	.165	619	.153	718	.144	824	.119	1188
3.0	.222	475	.204	565	.188	663	.174	770	.163	883	.135	1273
3.2	.249	507	.229	603	.211	708	.195	821	.182	942	.152	1357
3.4	.278	538	.255	641	.235	752	.218	872	.204	1001	.169	1442
3.6	.308	570	.283	678	.261	796	.242	923	.226	1060	.188	1527
3.8	.340	601	.312	716	.288	840	.267	974	.249	1119	.207	1612
4.0	.373	633	.342	754	.315	885	.293	1026	.273	1178	.228	1697
4.2	.408	665	.374	791	.345	929	.320	1077	.299	1237	.249	1782
4.4	.444	697	.407	829	.375	973	.348	1129	.325	1296	.271	1866
4.6	.482	728	.441	867	.407	1017	.378	1180	.353	1355	.294	1951
4.8	.521	760	.476	905	.440	1062	.409	1231	.381	1414	.318	2036
5.0	.561	792	.513	942	.474	1106	.440	1283	.411	1472	.342	2121
5.2	.602	823	.552	980	.510	1150	.473	1334	.441	1531	.368	2206
5.4	.645	855	.591	1018	.546	1194	.507	1385	.473	1590	.394	2291
5.6	.690	887	.632	1055	.583	1239	.542	1437	.506	1649	.421	2376
5.8	.735	918	.674	1093	.622	1283	.578	1488	.540	1708	.450	2460
6.0	.782	950	.717	1131	.662	1327	.615	1539	.574	1767	.479	2545
7.0	1.040	1109	.953	1319	.879	1548	.817	1796	.762	2061	.636	2968

TABLE OF CAPACITY OF PUMPS.

Diam. of cyl., inches.	Area circle, sq. in.	Length of stroke in inches, and capacity of stroke in gallons, of pump cylinder with given diameter.												Diam. of cyl., inches.
		4	5	6	8	10	12	14	15	16	18	20	24	
1¼	1.23	.0212	.0266	.0319	.0425	.0531	.0637	.0743	.0797	.0848	.0955	.1062	.1274	1¼
1⅜	1.48	.0256	.0321	.0385	.0513	.0642	.077	.089	.0963	.1027	.1156	.1280	.1541	1⅜
1½	1.77	.0306	.0382	.0459	.0612	.0765	.0918	.1071	.1147	.1224	.1377	.1530	.1836	1½
1¾	2.41	.0416	.0521	.0625	.0833	.1041	.1249	.1457	.1562	.1666	.1874	.2082	.2499	1¾
2	3.14	.0544	.068	.0816	.1088	.136	.1632	.1904	.204	.2176	.2448	.2720	.3264	2
2¼	3.98	.0688	.086	.1033	.1377	.1721	.2063	.241	.258	.2754	.3096	.3442	.4128	2¼
2½	4.91	.085	.1062	.1275	.17	.2125	.255	.2975	.3187	.34	.3825	.425	.51	2½
2¾	5.94	.1028	.1285	.1543	.2057	.2571	.3085	.3598	.3855	.4114	.4626	.5142	.617	2¾
3	7.07	.1224	.1530	.1836	.2448	.306	.3672	.4284	.459	.4896	.5508	.612	.7344	3
3¼	8.30	.1436	.1795	.2154	.2872	.3594	.4312	.503	.5385	.5748	.6466	.7182	.8624	3¼
3½	9.62	.1666	.2082	.2499	.3332	.4165	.4998	.5831	.6247	.6664	.7497	.833	.9996	3½
3¾	11.05	.1912	.239	.2868	.3824	.478	.5736	.6692	.687	.7648	.8605	.9561	1.147	3¾
4	12.57	.2176	.272	.3264	.4352	.544	.6528	.7616	.816	.8704	.9792	1.088	1.3056	4
4¼	14.19	.2456	.307	.3684	.4912	.6141	.7368	.8596	.921	.9824	1.105	1.228	1.473	4¼
4½	15.90	.2754	.3442	.4131	.5508	.6885	.8262	.9639	1.0327	1.1016	1.2393	1.377	1.6524	4½
4¾	17.73	.3068	.3835	.4602	.6136	.7671	.9204	1.073	1.15	1.2227	1.380	1.534	1.84	4¾
5	19.64	.34	.425	.51	.68	.85	1.02	1.19	1.275	1.36	1.53	1.7	2.04	5
5¼	21.65	.3748	.4685	.5622	.7496	.9371	1.124	1.311	1.405	1.499	1.686	1.874	2.228	5¼
5½	23.76	.4114	.5142	.6171	.8228	1.0285	1.2340	1.4399	1.5427	1.6456	1.8513	2.057	2.4684	5½
5¾	25.97	.4496	.562	.6744	.8992	1.124	1.348	1.573	1.686	1.789	2.022	2.248	2.696	5¾
6	28.27	.4896	.612	.7344	.9792	1.2240	1.4688	1.7136	1.8362	1.9584	2.2032	2.448	2.9376	6
6¼	30.68	.5312	.6640	.7968	1.062	1.328	1.593	1.859	1.992	2.124	2.39	2.656	3.186	6¼
6½	33.18	.5744	.7182	.8610	1.1488	1.4364	1.7955	2.0109	2.1546	2.2982	2.5885	2.8728	3.4473	6½
6¾	35.79	.6196	.7745	.9294	1.239	1.549	1.858	2.168	2.323	2.479	2.788	3.098	3.716	6¾
7	38.49	.6664	.833	.9996	1.3328	1.666	1.9992	2.3324	2.499	2.6656	2.9988	3.332	3.9984	7
7¾	47.17	.8168	1.021	1.225	1.633	2.042	2.45	2.858	3.063	3.266	3.674	4.084	4.9	7¾
8	50.27	.8704	1.088	1.3056	1.7408	2.176	2.6112	3.0464	3.264	3.4816	3.9168	4.352	5.2224	8
9	63.62	1.1010	1.377	1.6524	2.2032	2.754	3.3048	3.8556	4.131	4.4064	5.0572	5.508	6.6096	9
10	78.54	1.36	1.7	2.04	2.72	3.4	4.08	4.76	5.1	5.44	6.12	6.8	8.16	10
11	95.03	1.6451	2.057	2.464	3.2911	4.1139	4.9367	5.7595	6.1709	6.5823	7.4051	8.2279	9.8735	11
12	113.10	1.9584	2.448	2.9376	3.9168	4.896	5.8752	6.8544	7.344	7.833	8.8128	9.792	11.7504	12
13	132.73	2.297	2.872	3.445	4.596	5.745	6.894	8.042	8.616	9.192	10.34	11.49	13.78	13
14	153.94	2.665	3.331	3.997	5.33	6.663	7.994	9.328	9.993	10.66	11.99	13.32	15.98	14
15	176.71	3.059	3.824	4.589	6.119	7.649	9.178	10.70	11.47	12.23	13.76	15.29	18.35	15
16	201.06	3.48	4.35	5.22	6.96	8.703	10.44	12.18	13.05	13.92	15.66	17.40	20.88	16
18	254.47	4.404	5.505	6.606	8.808	11.01	13.21	15.41	16.51	17.61	19.81	22.02	26.42	18
20	314.16	5.440	6.8	8.16	10.88	13.6	16.32	19.04	20.4	21.76	24.48	27.2	32.64	20

TABLE OF THEORETICAL HORSE POWER REQUIRED TO RAISE WATER TO DIFFERENT HEIGHTS

Feet. / Gals. per min.	5	10	15	20	25	30	35	40	45	50	60	75	90	100	125	150	175	200	250	300	350	400	Feet. / Gals. per min.
5	.006	.012	.019	.025	.031	.037	.044	.05	.06	.06	.07	.09	.11	.12	.16	.19	.22	.25	.31	.37	.44	.50	5
10	.012	.025	.037	.050	.062	.075	.087	.10	.11	.12	.15	.19	.22	.25	.31	.37	.44	.50	.62	.75	.87	1.00	10
15	.019	.037	.056	.075	.094	.112	.131	.15	.17	.19	.22	.28	.34	.37	.47	.56	.66	.75	.94	1.12	1.31	1.50	15
20	.025	.050	.075	.100	.125	.150	.175	.20	.22	.25	.30	.37	.45	.50	.62	.75	.87	1.00	1.25	1.50	1.75	2.00	20
25	.031	.062	.093	.125	.156	.187	.219	.25	.28	.31	.37	.47	.56	.62	.78	.94	1.09	1.25	1.56	1.87	2.19	2.50	25
30	.037	.075	.112	.150	.187	.225	.262	.30	.34	.37	.45	.56	.67	.75	.94	1.12	1.31	1.50	1.87	2.25	2.62	3.00	30
35	.043	.087	.131	.175	.219	.262	.306	.35	.39	.44	.52	.66	.79	.87	1.08	1.31	1.53	1.75	2.19	2.62	3.06	3.50	35
40	.050	.100	.150	.200	.250	.300	.350	.40	.45	.50	.60	.75	.90	1.00	1.25	1.50	1.75	2.00	2.50	3.00	3.50	4.00	40
45	.056	.112	.168	.225	.281	.337	.394	45	.51	.56	.67	.84	1.01	1.12	1.41	1.69	1.97	2.25	2.81	3.37	3.94	4.50	45
50	.062	.125	.187	.250	.312	.375	.437	.50	.56	.62	.75	.94	1.12	1.25	1.56	1.87	2.19	2.50	3.12	3.75	4.37	5.00	50
60	.075	.150	.225	.300	.375	.450	.525	.60	.67	.75	.90	1.12	1.35	1.50	1.87	2.25	2.62	3.00	3.75	4.50	5.25	6.00	60
75	.093	.187	.281	.375	.469	.562	.656	.75	.84	.94	1.12	1.40	1.69	1.87	2.34	2.81	3.28	3.75	4.69	5.62	6.56	7.50	75
90	.112	.225	.337	.450	.562	.675	.787	.90	1.01	1.12	1.35	1.68	2.02	2.25	2.81	3.37	3.94	4.50	5.62	6.75	7.87	9.00	90
100	.125	.250	.375	.500	.625	.750	.875	1.00	1.12	1.25	1.50	1.87	2.25	2.50	3.12	3.75	4.37	5.00	6.25	7.50	8.75	10.00	100
125	.156	.312	.469	.625	.781	.937	1.094	1.25	1.41	1.56	1.87	2.34	2.81	3.12	3.91	4.69	5.47	6.25	7.81	9.37	10.94	12.50	125
150	.187	.375	.562	.750	.937	1.125	1.312	1.50	1.69	1.87	2.25	2.81	3.37	3.75	4.69	5.62	6.56	7.50	9.37	11.25	13.12	15.00	150
175	.219	.437	.656	.875	1.093	1.312	1.531	1.75	1.97	2.19	2.62	3.28	3.94	4.37	5.47	6.56	7.66	8.75	10.94	13.12	15.31	17.50	175
200	.250	.500	.750	1.000	1.250	1.500	1.750	2.00	2.25	2.50	3.00	3.75	4.50	5.00	6.25	7.50	8.75	10.00	12.50	15.00	17.50	20.00	200
250	.312	.625	.937	1.250	1.562	1.875	2.187	2.50	2.81	3.12	3.75	4.69	5.62	6.25	7.81	9.37	10.94	12.50	15.72	18.75	21.87	25.00	250
300	.375	.750	1.125	1.500	1.875	2.250	2.625	3.00	3.37	3.75	4.50	5.62	6.75	7.50	9.37	11.25	13.12	15.00	18.75	22.50	26.25	30.00	300
350	.437	.875	1.312	1.750	2.187	2.625	3.062	3.50	3.94	4.37	5.25	6.56	7.87	8.75	10.94	13.12	15.31	17.50	21.87	26.25	30.62	35.00	350
400	.500	1.000	1.500	2.000	2.500	3.000	3.500	4.00	4.50	5.00	6.00	7.50	9.00	10.00	12.50	15.00	17.50	20.00	25.00	30.00	35.00	40.00	400
500	.625	1.250	1.875	2.500	3.125	3.750	4.375	5.00	5.62	6.25	7.50	9.37	11.25	12.50	15.62	18.75	21.87	25.00	31.25	37.50	43.75	50.00	500

TABLE OF ATOMIC WEIGHTS (1912).

Element.	Symbol.	Atomic weight O = 16.	Element.	Symbol.	Atomic weight O = 16.
Aluminium	Al	27.1	Molybdenum	Mo	96.0
Antimony	Sb	120.2	Neodymium	Nd	144.3
Argon	A	39.88	Neon	Ne	20.2
Arsenic	As	74.96	Nickel	Ni	58.68
Barium	Ba	137.37	Nitrogen	N	14.01
Bismuth	Bi	208.0	Osmium	Os	190.9
Boron	B	11.0	Oxygen	O	16.0
Bromine	Br	79.92	Palladium	Pd	106.7
Cadmium	Cd	112.4	Phosphorus	P	31.04
Cæsium	Cs	132.81	Platinum	Pt	195.2
Calcium	Ca	40.07	Polonium	Po	(?)
Carbon	C	12.0	Potassium	K	39.10
Cerium	Ce	140.25	Præsodymium	Pr	140.6
Chlorine	Cl	35.46	Radium	Ra	226.4
Chromium	Cr	52.0	Rhodium	Rh	102.9
Cobalt	Co	58.97	Rubidium	Rb	85.45
Columbium	Cb	93.5	Ruthenium	Ru	101.7
Copper	Cu	63.57	Samarium	Sm	150.4
Dysprosium	Dy	162.5	Scandium	Sc	44.1
Erbium	Er	167.7	Selenium	Se	79.2
Europium	Eu	152.0	Silicon	Si	28.3
Fluorine	F	19.0	Silver	Ag	107.88
Gadolinium	Gd	157.3	Sodium	Na	23.00
Gallium	Ga	69.9	Strontium	Sr	87.63
Germanium	Ge	72.5	Sulphur	S	32.07
Glucinum	Gl	9.1	Tantalum	Ta	181.5
Gold	Au	197.2	Tellurium	Te	127.6*
Helium	He	3.99	Terbium	Tb	159.2
Hydrogen	H	1.008	Thallium	Tl	204.0
Indium	In	114.8	Thorium	Th	232.
Iodine	I	126.92	Thullium	Tm	168.5
Iridium	Ir	193.1	Tin	Sn	119.0
Iron	Fe	55.85	Titanium	Ti	48.1
Krypton	Kr	82.92	Tungsten	W	184.0
Lanthanum	La	139.0	Uranium	U	238.5
Lead	Pb	207.1	Vanadium	V	51.0
Lithium	Li	6.94	Xenon	Xe	130.2
Lutecium	Lu	174.0	Ytterbium	Yb	172.0
Magnesium	Mg	24.32	Yttrium	Yt	89.0
Manganese	Mn	54.93	Zinc	Zn	65.37
Mercury	Hg	200.6	Zirconium	Zr	90.6

* Flint, *Am. Jour. Sci.*, Vol. 30, p. 1209, 1910, gives atomic weight as 124.3.

COST OF COMPLETED WATER-WORKS PIPE LINES, VALVES NOT INCLUDED. PIPE AT $28.00 PER TON.

Size, inches.	Per lineal foot of line.		Size, inches.	Per lineal foot of line.	
	Light pipe.	Heavy pipe.		Light pipe.	Heavy pipe.
4	$0.55	$0.75	20	$3.00	$4.00
6	.65	.90	24	3.50	4.80
8	1.00	1.50	30	4.50	6.50
10	1.50	1.75	36	6.00	8.50
12	1.75	2.00	42	8.00	12.00
14	2.00	2.35	48	10.00	15.00
16	2.25	3.00	54	12.00	18.00
18	2.50	3.20	60	15.00	24.00

Prices are assumed as averages for territory where there is a variation from sand and light soil to clay and hard pan.

	Per cent.
Interest on investment	5
Depreciation	5
Repairs	2
Taxes	1
Insurance	1
Total	14

WROUGHT-IRON WELDED STEAM, GAS AND WATER PIPE.
(Table of Standard Dimensions.)

Diameter.			Thickness.	Circumference.		Transverse areas.			Length of pipe per square foot of		Length of pipe containing one cubic foot.	Nominal weight per foot.	Number of threads per inch of screw
Nominal internal.	Actual external.	Actual internal.		External.	Internal.	External.	Internal.	Metal.	External surface.	Internal surface.			
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Sq. ins.	Sq. ins.	Sq. ins.	Feet.	Feet.	Feet.	Pounds.	
$\frac{1}{8}$	.405	.27	.068	1.272	.848	.129	.0573	.0717	9.44	14.15	2513.	.241	27
$\frac{1}{4}$	.54	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.49	1383.3	.42	18
$\frac{3}{8}$	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18
$\frac{1}{2}$	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
$\frac{3}{4}$	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	$11\frac{1}{2}$
$1\frac{1}{4}$	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	$11\frac{1}{2}$
$1\frac{1}{2}$	1.9	1.611	.145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	$11\frac{1}{2}$
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	$11\frac{1}{2}$
$2\frac{1}{2}$	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
$3\frac{1}{2}$	4	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
$4\frac{1}{2}$	5	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.34	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	8
11	12	11.25	.375	37.699	35.343	113.098	99.402	13.696	.318	.339	1.456	45.95	8
12	12.75	12.	.375	40.055	37.7	127.677	113.098	14.579	.299	.319	1.27	48.985	8
13	14	13.25	.375	43.982	41.626	153.938	137.887	16.051	.273	.288	1.04	53.921	8
14	15	14.25	.375	47.124	44.768	176.715	159.485	17.23	.255	.268	.903	57.893	8
15	16	15.25	.375	50.265	47.909	201.062	182.655	18.407	.239	.250	.788	61.77	8
....	18	17.25	.375	56.549	54.192	254.47	233.706	20.764	.212	.221	.616	69.66	
....	20	19.25	.375	62.832	60.476	314.16	291.04	23.12	.191	.198	.495	77.57	
....	22	21.25	.375	69.115	66.759	380.134	354.657	25.477	.174	.179	.406	85.47	
....	24	23.25	.375	75.398	73.042	452.39	424.558	27.832	.159	.164	.339	93.37	

DIAMETER AND CAPACITY OF PIPES AND CYLINDERS, AND WEIGHT OF CONTAINED WATER IN 100 FEET OF PIPE.

Diameter, inches.	For 1 foot in length.		
	Cubic feet, also area in square feet.	U. S. gallons, 231 cubic inches.	Area, square inches.
1/4	.0003	.0025	.04909
5/16	.0005	.004	.0767
3/8	.0008	.0057	.11045
7/16	.001	.0078	.15033
1/2	.0014	.0102	.19635
9/16	.0017	.0129	.2485
5/8	.0021	.0159	.3068
11/16	.0026	.0193	.37122
3/4	.0031	.0230	.44179
13/16	.0036	.0269	.51849
7/8	.0042	.0312	.60132
15/16	.0048	.0359	.69029
1	.0055	.0408	.7854
1 1/4	.0085	.0638	1.2272
1 1/2	.0123	.0918	1.7671
1 3/4	.0167	.1249	2.4053
2	.0218	.1632	3.1416
2 1/4	.0276	.2066	3.9761
2 1/2	.0341	.2550	4.9087
2 3/4	.0412	.3085	5.9396
3	.0491	.3672	7.0686
3 1/4	.0576	.4309	8.2958
3 1/2	.0668	.4998	9.6211
3 3/4	.0767	.5738	11.045
4	.0873	.6528	12.566
4 1/4	.0985	.7369	14.186
4 1/2	.1134	.8263	15.904
4 3/4	.1231	.9206	17.721
5	.1364	1.020	19.635
5 1/4	.1503	1.125	21.648
5 1/2	.1650	1.234	23.758
5 3/4	.1803	1.349	25.967
6	.1963	1.469	28.274
6 1/4	.2131	1.594	30.680
6 1/2	.2304	1.724	33.183

Pounds weight of water, per 100 feet in pipe.	
Diameter, pipe, inches.	Pounds in 100 feet.
1 3/4	104.27
2	136.20
2 1/4	172.37
2 1/2	212.8
2 3/4	257.48
3	306.43
3 1/4	359.63
3 1/2	417.08
3 3/4	478.8
4	544.76
4 1/4	614.98
4 1/2	689.46
4 3/4	768.2
5	851.19
5 3/4	1125.7
6	1225.7
6 1/2	1438.5

DIAMETER AND CAPACITY OF PIPES AND CYLINDERS, AND WEIGHT OF CONTAINED WATER IN 100 FEET OF PIPE (*Continued*).

Diameter, inches.	For 1 foot in length.		
	Cubic feet, also area in square feet.	U. S. gallons, 231 cubic inches.	Area, square inches.
6¾	.2485	1.859	35.785
7	.2673	1.999	38.485
7¼	.2867	2.145	41.282
7½	.3068	2.295	44.179
7¾	.3276	2.45	47.173
8	.3492	2.611	50.265
8¼	.3712	2.777	53.456
8½	.3941	2.948	56.745
8¾	.4176	3.125	60.132
9	.4418	3.305	63.617
9¼	.4667	3.491	67.201
9½	.4922	3.682	70.882
9¾	.5185	3.879	74.662
10	.5454	4.08	78.54
10¼	.5730	4.286	82.516
10½	.6013	4.498	86.59
10¾	.6303	4.715	90.763
11	.66	4.937	95.033
11¼	.6903	5.164	99.402
11½	.7213	5.396	103.87
11¾	.7530	5.633	108.43
12	.7854	5.875	113.1
12½	.8522	6.375	122.72
13	.9218	6.895	132.73
13½	.994	7.436	143.14
14	1.069	7.997	153.94
14½	1.147	8.578	165.13
15	1.227	9.180	176.71
15½	1.310	9.801	188.69
16	1.396	10.44	201.06
16½	1.485	11.11	213.82
17	1.576	11.79	226.98
17½	1.670	12.49	240.53
18	1.768	13.22	254.47
18½	1.867	13.96	268.80

Pounds weight of water, per 100 feet in pipe.	
Diameter, pipe, inches.	Pounds in 100 feet.
6¾	1551.29
7	1668.33
7½	1915.18
8	2179.04
8½	2459.94
9	2757.85
9½	3072.79
10	3404.76
10½	3753.74
11	4119.75
11½	4502.79
12	4902.85
12½	5319.93
13	5754.04
14	6673.32
15	7660.7
.....	.....
.....	.....
.....	.....

GALLONS IN CISTERNS AND TANKS 5 TO 20 FEET IN DEPTH BY 5 TO 25 FEET IN DIAMETER.

Depth in feet.	Diameter in feet.																
	5	6	7	8	9	10	11	12	13	14	15	16	18	20	22	24	25
5	725	1060	1440	1875	2380	2,925	3,550	4,237	4,960	5,765	6,698	7,520	9,516	11,750	14,215	16,918	18,358
6	870	1270	1728	2250	2855	3,510	4,260	5,084	5,952	6,918	8,038	9,024	11,419	14,100	17,059	20,302	22,030
7	1015	1480	2016	2625	3330	4,095	4,970	5,931	6,944	8,071	9,378	10,528	13,322	16,450	19,902	23,680	25,701
8	1160	1690	2304	3000	3805	4,680	5,680	6,778	7,936	9,224	10,718	12,032	15,225	18,800	22,745	27,070	29,372
9	1305	1900	2592	3375	4280	5,265	6,390	7,625	8,928	10,377	12,058	13,536	17,128	21,150	25,588	30,454	33,043
10	1450	2110	2880	3750	4755	5,850	7,100	8,472	9,920	11,530	13,398	15,040	19,031	23,500	28,431	33,838	36,714
11	1595	2320	3168	4125	5230	6,435	7,810	9,319	10,913	12,683	14,738	16,544	20,934	25,850	31,274	37,222	40,385
12	1740	2530	3456	4500	5705	7,020	8,520	10,166	11,904	13,836	16,078	18,048	22,837	28,200	34,117	40,606	44,056
13	1885	2740	3744	4875	6180	7,605	9,230	11,013	12,896	14,989	17,418	19,552	24,740	30,550	36,960	43,990	47,727
14	2030	2950	4032	5250	6655	8,190	9,940	11,860	13,888	16,142	18,758	21,056	26,643	32,900	39,803	47,374	51,398
15	2175	3160	4320	5625	7130	8,775	10,650	12,707	14,880	17,295	20,098	22,260	28,546	35,250	42,646	50,758	55,069
16	2320	3870	4608	6000	7605	9,360	11,360	13,554	15,872	18,448	21,438	24,064	30,449	37,600	45,489	54,142	58,740
17	2465	3580	4896	6375	8080	9,945	12,070	14,401	16,864	19,601	22,778	25,568	32,352	39,950	48,332	57,520	62,411
18	2610	3790	5184	6750	8535	10,530	12,780	15,248	17,856	20,754	24,118	27,072	34,255	42,300	51,175	60,910	66,082
19	2755	4000	5472	7125	9010	11,115	13,490	16,095	18,848	21,907	25,458	28,576	36,158	44,650	54,018	64,294	69,753
20	2900	4210	5760	7500	9490	11,700	14,200	16,942	19,840	23,060	26,798	30,080	38,062	47,000	56,861	67,678	73,424

For tanks that are tapering, measure the diameter four-tenths of distance from the large end.

Convenient Equivalents. (U. S. Geol. Survey.)

The following is a list of convenient equivalents for use in hydraulic computations:

1 second-foot equals 40 California miner's inches (law of March 23, 1901).

1 second-foot equals 38.4 Colorado miner's inches.

1 second-foot equals 40 Arizona miner's inches.

1 second-foot equals 7.48 United States gallons per second; equals 448.8 gallons per minute; equals 646,272 gallons for one day.

1 second-foot equals 6.23 British imperial gallons per second.

1 second-foot for one year covers 1 square mile 1.131 feet or 13.572 inches deep.

1 second-foot for one year equals 31,536,000 cubic feet.

1 second-foot equals about 1 acre-inch per hour.

1 second-foot for one day covers 1 square mile 0.03719 inch deep.

1 second-foot for one 28-day month covers 1 square mile 1.041 inches deep.

1 second-foot for one 29-day month covers 1 square mile 1.079 inches deep.

1 second-foot for one 30-day month covers 1 square mile 1.116 inches deep.

1 second-foot for one 31-day month covers 1 square mile 1.153 inches deep.

1 second-foot for one day equals 1.983 acre-feet.

1 second-foot for one 28-day month equals 55.54 acre-feet.

1 second-foot for one 29-day month equals 57.52 acre feet.

1 second-foot for one 30-day month equals 59.50 acre-feet.

1 second-foot for one 31-day month equals 61.49 acre-feet.

100 California miner's inches equals 18.7 United States gallons per second.

100 California miner's inches equals 96.0 Colorado miner's inches.

100 California miner's inches for one day equals 4.96 acre-feet.

100 Colorado miner's inches equals 2.60 second-feet.

100 Colorado miner's inches equals 19.5 United States gallons per second.

100 Colorado miner's inches equals 104 California miner's inches.

100 Colorado miner's inches for one day equals 5.17 acre-feet.

100 United States gallons per minute equals 0.223 second-foot.

100 United States gallons per minute for one day equals 0.442 acre-foot.

1,000,000 United States gallons per day equals 1.55 second-feet.

1,000,000 United States gallons equals 3.07 acre-feet.

1,000,000 cubic feet equals 22.95 acre-feet.

1 acre-foot equals 325,850 gallons equals 43,560 cubic feet.

1 inch deep on 1 square mile equals 2,323,200 cubic feet.

1 inch deep on 1 square mile equals 0.0737 second-foot per year.

1 foot equals 0.3048 meter.

1 mile equals 1.60935 kilometers.

1 mile equals 5280 feet.

1 acre equals 0.4047 hectare.

1 acre equals 43,560 square feet.

1 acre equals 209 feet square, nearly.

1 square mile equals 2.59 square kilometers

1 cubic foot equals 0.0283 cubic meter.

1 cubic foot equals 7.48 gallons.

1 cubic foot of water weighs 62.5 pounds.

1 cubic meter per minute equals 0.5886 second-foot.

1 horse power equals 550 foot-pounds per second.

1 horse power equals 76.0 kilogram-meters per second.

1 horse power equals 746 watts.

1 horse power equals 1 second-foot falling 8.80 feet.

$1\frac{1}{3}$ horse powers equals about 1 kilowatt.

To calculate water power quickly: $\frac{\text{Sec.-ft.} \times \text{fall in feet}}{11}$ = net horse power on water wheel realizing 80 per cent of theoretical power.

Definition of Terms.

The volume of water flowing in a stream — the "run-off" or "discharge" — is expressed in various terms, each of which has become associated with a certain class of work. These terms may be divided into two groups: (1) Those which represent a rate of flow, as second-feet, gallons per minute, miner's inches, and run-off in second-feet per square mile, and (2) those which represent the actual quantity of water, as run-off in depth in inches and acre-feet. They may be defined as follows:

"Second-foot" is an abbreviation for cubic foot per second and is the rate of discharge of water flowing in a stream 1 foot wide, 1 foot deep, at a rate of 1 foot per second. It is generally used as a fundamental unit from which others are computed by the use of the factors given in the table of equivalents on previous pages.

"Gallons per minute" is generally used in connection with pumping and city water supply.

The "miner's inch" is the rate of discharge of water that passes through an orifice 1 inch square under a head which varies locally. It is commonly used by miners and irrigators throughout the West and is defined by statute in each state in which it is used.

"Second-feet per square mile" is the average number of cubic feet of water flowing per second from each square mile of area drained, on the assumption that the run-off is distributed uniformly both as regards time and area.

"Run-off in inches" is the depth to which the drainage area would be covered if all the water flowing from it in a given period were conserved and uniformly distributed on the surface. It is used for comparing run-off with rainfall, which is usually expressed in depth in inches.

"Acre-foot" is equivalent to 43,560 cubic feet, and is the quantity required to cover an acre to the depth of 1 foot. It is commonly used in connection with storage for irrigation work.

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