Hunt (A.E.) & Clapp (Geo. H.)

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THE IMPURITIES OF WATER.

BY A. E. HUNT AND GEORGE H. CLAPP, PITTSBURGH, PA.

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THIS paper constitutes in substance a part of a more elaborate chapter, accompanied with extended tables of analyses, prepared for the book of Mr. Fred. H. Whipple on "Water Supply." In advance of that use of the material, however, it seemed appropriate to lay a portion of it before the Institute; and this opinion of the authors, the Council, by accepting the paper, has ratified.

It may seem at first glance, nevertheless, that a paper dealing chiefly with this subject in its sanitary aspects, and only treating in a subordinate way of the one subject (boiler-scale) usually deemed to concern our professions, is somewhat out of place in our *Transactions.* But reflection will, we trust, correct this impression. In recent periods, and in continually increasing degree, the managers of mining and metallurgical operations, especially the latter, have found themselves charged with the care of large numbers of men; and the sanitary conditions of such establishments have become an important factor in their technical and commercial success. A general survey of the organic as well as the inorganic impurities of water may be suggestive and useful to such; and since the chemists at metallurgical works might easily, with slight guidance, and without extra expense to their employers, ascertain the sanitary conditions presented by the water-supply, this subject may well be laid before them. At the same time, it is not proposed that our *Transactions* shall be crowded, to the exclusion of more directly professional material, with details of sanitary science. These must, of course, be sought in special treatises, or at the hands of expert specialists.

To prove the importance of this subject, we need only point to the startling proofs, collected since the announcement of the germ-theory of disease, that a contaminated water-supply is the active agent in spreading numerous epidemics, for which such a cause was formerly unsuspected.

There is, perhaps, no question which more severely taxes the resources of science than the determination of the fitness or unfitness of a water-supply. Not only must waters of bad taste or smell and carrying considerable amounts of foreign matter be rejected, but many waters not only agreeable to the taste, but colorless, odorless, and containing very little suspended matter, are often the abundant sources of disease.

It has long been known that dissolved oxygen plays an important part in the purification of water; that the amount of oxygen contained in water carrying putrefiable organic matter is very low; and that where oxygen is deficient, and organic contamination considerable, fish and higher grades of animal life desert the water, while microscopic examination shows an abundance of the lower forms of vegetable and animal life, such as *algæ* and *infusoria*. It has been further observed that common fish, such as sunfish and suckers, will live nearer the source of contamination than the higher-mettled salmon and bass. Practical data thus given by nature should go hand in hand with the chemical analysis of a water-supply; for the evidence of nature is based upon larger samples, and hence better averages, than the chemist can command for analysis.

Color.—By reason of vegetable and peaty matter, many samples, especially of surface-waters, have a decided color; a yellowish-brown of various shades and degrees of intensity being the prevailing hue. Professor T. M. Drown has adopted a very satisfactory series of standards for comparison of these shades, by solutions containing the Nessler reagent with certain known amounts of ammonia, so that the degree of color can be expressed in terms of given amounts of Nesslerized ammonia.

These colored waters are not necessarily unwholesome. On the contrary, while they are not as attractive for drinking, and nearly always show more or less albuminoid ammonia, they often contain very little free ammonia, and are sometimes quite wholesome and pure.

Suspended Matter.—In the analysis of drinking-water, the character of the suspended matter, and its capacity to settle, or, on the other hand, to remain in fine suspension, and be served to the consumer through the service-mains, should be the criterion as to the advisability of filtering before analysis. In general, the chemist should seek to include in his analysis whatever the consumer includes in the water he drinks.

Odor.—The odor a water gives should be noted. Many waters have decided odors, some already formed from the gases dissolved in the water, and constantly given off from it, or easily liberated by shaking the water, and sometimes liable to be generated by chemical or other changes in the dissolved or suspended matter. The odors of waters may best be tested in a confined space, as by shaking a wide-mouthed gallon-bottle, half filled with the water, and immediately smelling the air in the bottle, which will be impregnated with the gases from the water.

Some waters give a different odor when cold than when hot; and the odor of some is due entirely to the suspended matter, and can be entirely removed by filtration, while in others filtration does not affect the odor.

Prof. Drown, in his paper on "The Odor and Color of Surface-Waters," read before the New England Water-Works Association, in 1887, suggests a series of terms for describing the various odors of waters, which we believe to be good, and have adopted in our own practice. He says of them:

"'Earthy' is the odor of freshly-turned soil or of a moist hot-house; it often passes into 'musty.' 'Straw-like' is the odor of moist straw; I think no one could mistake it, or fail to recognize it; it is one of the most frequent odors met with in surface-waters 'Mouldy' is the odor of moist straw which has begun to decompose; there is nothing disagreeable suggested by it; it is also somewhat allied to earthy or loamy odor. 'Mustiness' is advanced mouldiness and verges on the disagreeable. It is the odor of damp, closed vaults. 'Wooden' is the odor of tubs with hot water; it suggests wash-day. 'Disagreeable' is a more difficult term to explain, first, because it is not easy to get agreement among different observers on this point, and secondly, because under it we include two classes of odors, namely those of growth and those of decay. Some aquatic plants and low animal organisms give off mal-odorous matters as the product of their normal growth, and all organisms are more or less mal-odorous in the process of decay. Now, it sometimes happens that these two odors cannot be sharply distinguished from one another; they are both unpleasant odors So in the absence of finer discrimination of odors, or the positive identification of the noxious plants or animals, there seems to be no other way than to include them under the head of 'disagreeable.' It is of interest to note in this connection, that the river waters rarely give, either hot or cold, these 'disagreeable' odors. They are generally confined to the waters of lakes, ponds, and reservoirs, which have abundant vegetation and but little motion. River waters, even those of considerable organic impurity, give 'straw-like' and 'mouldy' odors, but the unpleasant, fishy, oily and rotting odors are, as far as my experience goes, generally absent. 'Offensive' is a term sufficiently characteristic, it is more than disagreeable and may be reserved for waters undergoing putrefaction change, or for those which contain considerable sewage. Of the odors of the waters at ordinary temperature, the most frequently recurring are 'straw-like' and 'mouldy' and 'disagreeable.' When heated, the 'wooden,' 'earthy' and 'musty' odors are apt to be developed."

"To express degrees of intensity of odor I am in the habit of using the qualifying terms; 'very faint,' 'faint,' 'distinct,' 'decided' and 'strong.' A good deal of personal equation comes in here. What is 'faint' to one is 'distinct' to another and 'very faint' to a third. Still there seems to be need of some degrees of comparison of intensity of odors, and, at all events, the use of any set of terms by the same observer will give comparable results."

"The origin of the odors of surface waters, when uncontaminated with sewage or other drainage, is clearly referable to the vegetable and peaty matters of the soil over and through which it flows, and to the vegetable and other growths in the water itself.

Water Analyses.—Sanitary analyses are made (1) to discover, with regard to a given water, whether it contains any organic or inorganic poisons, or such an amount of earthy constituents as will make it deleterious for drinking and cooking; or (2) to determine its value as a mineral (medicinal) water.

Commercial analyses are made to determine concerning a given water, (1) its applicability for making steam; (2) its hardness, or the facility with which it will "form a lather" necessary for washing; or (3) its adaptation to other manufacturing purposes than those mentioned above.

The common impurities of water are held in suspension (organic matter, both living and dead, and silica, clay, or other materials which the water may have been in contact); or in solution (mineral salts and acids, and the products of the decomposition of organic matter from sewage or other contamination).

The results of water-analyses are reported in grains per Imperial, or United States wine, gallon, or in parts per thousand, hundred-thousand, or million. The imperial gallon is reckoned as 277 cubic inches, or ten pounds, or 70,000 grains, and the United States, or wine, gallon, as 231 cubic inches, or 58,372 grains, of pure water, at 4 degrees C.

Until quite recently, the standard method of reporting adopted by English and American chemists has been in grains per Imperial gallon; but at a late meeting of the Chemical Section of the American Association for the Advancement of Science, held in Buffalo, it was decided to report all water-analyses in parts per thousand, hundred-thousand and million, and circulars were sent to the different chemists throughout the country, asking their co-operation in establishing this uniform practice.

To chemists who have been using the old method, the transition will be simple, as the Imperial gallon of water weighs 70,000 grains; and by taking 70 cubic centimeters (70,000 milligrammes), of water for analysis, we have a miniature gallon, in which the milligramme corresponds to the grain.

Uniformity in reporting results of chemical analyses is of great advantage for comparison. It seems to some desirable to have a well-known volume in mind when looking over analyses. But "grains per gallon" does not ordinarily mean grains per U. S. standard, or wine, gallon, but grains per Imperial gallon (not a well-known volume to us), and moreover, parts per 100,000 can easily be converted into grains per gallon, if desired, by dividing the results by 10 and multiplying by 7. The practical usefulness in this instance, however, of the conception of the gallon as a unit-volume, is doubtful. The largest proportion of impurities found in any water used for potable or manufacturing purposes (except for making steam), is so small that the measure of volume is only comparative. For instance, 70 parts per 100,000, the greatest amount of impurities that could ordinarily be allowed in potable water, only means 7-100 of one per cent.; so that in practice the figures come to have significance, not in their relations to the unit-volume, but only by comparison with one another, or with certain standards.

Sampling.—A sample of water taken for analysis should be at least one-half gallon, if practicable. It should be kept in a cool and dark place until examined, and where possible, the analysis should be commenced within a few days. (In case of necessity, if extreme care be taken, as small a quantity as 50 cubic centimeters, or two fluid-ounces, may suffice for analysis.) It should be collected in a *perfectly clean* glass-stoppered bottle,* which should be rinsed out with the water before finally taking the sample. To insure a fair average for such a test, if the water be taken from a pump or faucet, it should be allowed to run some little time before collecting the sample. Samples should not be taken too near the shore of a pond or stream of water, if the average of the whole is desired.

In collecting, the mouth of the bottle should be opened some little depth under the surface of the water, to avoid the entrance of any surface-scum. A note should also be made, whether there has been previous long drought or heavy rain, and what is the condition of the water-level, together with a statement as to the neighborhood of any probable source of contamination.

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* Although it is preferable to have a glass-stopper to the bottle, still a clean and new cork will answer, but a cork contaminated with any other substance or luted with any sort of paste, might seriously injure the water for analysis.

Sanitary Analyses.—The difference in the specific gravity of waters, due to their relative degrees of purity, is very slight; so slight that, between pure distilled water and water that is very bad and has over 200 parts per 100,000 of total solid residue, the difference is in the fourth decimal place, and very close to the factor of error or variance in making specific-gravity tests. Hence no reliable tests can ordinarily be made in this way as to the comparative purity of samples of water.

The impurities in suspension vary from practically nothing in pure spring- and deep lake-waters, to perhaps 500 parts per 100,000 in the water of many rivers, after heavy freshets.

In solution, some pure artesian well-waters, some spring-water, rain-water, etc., have as little as 5 parts per 100,000, while the analyses of sea-water, some lake and river waters, and of some deep wells, range far above this proportion. Sea-water contains about 4100 parts.

For sanitary purposes, it is necessary to analyze water for the presence of metallic, and, occasionally, of vegetable, poisons, mineral acids, or septic poisons from contaminations of sewage. Such septic poisons cannot be separated, and their weight directly determined by analysis; for they never have a definite and exact chemical composition, like metallic poisons.

The presence of septic poisons in water is shown by an excess of nitrogenous matter, indicated by the amount of chlorine and of free and albuminoid ammonia in the solution; the chlorine largely coming from the chlorides of soda and potash, which, with urea, are among the principal ingredients of ordinary urine.

Ammonia is evolved as the result of the decomposition of nitrogenous organic matter. Its presence in water in the small amounts reported in the analyses, even of the foulest waters, is harmless; it is only as indicative of decomposing organic matter that it shows the poisonous nature of the water in which it is found in considerable proportions.

Albuminoid ammonia is the term given to nitrogenous organic matter of such a character that it is converted into ammonia by letting the water-solution of it stand.

In large cities it is estimated that 30 gallons of water *per capita* of population, on the average, flows through the service-mains daily. A very large portion of this reaches the sewers and constitutes the bulk of the sewage. As a simple calculation, based upon the nature and amount of the contaminating material, will show, the average sewage contains in 100,000 parts, about 10 parts of free ammonia, and from 0.01 to 0.06 parts of albuminoid ammonia. When the free ammonia exceeds 0.02 parts per 100,000 in water taken from a thickly populated district, it is a probable sign that the water consists of dilute sewage. In such cases, the water will also usually contain over 0.6 parts of chlorine for river-water, and over 0.8 parts of chlorine for deep well- or spring-waters. The presence of albuminoid ammonia (over 0.018 parts per 100,000) with but little free ammonia and chlorine, is generally an indication of vegetable contamination, injurious to health. A sample of water containing per 100,000 more than 0.7 parts of chlorine, together with more than 0.015 parts of free and albuminoid ammonia, or both, can be declared with a considerable degree of certainty to contain decomposing nitrogenous organic matter which, either in itself or in the accompanying germs, contains septic poisons and will be dangerous to drink, although the character of the organic contamination is so varied that no exact danger-limit can, with our present knowledge of these impurities, be positively fixed. Not that the presence of chlorine, which is so often present in combination with sodium, as common salt, is dangerous in itself, or that minute amounts of free and albuminoid ammonia poison the water; but that they are indications of the presence of septic poisons, which cannot be separated by themselves.

"Nesslerizing" is a method discovered by the chemist Nessler, for determining the strength of dilute solutions of ammonia by comparing the yellowish-brown color given to the ammonia-solution by the Nessler reagent,—an alkaline solution of iodide of potassium saturated with periodide of mercury,—the color being more or less intense, according to the proportion of ammonia present in the solution tested. In testing samples of water, they are first distilled, and the ammonia which is carried over in the distillate is then determined by Nesslerizing. The ammonia found in the first distillate, before the addition of any reagents, is the free ammonia; the albuminoid is distilled over after the addition of caustic potash and permanganate of potash to oxidize the nitrogenous matter that is capable of producing ammonia on standing. It is called "albuminoid" ammonia, because albumen in water-solution, when treated as described above, yields ammonia.

The free ammonia represents the amount of change or complete decomposition of nitrogenous matter which has already taken place in the water; the albuminoid ammonia, the amount of change of which the water is still capable by reason of the presence of nitrogenous matter.

Complete oxidation of animal or other nitrogenous matter will result in the formation of nitric and carbonic acids, which, in the presence of alkalies or alkaline earths, will form nitrates and carbonates, comparatively harmless in themselves.

The presence of nitrites and of ammonia shows intermediate states of decomposition of the organic matter, due, very likely, to the microbes and living germs of disease, which are nearly always present with decomposing organic matter. Nitrous acid, which combines with alkalies and alkaline earths to produce nitrites, is an intermediate state between ammonia and nitric acid salts or nitrates.

The metallic poisons apt to be found in potable waters are lead, zinc, iron, and copper. Chromium and arsenic are rarely found, and their presence in water, in any quantity, should be considered dangerous.

Authorities differ as to the amounts of metal which would be considered injurious. Wanklyn states that "a good drinking-water should not contain more than one-tenth or two-tenths grains of iron per gallon, or more than one-tenth of lead or copper." It is a question whether so small a quantity of iron should condemn a water. Many iron-springs, considered healthful, contain a much larger amount. Undoubtedly, the form in which the iron-salt exists would largely influence its action.

Well-authenticated cases of lead-poisoning have been occasioned by the cumulative action of lead which had been taken into the system in water containing 0.2 parts of lead per 100,000.

A very simple test for metals can be made by taking a miniature gallon of the water (70 cubic centimeters) in a clean porcelain dish, adding three drops of sulphide of ammonia, which should give but a very slight coloration to the fluid, and which should be instantly cleared up and become invisible by the addition of a few drops of hydrochloric acid. Good water will answer to this test, and water that does not should be examined carefully and quantitatively for the presence of metallic impurities, before being accepted as potable.

Microscopic Examination of Water.—There are many living organisms, both animal and vegetable, which infest some waters, and which have to be examined microscopically. The microbes, ferments, and germs existing in some waters are the causes of many diseases flesh is heir to. Every year scientific research, especially with the aid of the microscope, is bringing to light new facts as to the presence and influence on human life and health of these minute organisms.

The microscopic examination of water is not so much to determine the larger forms of animal and vegetable life, as it is to separate and identify the septic or pathogenic microbes that are due to sewage-contamination, or are taken up from the air and soil in fever- and cholera-infected districts. Decomposing nitrogenous organic matter we cannot say positively is poisonous, but we know by the aid of the microscope that associated with it are many microbes, some of which may be germs of specific diseases.

These microbes are the different forms of *Bacillus*, as the *B. tuberculosis*, which is the organism causing tubercular consumption; the "*Comma Bacillus*" of Koch, which is now generally conceded to be the cause of Asiatic cholera, and others which have not been so positively identified, such as the *Bacilli* of typhoid and relapsing fevers, and that of yellow fever, which Dr. Freire, of Brazil, claims to have identified and cultivated. These organisms are only found in waters polluted with surface drainage and sewage contaminated by the *dejecta* of fever patients, the *sputum* of persons suffering from tubercular consumption, or similar matter expelled from the bodies of patients in some of the many diseases caused by the presence of pathogenic microbes. These dangers are now so universally recognized, that State Boards of Health are publishing very stringent rules for the destruction of such poisonous matter, and, indeed, of anything with which it may have come in contact.

The investigation and the determination of the different forms of microbes require the highest skill of the trained microscopist; and any statements made by investigators without such training and skill are very likely to be erroneous. These organisms are among the smallest and least differentiated with which the microscopist has to deal. They are distinguished by different methods of cultivation, and by the way in which the different groups take certain well-known and distinctive stains; the water-soluble aniline dyes being those generally used for this purpose.

Micro-organisms are classified as aerobic and anaerobic, (or those which require oxygen for their development and those which do not), septic and non-septic, pathogenic and non-pathogenic; the septic being those which cause putrefaction in dead bodies, while the pathogenic are those which cause disease.

These minute organisms may be separated from water by adding about one cubic centimeter of a one and one-half per cent. solution of osmic acid to 30 or 40 cubic centimeters of water. All organisms are by this reagent precipitated as a thick, dark-colored deposit, from which the water is decanted off, leaving the deposit to be examined afterwards under the microscope. In this deposit will be found a large number of septic and non-septic organisms which occur in all surface waters; and without careful training in a biological laboratory, it will be impossible to distinguish the various forms.

Cultivation-experiments are carried on, either by plate- or "flask-" culture, in the different organic or inorganic media which have been proved suitable for the purpose. A list of such media can be found in any of the standard works on microscopy; most fully, perhaps, in Klein's "Micro-Organisms and Disease," fourth edition. The methods of sterilizing all the apparatus and media, and of preserving them from contamination by the air, or from any other cause, are there explained.

After inoculating the culture-medium, the growth of the colonies is carefully watched for several days; and if the colonies appear to be pure—that is, composed of only one microbe—fresh tubes or plates are inoculated, and this is repeated several times, until there is no doubt of the purity of the culture.

The microbes must then be studied by their reaction with certain stains, and by their effect upon living animals. The number of organisms in water is estimated by inoculating a certain amount of sterilized gelatine on a plate with a measured amount of water and counting the number of colonies which develope.

The Total Solid Residue.—The total solid residue in water varies from 5 parts per 100,000 in some deep, pure spring-waters to 4100 parts in ocean-water. The character of this residue, as well as its amount, should be known, to establish the value of water for drinking. In most cases, where the total solid residue left upon evaporation does not exceed 40 parts per 100,000, it is not found upon examination to injure the water for such purposes. A larger amount than 40 parts per 100,000 should occasion a further investigation of the water. Of course, if the total solid residue consists of very poisonous matter, a smaller amount will cause injury.

The solid residue may consist of lime, soda, magnesia and potash, or organic matter, and of finely divided silica. The chloride, bicarbonate, and sulphate are the salts of lime most commonly looked for in waters to be tested as to fitness for drinking and cooking. The presence of more than 15 parts per 100,000 of these lime salts should condemn a water for such purposes, under ordinary circumstances. However, in a good many of the Western states, the people are obliged to use water containing a larger amount of lime than this. A large amount of lime in drinking-water is liable to produce *goitre*, calculus, urinary and dyspeptic diseases. On the other hand, the presence of lime salts in sufficient quantity to render the water perceptibly hard, yet less than 35 parts per 100,000, has not proved unwholesome. In fact, many cities having hard drinking-water have a very favorable mortality as compared with similar cities having soft drinking-water, carrying less than 15 parts per 100,000 of lime salts.

The following definition of liquids which should be deemed polluting and inadmissible into a stream, was formulated by the Rivers Pollution Commission of Great Britain (1886).

(a.) Any liquid which has not been subjected to perfect quiet in subsidence-ponds of sufficient size for a period of at least six hours, or which, having been so subjected to subsidence, contains in suspension more than one part by weight of dry organic matter in 100,000 parts by weight of the liquid, or which, not having been so subjected to subsidence, contains in suspension more than three parts by weight of dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid.

(b.) Any liquid containing, in solution, more than two parts by weight of organic carbon or 0.3 part by weight of organic nitrogen in 100,000 parts by weight.

(c.) Any liquid which shall exhibit by daylight a distinct color when a stratum of it one inch deep is placed in a white porcelain or earthenware vessel.

(d.) Any liquid which contains in solution, in 100,000 parts, by weight, more than two parts by weight of any metal except calcium, magnesium, potassium, or sodium.

(e.) Any liquid which in 100,000 parts by weight contains, whether in solution or suspension, in chemical combination or otherwise, more than 0.05 part by weight of metallic arsenic.

(f.) Any liquid which, after acidification with sulphuric acid contains, in 100,000 parts by weight, more than one part by weight of free chlorine.

(g.) Any liquid which contains, in 100,000 parts by weight, more than one part by weight of sulphur, in the condition of either sulphuretted hydrogen or a soluble sulphuret.

(h.) Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 1000 parts by weight of distilled water.

(i.) Any liquid possessing an alkalinity greater than that which is produced by adding one part by weight of dry caustic soda to 1000 parts by weight of distilled water.

(k.) Any liquid exhibiting a film of petroleum or hydro-carbon upon its surface, or containing in suspension, in 100,000 parts, more than 0.05 part of such oil.

To these standards was attached the proviso, that "no effluent water shall be deemed polluting if it be not more contaminated with any of the above named polluting ingredients than the stream or river into which it is discharged."

Mineral Waters.—Natural spring-waters impregnated with mineral substances to such an extent as to have a medicinal effect, are called mineral waters Such waters are commonly divided, according to the character of the foreign substances held in solution, under the heads of carbonated, alkaline, sulphuretted, saline (including magnesian, chalybeate, and chlorinated), and siliceous waters. It is not necessary to describe these various classes here. The subject is one, with the general features of which our members are presumed to be acquainted, and the thorough discussion of which, though it would be both pertinent and valuable, is not within the purpose of the present paper.

Commercial Analyses.—By far the most common commercial analysis of water is made to determine its fitness for making steam. Water containing more than 5 parts per 100,000 of free sulphuric or nitric acid is liable to cause serious corrosion, not only of the metal of the boiler itself, but of the pipes, cylinders, pistons and valves with which the steam comes in contact. Sulphuric acid is the only one of these acids liable to be present in the water from natural sources; it being often produced in the waters of the coal and iron districts, by the oxidation of iron pyrites to sulphate of iron, which, being soluble, is lixiviated from the earth strata and carried into the stream. The presence of organic matter taken up by the water in its after-course, reducing the iron and lining the bottom of the stream with red oxide of iron, and leaving a considerable proportion of the sulphuric acid free in the water. This is a troublesome feature with the water necessarily used in many of the iron districts of this country. The sulphuric acid may come from other natural chemical reactions than the one described above.

Muriatic and nitric acids, as well as often sulphuric acid, may be conveyed into water through the refuse of various kinds of manufacturing establishments discharged into it.

The large total residue in water used for making steam causes the interior linings of the boilers to become coated, clogs their action and often produces a dangerous hard scale, which prevents the cooling action of the water from protecting the metal against burning.

Lime and magnesia bicarbonates in water lose their excess of carbonic acid on boiling, and often, especially when the water contains sulphuric acid, produce, with the other solid residues constantly being formed by the evaporation, a very hard and insoluble scale. A larger amount than 100 parts per 100,000 of total solid residue will ordinarily cause troublesome scale, and should condemn the water for use in steam-boilers, unless a better supply cannot be obtained.

The following is a tabulated form of the causes of trouble with water for steam-purposes, and the proposed remedies, given by Prof. L. M. Norton, in his lecture on " Industrial Chemistry :"

Brief Statement of Causes of Incrustation.

1. Deposition of suspended matter.
2. Deposition of dissolved salts from concentration.
3. Deposition of carbonates of lime and magnesia by boiling off carbonic acid, which holds them in solution.
4. Deposition of sulphates of lime, because sulphate of lime is but slightly soluble in cold water, less soluble in hot water, insoluble above 140 degrees centigrade.
5. Deposition of magnesia, because magnesium salts decompose at high temperature.
6. Deposition of lime soap, iron soap, etc., formed by saponification of grease.

Various Means for Preventing Incrustation.

1. Filtration.
2. Blowing off.
3. Use of internal collecting apparatus or devices for directing the circulation.
4. Heating feed-water.

5. Chemical or other treatment of water in boiler.
6. Introduction of zinc into boiler.
7. Chemical treatment of water outside of boiler.

Tabular View.

Troublesome Substance.	Trouble.	Remedy or Palliation.
Sediment, mud, clay, etc.	Incrustation.	Filtration. Blowing off.
Readily soluble salts.	"	Blowing off.
Bicarbonates of lime, magnesia, iron.	"	Heating feed. Addition of caustic soda, lime, or magnesia, etc.
Sulphate of lime.	"	Addition of carbonate of soda, barium chloride, etc.
Chloride and sulphate of magnesium.	Corrosion.	Addition of carbonate of soda, etc.
Carbonate of soda in large amounts.	Priming.	Addition of barium chloride, etc.
Acid (in mine waters).	Corrosion.	Alkali.
Dissolved carbonic acid and oxygen.	"	Heating feed. Addition of caustic soda, slacked lime, etc.
Grease (from condensed water).	"	Slacked lime and filtering. Carbonate of soda. Substitute mineral oil.
Organic matter (sewage).	Priming.	Precipitate with alum or ferric chloride and filter.
Organic matter.	Corrosion.	Ditto.

The mineral matters causing the most troublesome boiler-scales are bicarbonates and sulphates of lime and magnesia, oxides of iron and alumina, and silica. The analyses of some of the most common and troublesome boiler-scales are given in the following table:

Analyses of Boiler-Scale.

	Sulphate of Lime.	Magnesia.	Silica.	Peroxide of Iron.	Water.	Chloride of Soda.	Carbonate of Lime.	Lime, CaO.	Sulphuric Acid.	Carbonic Acid.	Authority.
From British Admiralty Report. Steamer Amethyst......	94.64	2.88	trace	trace	2.45	trace					Admir'lty Report.
Malabar.......	95.93	3.10	0.40	0.40	....	“					“
Fox.............	77.30	10.55	trace	5.80	6.00	“					“
Patrothus......	96.37	1.62	0.60	0.60	1.75	“					“
Velindra......	91.38	2.31	1.40	1.60	3.30	“					“
Other Sea-Going Scale. (Wallace.) Atmospheric Pressure of 0.34	33.95	40.05	trace	1.33	24.67	trace	....				Wallace.
0.4 to 0.51	66.88	18.96	“	0.50	11.66	“	0				“
0.7	69.77	15.75	0.16	1.36	8.25	0.99	3.44				“
1 to 1.12	74.21	14.95	0.57	1.34	6.89	2.04	....				“
1.4	72.85	13.18	0.80	2.40	8.27	2.16	0.34				“
Hartford, Conn., River Water.........	22.70	5.32		4.57				40.0	2.63	15.62	Mac Farlane.
Same as above after using Soda Ash....	18.55	3.33		2.23				42.35	....	24.95	“
Holyoke, Mass..........	12.49	7.34		3.57				29.41	0.64	25.03	“
Southington, Conn., Well Water I....	23.50	10.66		0.60				34.83	6.89	18.74	“
II.....	28.85	5.58		1.01				40.90	2.33	17.03	“
Danbury, Conn., Brook	15.07	4.94		12.77				34.66	0.48	21.15	“
North Adams, Mass., Brook	4.23	4.27		1.12				35.01	46.51	....	“
St. Croix River.........	0.61	4.80		1.12				35.49	52.03	....	“
Atmospheric Pressure. 2.5 to 3	50.75	1.19	0.47	2.24	3.68		44.25				Fischer.
3	67.14	9.69	trace	5.28	7.90		14.65				“
3.5	79.71	3.83	0.88	1.67	3.45		8.30				“
3.5	31.96	7.11	trace	2.10	2.31		55.65				“
5	80.74	4.36	....	0.52	4.21		8.20				“
5—6	98.04	....	....	0.20	....	....	....				“
N. Y. C. & H. Ry., No. 1...	74.07	9.19	0.65	0.08	1.14		14.78				Chandler.
“ “ 2...	71.37		1.76								“
“ “ 3...	62.86	18.95	2.60	0.92	1.28		12.62				“
“ “ 4...	53.05		4.79								“
“ “ 5...	46.83		5.32								“
“ “ 6...	30.80	31.17	7.75	1.08	2.44		26.93				“
“ “ 7...	4.95	2.61	2.07	1.03	0.63		86.25				“
“ “ 8...	0.88	2.84	0.65	0.36	0.15		93.19				“
“ “ 9...	4.81		2.92								“
“ “ 10...	30.07		8.24								“

The following table shows the analyses of samples of water giving bad results for steam-purposes:

Analyses in Parts per Hundred Thousand of Waters Giving Bad Results for Steam-Purposes.

	Bicarbonate of Lime Deposited on Boiling.	Bicarbonate of Magnesia Depos'd on Boil'g	Total Lime.	Total Magnesia.	Sulphuric Acid.	Chlorine.	Iron.	Organic Matter.	Alumina.	Chloride of Sodium.	
Feed-water giving Scales 2.5—3...	225	19	450	85	219	293	Se	e Ta Boil	ble er Sc	D of ales.	Fischer.
" 3 atmosph.	88	3	147	22	121	59					"
" 3.5 "	tr'ce	0	46	9	40	......					"
" 3.5 "	63	39	155	68	89	91					"
" 5 "	46	0	244	32	232	9					"
" 5—6 "	tr'ce	0	599	81	306	770					"
Coal-mine wat'r	110	25	119	39	890	590	780	30	640		A. E. Hunt.
Salt-well.........	151	38	1.90	48	360	990	38	21	30	13.10	A. E. Hunt.
Spring...........	75	89	95	120	310	21	75	10	80	36	"
Monongahela River*..........	130	21	161	33	210	38	70				"
"	80	70	94	81	219	210	90				"
"	32	82	61	1.04	28	1.90	38				"
Allegheny riv'r near Oil-w'rks	30	50	41	68	890	42	23				"

Many substances have been added with the idea of causing chemical action which will prevent boiler-scale. As a general rule, these do more harm than good; for a boiler is among the worst possible places in which to carry on a chemical reaction, where it nearly always causes more or less corrosion of the metal, and is liable to cause dangerous explosions.

In cases where water containing large amounts of total solid residue is necessarily used, a heavy petroleum oil, free from tar or wax, which is not acted upon by acids or alkalies, not having sufficient wax in it to cause saponification, and which has a vaporizing-point at nearly 600 degrees Fahrenheit, will give the best results in preventing boiler-scale. Its action is to form a thin greasy film over the boiler-linings, protecting them largely from the action of acids in the water, and greasing the sediment which is formed, thus preventing the formation of scale and keeping the solid residue from the evaporation of the water in such a plastic, suspended condition

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* Taken near discharge-pipes from large manufacturing establishments.

that it can be easily ejected from the boiler by the process of "blowing off." If the water is not blown off sufficiently often, this sediment forms into a kind of a "putty" that will necessitate cleaning the boilers. Any boiler using bad water should be blown off every twelve hours. The formation of scale of hard residue on the boiler-linings will be almost entirely prevented by the use of this oil, which is manufactured in Pittsburgh, and sold in the markets under the name of "Boiler Scale Resolvent."

Hardness of Water.—The hardness of water, or its opposite quality, indicated by the ease with which it will form a lather with soap, depends almost altogether upon the presence of compounds of lime and magnesia. Almost all soaps consist, chemically, of oleate, stearate, and palmitate, of an alkaline base, usually soda and potash. The more lime and magnesia in a sample of water, the more soap a given volume of the water will decompose, so as to give insoluble oleate, palmitate, and stearate of lime and magnesia, and consequently the more soap must be added to a gallon of water in order that the necessary quantity of soap may remain in solution to form the lather. The relative hardness of samples of water is still generally expressed in terms of the number of standard soap-measures consumed by a gallon of water in yielding a permanent lather, rather than in parts per hundred thousand, for the reason that as the relative hardness of samples of water has come to be a commercial quality, and is determined by many who are not chemists, it has been found more difficult to change the method of reporting. As before explained, reports in degrees or grains per imperial gallon can be readily transposed in parts per hundred thousand by multiplying the number of grains by 10 and dividing the product by 7.

The standard soap-measure is the quantity required to precipitate one grain of carbonate of lime.

It is commonly reckoned that one gallon of pure distilled water takes one soap-measure to produce a lather. Therefore, one is deducted from the total number of soap-measures found to be necessary to use to produce a lather in a gallon of water, in reporting the number of soap-measures, or "degrees" of hardness of the water sample. In actually making tests for hardness, the "miniature gallon," or seventy cubic centimeters, spoken of on a previous page, is used rather than the inconvenient larger amount. The standard measure is made by completely dissolving ten grammes of pure castile soap (containing 60 per cent. olive oil) in a liter of weak alcohol (of about 35 per cent. alcohol). This yields a solution containing exactly the evaporation of the water in such a plastic suspended condition sufficient soap in one cubic centimeter of the solution to precipitate one milligramme of carbonate of lime, or, in other words, the standard soap-solution is reduced to terms of the "miniature gallon" of water taken. The correctness of the standard soap-solution is standardized against a solution of one gramme of carbonate of lime, dissolved in hydrochloric acid, carefully neutralized with ammonia and diluted to one litre, so that each cubic centimeter represents one milligramme of carbonate of lime.

If a water charged with bicarbonate of lime, magnesia, or iron, is boiled, it will, on the excess of the carbonic acid being expelled, deposit a considerable quantity of the lime, magnesia, or iron, and consequently the water will be softer. The hardness of the water after this deposit of lime, after long boiling, is called the *permanent hardness*, and the difference between it and the total hardness is called *temporary hardness*.

Lime salts in water react *immediately* on soap-solutions, precipitating the oleate, palmitate, or stearate of lime at once. Magnesia salts, on the contrary, require some considerable time for reaction. They are, however, more powerful hardeners; one equivalent of magnesia salts consuming as much soap as one and one-half equivalents of lime.

The presence of soda and potash salts softens rather than hardens water.

The applicability of a given water for very many of the manufacturing industries requires its analysis for the contained impurities. The most common injurious impurities for manufacturing purposes are the free acids, excessive amounts of total solids, and salts affecting the relative hardness.

NOTE BY THE SECRETARY.—Comments or criticisms upon the foregoing paper, whether private corrections of typographical or other errors, or communications for publication as "Discussion," or independent papers on the same or a related subject, are earnestly invited.