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WATER SUPPLIES

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THEIR PURIFICATION, FILTRATION AND STERILISATION

A HANDBOOK FOR THE USE OF LOCAL AND MUNICIPAL AUTHORITIES

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PREFACE

SINCE 1896 when one of us made a summary of the results obtained from the chemical and bacteriological examination of water and their bearing on the purification works necessary for ensuring a proper supply for drinking purposes, the science of water purification has developed in several important directions, and the earlier methods in use in England during the greater part of the last century have been improved almost out of recognition. This development has been mainly due to the zeal and enterprise of the growing cities in America which have realised that one of the most essential factors for the well-being of a community is an ample supply of clean and wholesome water. Whilst these American investigations were in progress, much new information on the natural changes which occur in water when stored and filtered was obtained here and on the continent from the accumulated data derived from a study of new sources and the variation in the quality of those municipal supplies which had been systematically studied during recent years.

The reports embodying these developments now form a voluminous literature, and the conclusions arrived at seem to indicate that many of the earlier processes for the protection of water from contamination can be modified with advantages which render it imperative that these departures from the primitive methods should be carefully considered by those interested in this branch of public health service.

Local considerations of expediency and of expense have also to be taken into account in dealing with these problems, and the engineering difficulties in the way of some of the larger schemes have sometimes been regarded as sufficient justification to delay or even to shelve indefinitely works which would have benefited large populations. It is hoped that without too many technical details, the following pages summarise the science and practice of modern water supply and water purification in a way which may be of use to many readers. Our thanks are due to the London Metropolitan Water Board and others who have kindly lent photographs and blocks for illustration.

SAMUEL RIDEAL,
ERIC K. RIDEAL.

28, Victoria Street,
Westminster,
September, 1914.

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CHAPTER I.

PURE WATER—INORGANIC CONSTITUENTS OF NATURAL WATERS.

In a strictly scientific sense absolutely pure water is a chemical ideal, because the liquid dissolves and absorbs a varying quantity of nearly all substances with which it comes in contact ; its preparation and preservation in a pure state are consequently problems of the greatest difficulty. For general purposes, however, it is not necessary, nor is it always advisable, that water should be pure to this extent ; it is sufficient if it is made and kept so pure as always to fulfil certain tests and come up to certain standards in its chemical or hygienic properties.

The impurities in nominally pure water are generally so insignificant that they may be disregarded as having no appreciable action on man or on industrial or technical processes. Some of them are occasionally present in such large quantities that their effect is felt ; while it is well known that they may even confer special utility, as in mineral waters, or in other cases be detrimental or poisonous. Since the injury wrought by an impurity is dependent on its nature, it is the business of the water-chemist to set limits to the degree of contamination, within ranges such that the constituents shall have no effect, or at least no bad effect, on the human system or in manufacturing operations. For this purpose it is needful to classify both the characters of the waters under investigation, and also the physical and chemical nature of the impurities.

The chief physical data that have to be ascertained are the following : turbidity, colour, taste, odour, original temperature, and sometimes electrical resistance. It is difficult to make physical factors exactly comparable, and much work has been devoted to establishing standards and degrees in these "organoleptic" characters, the chief results of which are given in the last chapter of this book.

The solid impurities may be divided into three groups according to their physical states—the suspended solids, the colloidal substances, and the matters really in solution. Chemically they may be classified as organic and inorganic constituents.

The Gaseous Contents of Waters.

A water to be palatable should be fully aerated, *i.e.* it should be nearly saturated with the natural constituents of the atmosphere, namely oxygen, nitrogen, and carbon dioxide or carbonic acid, otherwise the liquid is flat and insipid. Deep waters have, as a rule, a larger quantity of nitrogen and less oxygen in solution for the following reason. Dissolved oxygen is consumed by fish life and also in the self-purification of rivers, since it oxidises the organic impurities they contain; in the case of deep well waters, to which the air has had little or no access, the process of natural purification has occurred long since, and has produced nitrogen gas, the free oxygen almost disappearing.

Since air contains about $\frac{1}{5}$ of its volume of oxygen, and $\frac{4}{5}$ of nitrogen, the relative partial pressures of each gas will be as $\frac{1}{5}$ is to $\frac{4}{5}$; according to Henry's law the quantity of gas dissolved is proportional to its coefficient of solubility and to its partial pressure. The coefficients of solubility of oxygen and nitrogen are 3 per cent. and $1\frac{1}{2}$ per cent. respectively, consequently the amounts dissolved from the air will be $3\% \times \frac{1}{5} = 0{\cdot}6$ per cent. for oxygen, and $1\frac{1}{2} \times \frac{4}{5} = 1{\cdot}2\%$ for nitrogen. The dissolved oxygen of water often gives an indication as to whether there is any putrescible organic matter present by which the oxygen is being consumed. This is ascertained by an incubation test as follows. Three accurately stoppered bottles are completely filled with the water, and kept at 16° C. (a convenient mean temperature): the dissolved oxygen remaining is determined after one, two, and five days. With pure waters there will be scarcely any difference, while with contaminated samples there will be a more or less rapid decline. The Royal Commission on Sewage Disposal of 1898 adopted this, as in their eighth report of 1912, as a part of their maximum limit of impurity to be allowed in ordinary sewage effluents. They proposed as a normal standard, suspended matter not to exceed 3 parts per 100,000; and when tested with its suspended matter included not to take up more than 2·0 parts per 100,000 of dissolved oxygen in five days at 65° F.

Roscoe and Lunt[*] have constructed the following table of the amounts of dissolved oxygen per litre in fully aerated water for each half-degree between 5° C. and 30° C., and for an observed pressure of 760 mm. (29·93 in.). When the observed pressure is below 760 mm., $\frac{1}{76}$ the value must be subtracted for every 10 mm. difference; the same value must be added when the pressure is above 760 mm. Parts by weight per 100,000 are obtained by dividing the number of cubic centimetres by 7.

Temp.	Cc. Oxygen.	Temp.	Cc. Oxygen.	Temp.	Cc. Oxygen.
5·0	8·68	13·5	7·20	22·0	6·04
5·5	8·58	14·0	7·12	22·5	5·99
6·0	8·49	14·5	7·04	23·0	5·94
6·5	8·40	15·0	6·96	23·5	5·89
7·0	8·31	15·5	6·89	24·0	5·84
7·5	8·22	16·0	6·82	24·5	5·80
8·0	8·13	16·5	6·75	25·0	5·76
8·5	8·04	17·0	6·68	25·5	5·72
9·0	7·95	17·5	6·61	26·0	5·68
9·5	7·86	18·0	6·54	26·5	5·64
10·0	7·77	18·5	6·47	27·0	5·60
10·5	7·68	19·0	6·40	27·5	5·57
11·0	7·60	19·5	6·34	28·0	5·54
11·5	7·52	20·0	6·28	28·5	5·51
12·0	7·44	20·5	6·22	29·0	5·48
12·5	7·36	21·0	6·16	29·5	5·45
13·0	7·28	21·5	6·10	30·0	5·43

With ordinary waters at common temperatures, if the

---

[*] *Trans. Chem. Soc.*, 1889, p. 552.

incubation test shows a fall from 7 c.c. per litre (= 1·0 part by weight per 100,000), oxidisable contamination is indicated.

A high carbon dioxide content is deleterious to the piping system of water-works (see further p. 48). It may be attributable to natural sources in the earth, and much is derived from the oxidation of organic matter, the fourth and fifth samples in the following table are instances of each of these causes. Sir E. Frankland * gives as the actual volumes of gases expelled on boiling five typical waters :—

CUBIC CENTIMETRES PER LITRE.

	Rain-water.	Cumberland mountain water.	Loch Katrine water.	Thames water.	Deep chalk well-water.
Nitrogen . . .	13·08	14·24	17·31	13·25	19·44
Oxygen	6·37	7·26	7·04	5·88	0·28
Carbonic acid . .	1·28	2·81	1·13	40·21	55.20
	20·73	24·31	25·48	59·34	74·92

The above carbon dioxide figures include not only the dissolved gas but also that present in combination as bicarbonate, since this is also evolved on boiling.

Ammonia is almost entirely absent from pure waters. Since it is one of the final products of the bacteriological decomposition of animal matter, it is usually an indication of pollution, and frequently a sign of contamination by urine. It is, however, oxidised with comparative ease by certain organisms to nitrites and nitrates, or used up by algæ, hence its presence points generally to recent contamination. It will be further dealt with later.

Hydrogen sulphide and sulphur dioxide are present in some mineral springs, the former constituting hepatic and the latter sulphurous waters. Sulphuretted hydrogen is at once revealed by an odour of rotten eggs and an unpleasant hepatic taste ; these waters are only used for medicinal or technical purposes, and will be described in that section of this chapter.

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* *Water Analysis*, 1880, p. 3.

Argon has been detected in the gases derived from some waters, proving that the gases were at any rate partly of atmospheric origin. Helium, a somewhat rare gas found occluded in certain minerals such as cleveite, is occasionally found in spring water.

The state of the gases in water is somewhat uncertain; it is generally assumed that those which exhibit a departure from Henry's law, such as carbon dioxide, ammonia, sulphur dioxide and hydrogen sulphide, are not simply dissolved, but have undergone some more or less complex chemical combination with the solvent.

The Mineral Solids of Waters.

The nature and amounts of the mineral salts will depend on the rocks or soils passed over or percolated through, since almost all substances are to a certain extent soluble in or acted on by water and air. The quantity dissolved will be affected by the surface exposed and by the time of contact, also by the degree of solubility of the substance and the presence of accessories like oxygen and carbonic acid. The solubility of substances, with certain exceptions (notably sulphate of lime), increases with rising temperature and pressure, hence many thermal deep springs contain abnormal amounts of dissolved ingredients, such as silica, which are deposited as crusts on exposure to air. In natural waters the following cations are usually to be found; ammonium, sodium, (potassium), calcium, (aluminium), iron, magnesium, (manganese), and traces of other metals. These are in solution with the following anions, carbonate, chloride (phosphate), nitrate (nitrite), sulphate, silica. Occasionally also we find poisonous substances such as arsenic, barium, boron, copper, lead, strontium, zinc; and in medicinal waters lithium, iodine, bromine, radium emanation and several other substances. The mineral constituent which is usually present in largest quantity in fresh water is calcium carbonate, dissolved by the carbon dioxide as bicarbonate (calcium hydrogen carbonate); magnesium carbonate is dissolved in a similar manner.

Chloride, nitrate, and sulphate of these two metals are common constituents and cause the water to become "hard"; the characteristics and treatment of hard waters will be dealt with in a later section.

Potassium salts are not usually present except in case of fæcal pollution. Common salt is always found, but not in large quantity except in some mineral waters, in the sea, or near brackish estuaries. Unless it can be traced to a marine origin or shown to have been dissolved from rocks, like the new red sandstone, which contain deposits of salt and brine springs, its presence in quantity is significant of animal contamination, chiefly from urine. The relationship of the geological formation of the source to the mineral contents of the water derived, is a very important one to water engineers, for a knowledge of the underlying strata will often settle the question as to whether a well should be sunk on any particular site or no. A table of the sources of water supply, and the probable chemical nature of the water that they will yield, is given in the appendix.

Among substances more rarely occurring in waters are the following.

Arsenic, in mineral waters such as Duerkheim, Val Sinestra, Wiesbaden, and others; also traces in some mining streams. It may originate from contamination by dye-works' effluents and the like. The two last sources may of course contribute other unusual substances.

Copper is very seldom naturally present. When either copper piping, or copper salt for sterilising is used, traces of the metal can generally be detected afterwards.

A serious and rather frequent contamination is that with compounds of lead, which is known to have a cumulative poisonous action, so that even a minute quantity taken day by day accumulates in the system, until the characteristic symptoms of "plumbism" or lead colic appear. The illness is severe and frequently fatal. Very few natural sources are thus tainted. In mining districts the metal is often found dissolved in issuing brooks, but in general it is entirely precipitated by the aqueous sulphates before it reaches the main stream. Therefore when lead is detected it is usually to be attributed to the material of the pipes or cisterns with which the water has been in contact.

The capacity for dissolving lead varies considerably. Acid waters derived from peaty moorlands are usually strongly plumbo-solvent (see Houston, Local Government Report, 1895). Free oxygen and free carbon dioxide increase this power to a high degree, and it is also augmented by nitrites or chlorides, owing to the formation of soluble basic lead salts.

The importance of ascertaining the nature and amount of the salts dissolved in a water cannot be too strongly emphasised, and is especially needed for their use in steam-boilers, since the formation of non-conducting crusts and the possibility of attack on the boiler-plates are grave problems. The composition of a variety of boiler incrustations is tabulated in the appendix. Inorganic suspended matters producing turbidity more particularly in times of flood, are small sand particles and clay. Soot is somewhat frequent in town waters, indicating either insufficient protection from atmospheric dust, or admixture with rain-water. Minute crystals of carbonate of lime are often observed in hard waters. Colloidal silica and alumina have sometimes been found, and are common in hot springs. But compounds of iron, as more or less impure ferric hydrate, are the most usual aqueous colloids, and their removal may form one of the most difficult problems the water engineer has to face. The iron generally occurs as bicarbonate, ferrous hydrogen carbonate, in solution ; in the presence of the oxygen of the air colloidal ferric hydroxide is produced according to the equation :—

$$2Fe(HCO_3)_2 + O + H_2O = Fe_2(OH)_6 + 4CO_2$$

Part is deposited in crusts or sediment, part remains suspended or colloidal and renders the liquid turbid, and a part stays in solution as bicarbonate with its brown-red colour. The carbonic acid liberated in the above equation is evidently free to act again on metal or rock.

Iron pyrites, FeS_2, may be slowly acted on in presence of carbonate of lime, water and oxygen as follows:—

$$FeS_2 + CaCO_3 + CO_2 + H_2O + 2O_2 = FeH_2(CO_3)_2 + CaSO_4 + S$$

or the pyrites may be oxidised by the air to sulphates of iron and sulphuric acid, which appear in many mine waters. The influence of colloids and their removal will be described later.

Saline and Medicinal Waters

come mainly from volcanic strata. The springs usually disengage a large quantity of various gases, including some of the rarer ones, and are often effervescent from the escape of CO_2, which may have been generated by (1) oxidation of carbonaceous material, (2) action of heat on calcium carbonate (limestone, marble, chalk), or on other carbonates, (3) decomposition of these by acids—even silicic and boric can decompose them at high temperatures. The oxidation of pyrites may give sulphuric acid, and hydrochloric acid is often evolved in the gases of volcanoes. Both of these acids therefore sometimes exist free in mineral waters, and sulphuric can decompose any salt and liberate its acid.

Sulphuretted hydrogen, H_2S, is produced by the action of acids on natural sulphides, some of which owe their origin to the reduction of sulphates. The sulphur springs of Krisuvik, Iceland, have long been known; they evolve both H_2S and SO_2, and deposit large crusts of sulphur from the mutual action of these gases. They are caused by the infiltration of heated water on vast beds of pyrites.

Nitrogen, and sometimes hydrogen and oxygen are also met with in the escaping gases. *Hydrocarbons*, occasionally present in thermal waters, are generated by volcanic energies, one of the theories of their production being as follows. Metallic carbides are first formed by the direct union of carbon with metals, or from the reduction of carbonates by carbon, both of which actions require a high temperature. The carbides are then decomposed by steam in a manner similar to the modern manufacture of acetylene, when lime having been first made from limestone in kilns:—

Limestone, marble, or chalk

$$CaCO_3 = CaO + CO_2,$$

is strongly heated with carbon, whereby calcium carbide is produced:—

$$CaO + 3C = CaC_2 + CO,$$

The carbide placed in water gives acetylene, C_2H_2:—

$$CaC_2 + H_2O = CaO + C_2H_2.$$

Carbides are well known to be present in ordinary iron, and traces are found in other metals. When these are acted on by acids or steam, the carbon combines with some of the evolved hydrogen to form hydrocarbons. Analogous circumstances will have occurred in nature. Hydrocarbons are also formed by the action of subterranean heat on vegetable and animal fossils, as with the fire-damp of coal mines. Some of these compounds are produced in fermentations of organic matter by anaerobic or putrefactive organisms, but this would hardly concern mineral springs.

Radium is met with in unusual quantities in some medicinal waters, and special therapeutic effects are attributed to it. The following table gives a number of examples:—

TABLE OF RADIOACTIVITY OF MINERAL WATERS.

Locality.	Litres of gas evolved per hour.	Temp. of water in ° C.	Radioactivity.		Authority and Notes.
			Maché units.	Grammes of radium per litre (Strutt's method).	
Yellowstone Park, U.S.A.—					
Hot River, Mammoth Springs		51°	26·3		Schlundt & Moore, U.S. Geol. Survey, Washington, Bull. 395, 35, 1909.
Apollinaris Spring. . .		9·2°	22·1		Ditto.
South Bench Spring. . .		86°	4·44		Ditto.

Locality.	Litres of gas evolved per hour.	Temp. of water in ° C.	Radioactivity.		Authority and Notes.
			Maché units.	Grammes of radium per litre (Strutt's method).	
Continental—					
Bad Gastein		36·3°	155		Friese, *Pharm. Zentr.*, 50, 579, 1910.
Baden Baden		23·5°	126		
Karlsbad, iron spring		8·4°	38·4		
Karlsbad, Sprudel		72·9°	0·4		Deposits about 110 lbs. per 24 hours of sinter containing radium.
Wildbach		32·9° to 35·8°	1·06 to 3·2		
Marienbad		4·8°	2·27		
Wiesbaden, Kochbrunnen	480 to 500	68°	1·23		Gases contain CO_2, N_2, O_2, and hydrocarbons, with smaller quantities of H_2S, argon, neon, helium, and radium emanation.
Bad Neuheim		15°	28·6		
Homburg V. d. H.		10·6°	8		
Durkheim, Max spring	30			$0·97 \times 10^{-10}$	Sediment contains Silica, Ca, Fe, Mn, As, etc.; and from 1·8 to 3 mgrm. of radium per grm. of sediment. Ebler & Fellner, *Z. anorg. Chem.*, 1911, 72, 233; Levin, *Phys. Zeits.*, 1910, 11, 322.
Bad Froy, Villnösstal, Tyrol.				"activity 30 to 40"."	*Monats.*, 1910, xxxi. 221.
Brambach, Saxony			2270 (Weidig, 1965)		"By far the most radioactive known." Fresenius & Czapski, *Chem. Zeit.*, 1911, 35, 722.
Finggi, Rome		about 10			
Val Lumpegnia, Switzerland			9·2		
Colombières-sur-Orb, France	1800			Radium emanation 860 mgm.-minutes per 24 hours.	Danne & Crémieux, *Comptes rendus*, 1911, cliii., 870.

Locality.	Litres of gas evolved per hour.	Temp. of water in ° C.	Radioactivity.		Authority and Note.
			Maché units.	Grammes of radium per litre (Strutt's method).	
Continental—					
Plombières, France				Average radioactivity 1·1 mgm.-minutes per 10 litres.	Water flow averages 507 litres per minute, containing 0·06 grm. of radium bromide. Brochet, *Comptes rendus*, 1910, cl, 145.*
La Toja, Spain .				$\cdot 0356 \times 10^{-5}$	De Rada, *Anal. Fis. Quim.*, 1912, x. 175.
Alturas de Palacios, Plasencia, Spain .		19·5°		Radioactivity 1944 volts per hour-litre.	Chofré, *ibid.*, 1909, 7, 479.
British—					
Bath : King's Well . . .	205	50°		0·139 mgm. radium in a million litres.	A litre of the gas contains in c.c. CO_2 36, N_2 964, O_2, H_2 and CH_4 none (or traces), argon 7·2, neon 2·3, helium 0·3. Masson & Ramsay, *J. Chem. Soc.*, 1912.
Buxton . . .				1·10 mgm. in a million litres.	MacOwen.
Strathpeffer .					A few litres of radium-containing water per day.
Harrogate †					

It has often been pointed out that we possess in Great Britain curative resorts and waters which are quite equal to those in other countries.

No exact classification of saline and medicinal springs is feasible, since in most cases each of them contains some proportion of the characteristic ingredient of another group, but it is convenient to arrange them under the following chief heads, according to the most important constituents :—

---

* Brochet has found that there are some springs in the Vosges running to waste which have high radioactivity, *ibid.*, p. 291.

† Prof. Smithells writes us that the Harrogate waters include a number of marked radioactivity, which are at present being examined at the Leeds University, but the report of actual figures is not yet published.

1. *Carbonated*, divided into (*a*) alkaline: $NaHCO_3$ (and rarely also some $KHCO_3$, as in Royat and Vichy); (*b*) magnesian: $MgH_2(CO_3)_2$ (Schwalbach); (*c*) calcareous, $CaH_2(CO_3)_2$.

2. *Chalybeate* or iron waters, containing ferrous bicarbonate and sometimes sulphate, also occasionally manganous bicarbonate.

3. *Muriated*, mainly NaCl, sometimes with a little KCl.

4. *Aperient or Sulphatic*, (*a*) Sulphate of soda (Glauber's salt); (*b*) Bitter; sulphate of magnesia (Epsom salt).

5. *Bromide and Iodide* waters, NaBr and NaI, are commonly classed together but have different therapeutical properties.

6. *Sulphuretted or Hepatic*, NaHS and H_2S.

7. *Arsenical.*

8. *Lithia* waters.

Waters strongly impregnated with various compounds have been utilised as industrial sources, *e.g.* brine, magnesian, iodised, and boracic springs. These have yielded in former ages, and sometimes are still forming, the deposits which are now worked, such as the soda lakes (Na_2CO_3), the Stassfurt salts (potash) and the sulphur beds of Iceland, Sicily, and Japan.

The study of the formation of deposits of aqueous origin has been greatly assisted by the results derived by the application of the phase-rule of Willard Gibbs and the practical experiments conducted by van't Hoff at Berlin. The exact conditions which gave rise to the Stassfurt deposits have been theoretically and experimentally worked out.

The evaporation of inland seas is going on at the present time, and in some cases the complicated process of salt deposition can actually be followed from year to year. Some examples of the total saline content in the liquids are as follows in grammes per litre:—Black Sea, 17·5; Atlantic Ocean, 35·5; Mediterranean, 40·7; Dead Sea, at surface, 27·1; ditto, 300 metres below surface, 278·1; showing in the last case how the liquid is more concentrated at lower depths.

When ordinary salt water which contains, together with sodium chloride, smaller quantities of magnesium, potassium, and calcium chlorides and sulphates, is evaporated at 25° C., deposition takes place of the various salts in the following order:—

1. Sodium chloride.

2. Sodium chloride and magnesium sulphate ($MgSO_4$, $7H_2O$).

3. Sodium chloride and potassium-magnesium sulphate, $MgK_2(SO_4)_2$, $4H_2O$ ("leonite").

4. Sodium chloride, leonite and potassium chloride, or sodium chloride and kainite ($MgSO_4$, KCl, $3H_2O$).

5. Sodium chloride, kieserite ($MgSO_4$, H_2O), and carnallite ($MgCl_2$, KCl, $6H_2O$).

6. Sodium chloride, kieserite, carnallite, and hydrated magnesium chloride ($MgCl_2$, $6H_2O$). The solution then dries up without further change.

This order of deposition observed by van't Hoff in the laboratory follows with remarkable closeness the natural sequence of the deposits at Stassfurt, indicating in a convincing manner the method and conditions of formation.

Similar phenomena happen in time with all land-locked bodies of fresh water. Rain charged with carbonic acid washes out the soluble constituents of the rocks, and by natural evaporation the solution becomes gradually more and more concentrated, till at last it gives rise to a "bitter" or a "soda" lake, which then begins to deposit saline matters as crusts. These crusts often contain carbonate of soda in the form of minerals such as "trona" and "natron," or as "urao," a sediment found at the bottom of a lake in Maracaibo, South America. According to Furer, between Wadi Shiati and Germa in Tripoli, there exists a lake called Wadi Trona, from which natural carbonate of soda mixed with common salt is obtained. It seems certain that the *nitre* of the Bible was of such a nature.

As the matters in solution in water become concentrated by evaporation, there is always a tendency towards the deposition of carbonates of lime and magnesia in incrustations with a separation of the sparingly soluble sulphate of lime, so that the proportion of carbonate of soda which perhaps was originally only small, increases in the solution. In a few localities the sodium carbonate is actually deposited in a comparatively pure condition. Instances are, Lake Doroninski near Chita in Siberia, and Lake Magadi in British East Africa. An examination in our laboratory of a product from the Chita site revealed the composition to correspond with the normal carbonate ("natron"), and to show only a trace of chloride.

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CHAPTER II.

ANIMAL AND VEGETABLE IMPURITIES.

MOST of the organic matter in water is either in solution or suspension; only a comparatively small amount is found in the colloidal state, such as certain albuminoid and humous compounds. Our object is to ascertain the nature and origin of the pollution, and the best methods for its prevention, and in many cases quantity is of less import than quality.

Of *soluble* organic contents the gravest impurity is recent excrementitious matter, entering by washing of the soil or through leaky pipes near middens or manure heaps. The fæcal or urinous substances rapidly undergo putrefying change effected by bacteria, and the complex products are again broken up with the evolution of gases. An example of a hydrolytic change caused by the growth of anaerobic organisms may be expressed, if we take an empirical formula for albumen, in this way:—

$$4C_8H_{13}N_2O_3 + 14H_2O = 4N_2 + 19CH_4 + 13CO_2 + 2H_2,$$

giving the gases which are commonly met with in these decompositions. If such a final result were reached, no organic matter would be left for oxidation, showing one process by which deep waters may become naturally purified out of contact with air, as after the exhaustion of their food the organisms would themselves disappear. Non-nitrogenous bodies like cellulose and woody fibre can similarly break down into CO_2, CH_4, and H_2.

Unfortunately, however, intermediate compounds are formed, some of which are highly noxious. The gases indeed may give the water a bright and sparkling appearance, and the saline matters may add a piquant taste, so that the liquid is often drunk without suspicion, and in recorded cases has even been preferred to a purer supply, although chemical and bacterial analysis would condemn it at once, and impaired health and well-known diseases are conclusively traced to its use in the raw state for drinking.

A scheme of the order in which many of these products are formed from proteids is as follows:—

They first give odorous bodies, like indol, skatol, H_2S and thio-compounds with albumoses and peptones.

The latter yield polypeptides and afterwards ptomaines and purin bases, which break up into a number of simpler bodies, with amino- and fatty acids, and phenol derivatives. Finally carbonic acid and ammonia are produced ; the latter should become oxidised to nitrites and then to nitrates, which are innocuous but a sign of former organic nitrogenous matter: the late Sir E. Frankland, in fact, tabulated them as "previous sewage contamination." Nitrites are an unfavourable indication, either that oxidation is incomplete, or that it has been reversed by some reduction of nitrates which may indicate anaerobic bacteria (some of which are among the most dangerous), and in many cases has to be explained.

Many of the organic products of decomposition have been isolated, but the work is at present scarcely begun. That on the polypeptides has been mainly carried out by E. Fischer.* Of the ptomaines that have been isolated may be mentioned neuridin and cadaverin, while among the amino-acids are glycocoll, leucin and tyrosin and many others. These yield amines and ammonia as well as some free nitrogen. The following amines have been separated, methylamines (a large quantity in herring brine), ethylamine, ethylene-diamine, indol, and others: all are injurious and may pass into drinking water as a consequence of putrefactive contamination.

Plant tissues break down in a similar manner as regards their proteid substances, but on account of their cellulosic and lignin (woody) constituents they can give a larger quantity of the intermediate brown amorphous products containing some

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* *Ber.*, 1908, *et seq.*

nitrogen which are called collectively *humus*. These make up with inorganic grit a large proportion of the sediment or sludge from impure waters, and are closely related to the organic matter of ordinary soil and peat; Adeney and S. Rideal have given a large number of facts with regard to them. A part dissolves in the colloid state in combination with ammonia, lime, or magnesia, and gives a brown colour to the liquid, but is not found to have any physiological effect beyond a laxative tendency associated with *paludism*. The solutions are not easily oxidised naturally, and require bleaching agents like hypochlorites or ozone, or a mordanting precipitant such as iron oxide, or better, alumina: they are partially thrown down by lime-water in the process of softening. They help nitrification, but are connected with a solvent action on metals: that on lead has often caused poisoning.

The above albuminous decompositions are accompaniments of the growth of small organisms. Probably they are all due to the agency of albuminolytic and proteolytic ferments secreted by the organisms, although up to the present time comparatively few of the ferments have been isolated, certainly not enough to account for the great variety of changes. Those yet to be discovered are almost sure to resemble generally the ones already well known, namely pepsin, trypsin, galactase, papain and urease.

This process of decomposition may be divided into three periods. Firstly, polypeptide formation: at this halting point the liquid is usually termed sewage. Secondly, the stage of amino-acid production, which may be taken to represent weak sewage or very impure water. Lastly, the conversion into ammonium compounds, which are oxidised to nitrites and nitrates; or briefly the stage of mineralised nitrogen, yielding a more or less potable fluid.

Two typical examples of organic admixture derived from vegetation may be cited. (1) Waters percolating from peaty uplands absorb varying amounts of organic impurities both dissolved and colloid, and are often highly acid because there is not sufficient carbonate of lime in the soil to neutralise the products of fermentation, such as humic, crenic, aprocrenic and volatile acids. The liquid is commonly clear and organisms are few ; the brown tint with flat marshy taste and sometimes odour are general characteristics. Methods of treatment will be discussed later. (2) The water of marshes or swamps contains similar impurities, but is on the other hand generally turbid, foul smelling, and swarming with life.

Although it is possible by habit to acquire immunity to both these classes of supply, they have a tendency to cause ague, dysentery, and a state to which the name *paludism* has been given (see *ante*).

Deposits of Dead and Living Matter

are apt to form in conduits, reservoirs, and cisterns, including hairs, epithelial scales, and even the entire dead bodies of small animals; wing scales of butterflies and moths, and parts of other insects. Fibres of clothing, sometimes dyed, may be identified under the microscope as silk, cotton, linen, or wool. Particles of muscular fibre when found in drinking water are considered to be evidence of contamination with fæcal matter. Plant-hairs, pollens, spiral vessels, leaf epidermis, fragments of straw and seed-coverings (especially those of cereals), and of vegetables more or less discoloured from decomposition, may be also met with, as well as starches of various kinds. Microscopic examination of the sediment should therefore never be neglected.

The Living Contents of Water

comprise members of nearly all the natural families. *Fish* are a sign of fair aeration, because they disappear as a river becomes increasingly foul, owing to the absorption of the dissolved oxygen necessary for their breathing. But it must be remembered that fish in large numbers are often seen to congregate at the mouths of sewers where fæcal matter is visibly floating, being attracted by the insects and fragments of food carried down with the sewage. They are really more affected by muddy water and by chemicals from

PLATE I.

Plankton obtained by Centrifuge (after Hassall).

1. Nassula sp. (Ciliate Infusorian).
2. Cercomonas (Flagellate Infusorian).
3. Actinophrys Sol (Rhizopoda).
4. Bursaria (reputed to give a "seaweed" odour).
5. Euplotes (Infusorian).
6. Anguillula.
7. Chilodon sub-dividing.
8. Vortiella.
9. Allied to Paramœcium.
10. Allied to Halteria.
11. Paramœcium.
12. Dinobryon (?).
13. Closterium (A Desmid; green alga).
14. Navicula sp. (A Diatom).
15. A Diatom.
16. Gomphonema.
17. Wool.
18. Vegetable débris.
19. Conferva (Chlorophyceæ).
20. Hair.
21. A Ciliate Infusorian.
22. A Diatom.
23. Diatoma Vulgare.
24. Torula (Fungus, yeast plant).
25. Vegetable débris.
26. Scenedesmus (one of the odour-producing organisms).
27. Allied to Halteria.
28. Paramœcium.

[*To face p.* 18.

factories than by excreta, so that their presence is by no means conclusive that the liquid is not dangerous for man to drink. Fish are utilised as natural cleansers in a number of sewage-treatment works, and consume much nitrogenous débris as well as animal and vegetable life.

Small eels and other fish have been found in mains, and house-pipes have sometimes been stopped by their bodies. Their presence may generally be taken to represent the result of carelessness or imperfect filtration.

Among the minute animals living in water some are visible to the naked eye, such as the water flea, *Daphnia pulex*, and *Cyclops quadricornis*. A small round worm called *Anguillula fluviatilis* is common in rivers and ponds, and sometimes makes its way into London waters. It is believed to be capable of living in the human intestine, and therefore might be dangerous, and must be regarded as a very bad feature in a potable water.

Animals occasionally cause contamination with parasitic worms, such as tape worms, guinea worms (*Filaria medinensis* and *dracunculus*), and in India the ova of a filaria have frequently been discovered in tanks. *Filaria* or *Bilharzia sanguinis hominis* has been traced to drinking water.

It was not till 1850 that the study of the organisms in drinking water was recognised as of sanitary importance, and Dr. Hassall, of London, was the first to call attention to it. For the smaller floating organisms, both animal and vegetable, Victor Hensen, of Kiel University, in 1887 invented the convenient collective term "plankton," from the Greek *πλανάομαι*, "I wander." He used a conical "plankton net," and other methods have been since introduced for making the examination, as far as possible, quantitative as well as qualitative, including pumps, centrifuges, and sand filtration, the latter the basis of the well-known Sedgwick-Rafter method. Whipple in America has made great use of this method.

We have seen that the process of natural purification may be divided into three stages or zones. Each of these has its own particular fauna and flora engaged in the work, but as

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* They sometimes come up the overflows of reservoirs.

their actions are not always beneficial, the growths have to be known and watched. Of course, as with higher life, the hardier species often persist through changed environments; differences, however, are found in the abundance, and there is a tendency for certain forms to become characteristic. We will first refer to the animals. In the *polypeptide stage* are found:—

Protozoa.—The genus *Amœba* of the Rhizopoda is looked upon as of bad significance; it is most frequent in poorly aerated waters containing much organic matter, and some of the species have been proved to be pathogenic. Goitre, Texas and blackwater fevers, malaria, Tsetze-fly disease, and forms of dysentery have all been associated with the presence of various protozoa, although, according to Mosler and Peiper * water is not the commonest vehicle of these infections.

Among flagellate infusoria, *Hexamitus inflatus* is frequently contributed by town sewage, along with the ciliates, *Paramæcium putrinum* and *caudatum.* The flagellate *Dinobryon sociale,* associated in branching threads, gives a yellow tint to some surface waters.

In the *amino-acid stage* are found the Rhizopods *Arcella vulgaris* and *Amœba radiosa* (both often present in water purified by biological methods); flagellate infusorians *Anthophysa vegetans* and *Euglena viridus;* and the typical ciliates *Stentor* and *Vorticella.* The stage of mineralised nitrogen is almost devoid of this class of organisms, but occasionally a green chlorophyll-containing ciliate, *Ophrydium versatile,* is met with.

Two other classes of animalculæ are often observed in waters, the Rotatoria, having wheel-like discs, and the Bryozoa, which exhibit coralline shapes. In the polypeptide stage the former are represented by *Rotifer actinurus* (which prefers waters poor in oxygen), while Bryozoa do not appear. The amino-acid stage is sometimes inhabited by the Rotatorian *Hydatina senta,* which feeds on the bacteria, and a Bryozoon, *Plumatella,* occurs as a thick felt-like matting on stones.

Crustacea have representatives among the fauna of the second and third stages. The amino-acid stage has been

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* "Tierische Parasiten," 2nd edit., Vienna, 1904.

PLATE II.

WATER FROM A WELL NEAR THE SEINE AT PARIS.

1. Cyclops (a Crustacean).
2. Mycelium, with spores.
3. Woody débris.
4. A Zooglœa Colony.
5. Humus (diagrammatic).

[*To face p.* 20.

sometimes recorded as containing such numbers of the "water flea," *Daphnia pulex*, that a pink tinge was given to the liquid. In the last stage *Cyclops* and *Canthocamptus* sometimes abound in sandfilters, *Gammarus pulex* in springs and brooks, and *Diaptomus* and *Bosmina* more particularly in lakes.

In the amino-acid stage a representative of the spongidæ, the freshwater *Eu-spongilla lacustris*, may appear as soft fibrous masses of brown or greenish colour, in tanks and water-butts where the liquid is in slow motion, also in mains when the filtration has not been efficient. The growth is most luxuriant in summer, when the products of decay often cause an unpleasant odour and taste. The spicules of the supporting skeleton will be found in the water sediment.

The smaller vegetable growths in the waters chiefly belong to the following groups.

1. *Diatomaceæ*, brown or nearly colourless, have a silicious skeleton with finely-marked box-like valves, and occur either free or connected in chains.

2. *Cyanophyceæ* are algæ of various colours, the green chlorophyll being associated with a blue colouring matter, Phycocyan. These are generally responsible for the growths observed on the surface of reservoirs, known as "water bloom."

3. *Chlorophyceæ*, or green algæ include *Protococcoideæ* (unicellular, cells single or in groups); *Confervaceæ* (multicellular, in threads or bands); and *Conjugatæ* (distinguished by their method of reproduction, and divided into the unicellular Desmids and the multicellular Zygnemaceæ). There are allied types mainly distinguished by the colouring matters which they contain, such as the Phæophyceæ, or brown algæ, and the Rhodophyceæ, or red algæ; these two, however, are chiefly marine. Occasionally we find fragments of higher plants which give rise to difficulty.

4. Some of the most important species belong to the *bacteria*, which according to their appearance under the microscope are described as *micrococci*, rounded forms, which may be (*a*) single—micrococci proper—or (*b*) in pairs, diplococci; (*c*) tetracocci, in fours; (*d*) cubical packets, *e.g.* Sarcina; Staphylococci, in grape-like bunches; Streptococci, in chains.

Such bacteria often occur in a gelatinous mass, termed a zooglœa colony. *Bacilli* are rod-shaped organisms, either single or in chains, often opening out into dumb-bell-shaped bodies. Spores may form in clear vesicles at the centre or ends. Screw-shaped or spiral bacteria are (*a*) *Vibrios*, short and undulating, (*b*) *Spirilla*, longer and in a distinct helix or screw, (*c*) *Spirochæta*, long thin threads, with numerous short turns of the spiral.

5. Spores and mycelium of the lower fungi, such as yeasts and moulds, are almost ubiquitous, and may penetrate into waters otherwise good. The mycelium has the form of unsegmented threads, straight or undulating, and often interlaced into flocculent masses.

In this group are Cladothrix, Leptothrix, Crenothrix,* and Beggiatoa. With the latter is often found Spirulina Jenneri (Kolkwitz).

In the polypeptide stage we find that the bacteria predominate, *e.g.*—

Micrococcus ureae, from urine. Sarcina paludosa, a large species found in decomposing sludge. Bacillus subtilis, one of the most frequent of the spore-bearing kinds. Proteus vulgaris, similar but smaller. Bacillus coli, a characteristic organism of fæces. Pseudomonas fluorescens, a rounded form very common in polluted rivers. Spirillum undula and volutans frequently swarm in town effluents. Sphærotilus natans, very common, forming whitish flakes like Cladothrix dichotoma. The ordinary name "sewage fungus" is applied to these and also to Beggiatoa and some others.

In the amino-acid stage the following forms are abundant. *Diatomaceæ.* Navicula, Synedra, Stephanodiscus, Asterionella, and numerous others, including the filamentous Fragillaria and Melosira, the latter causing odour.

Cyanophyceæ have several objectionable species, such as Oscillaria and Anabæna flos-aquæ (bluish water bloom).†

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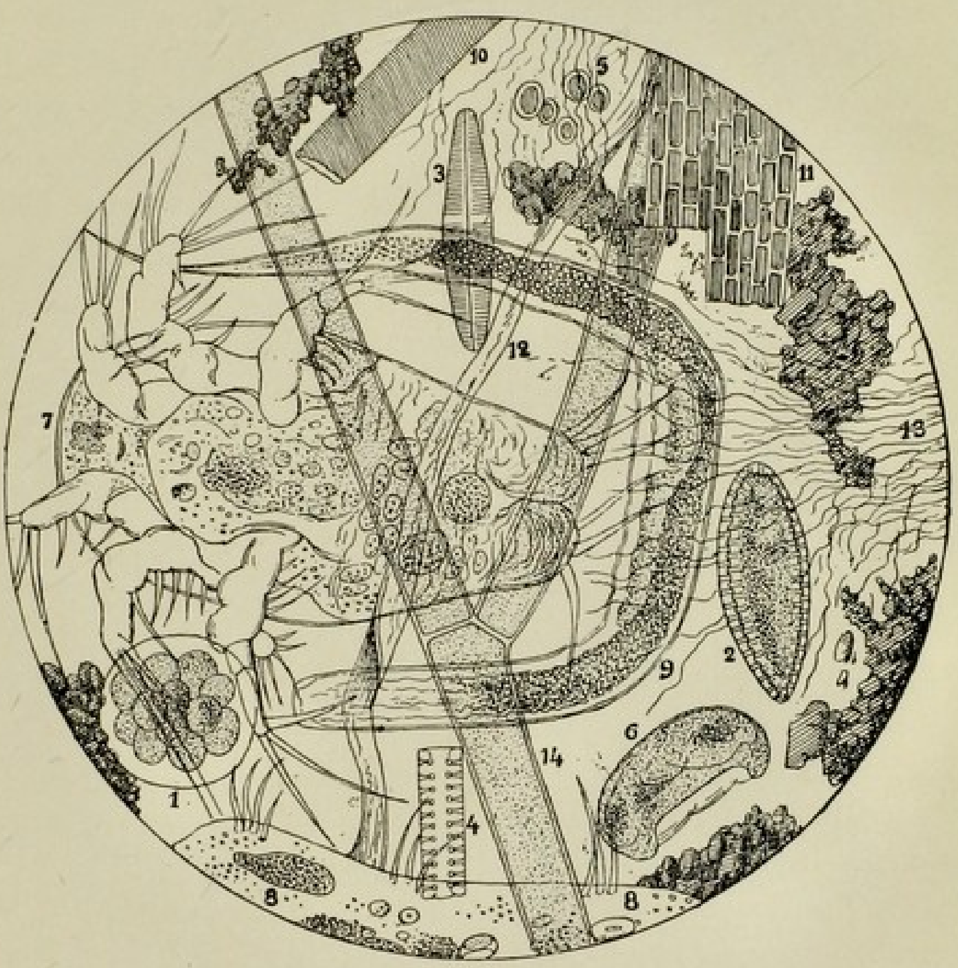
* Crenothrix has two important species, *ochracea*, or polyspora, secreting iron, and *manganifera*, secreting manganese.

† Early in 1910 the Rothsee near Lucerne was turned a brilliant copper-red by Oscillaria rubescens.

PLATE III.



ANIMAL AND VEGETABLE IMPURITIES IN WATER.

1. Pandorina (Desmid),
2. Surirella (Diatomaceæ).
3. Stauroneis (Diatomaceæ).
4. Tabellaria (Diatomaceæ) (reputed to give a "geranium taste" to water).
5. Protococcus (Chlorophyceæ).
6. Infusorian (Colpidium).
7. Daphnia Pulex (the Water Flea).
8. An Entomostracan.
9. Anguillula.
10. Muscular Fibre.
11. Vegetable tissue and earthy matter.
12. Cotton Fibre.
13. Fungus Mycelium.
14. Cladophora (Chlorophyceæ).

[*To face p.* 22.

Confervaceæ. Cladophora crispata is capable of growing into thick strands of a yard long, which are very strong and not slimy.

Stigoclonium and Ulothrix are common forms.

Conjugatæ. Spirogyra and its allies grow in thick tufts.

Closterium and other free-floating desmids are sometimes so plentiful as to colour water green.

The *bacteria* of this stage are mainly sulphur and soil organisms. White masses of a fungus, Leptomitus lacteus, are often troublesome.

Stage of Mineralised Nitrogen.

Melosira is sometimes a greater nuisance here than in the last stage, and the free-floating organisms are of species too numerous to mention. Anabæna flos-aquæ is again found, and Chlorophyceæ flourish. *Hydrodictyon* (see further, Chapter VII) frequently forms the main portion of the "Schmutzdecke" or upper film of sand filters.

Higher animal and vegetable aquatic life plays a part in the biological cycle of natural purification. Organic solid impurities are decomposed by bacteria, which in turn are consumed by protozoa; the latter are the food of rotifers and crustacea, and these are eaten by fish. The products of liquefaction of the organic impurities furnish food for diatoms and other algæ, and these are fed on by various aquatic animals. Green algæ are destructive to microbes, and according to Dr. Strohmeyer of Hamburg a healthy growth of algæ may, under favourable conditions, sterilise the surrounding water in the course of one day. Many other kinds of plankton also feed on bacteria. Objections to this natural method of purification are that not only are the growths liable to cause obstruction, but may also become offensive from their death and decay.

The Iron Algæ.

Certain organisms are peculiar to waters containing iron. Their membranes are usually covered with a coating of ferric hydroxide, giving them a brownish-red appearance. Such fungi have the power of secreting oxides of iron, aluminium or manganese, and are said to be *chemiotactic.* Molisch growing certain of them in iron-free media proved that in the absence of iron, manganese was attracted. The method of deposition is not clear. Zopf considers it to be a purely mechanical action. Cohn compares the deposition of iron hydroxide to that of silica in diatoms, etc. Winogradsky believes that the energy derived from the chemical oxidation of the ferrous-hydrogen carbonate to ferric hydroxide provides the necessary energy for the growth of the organisms.

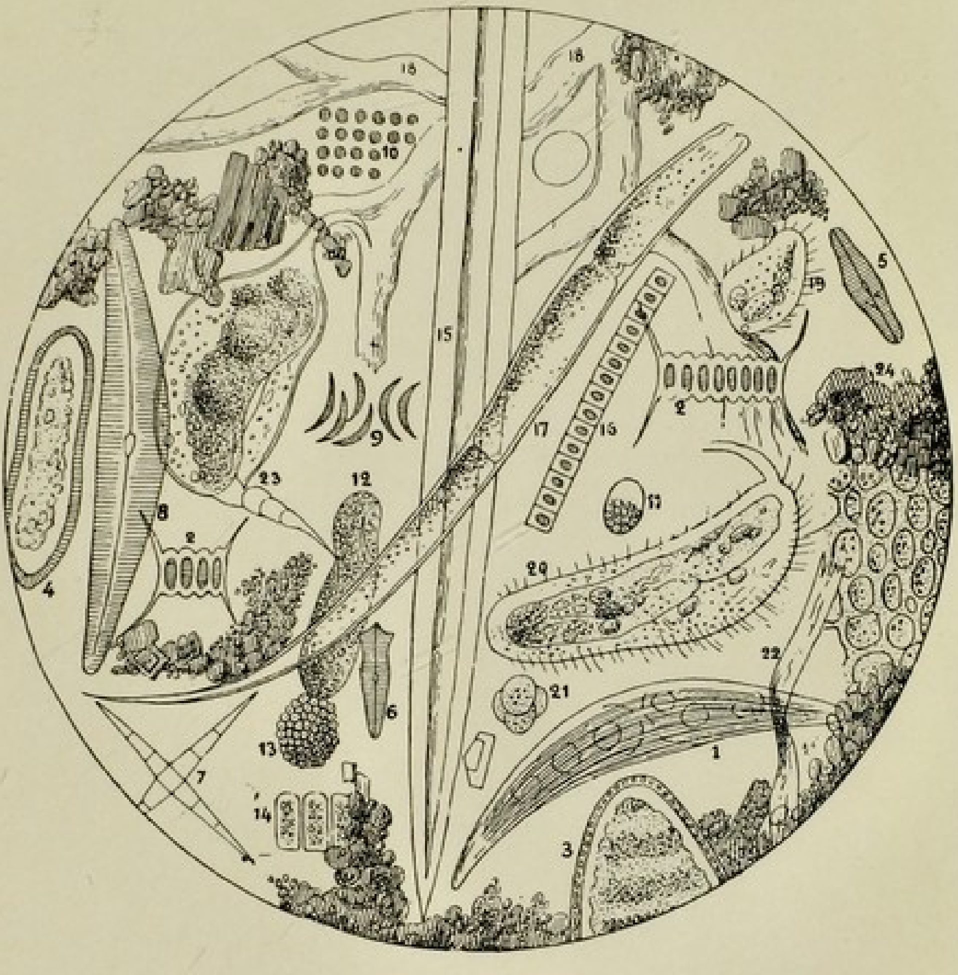
Usual types are Crenothrix polyspora (Cohn, 1870): reproduction by threads dividing to form cocci, and eventually filaments and zooglœæ. The water of Cheltenham was turned a deep red colour by the growth of this organism in 1896.

Leptothrix (Crenothrix) ochracea is present in most iron waters as a network of cylindrical rods. Reproduction by means of protuberances which grow out to new threads. Three similar fungi are Spirophyllum ferrugineum (Ellis in the Glasgow water), Clonothrix fusca (Schorler in the Dresden water, 1904), Chlamydothrix (Gallionella) ferruginea. Reproduction as in the above-mentioned Leptothrix.

The Sulphur Organisms.

Their characteristic property is the oxidation of the hydrogen sulphide found in sulphur springs to sulphites and to sulphates. Since hydrogen sulphide has been shown to be liberated together with other complex sulphur-containing compounds in the primary decomposition of proteids, we may expect to find these organisms in waters which have been recently polluted. Thiophysa is colourless and does not form threads. Monas Muelleri and Monas fallax are spherical or ellipsoidal. More usual is the fungus *Thiothrix,* which appears as colourless motionless threads attached to a cushion-like tuft. They possess a common thread membrane in

PLATE IV.



SEINE AT PORT À L'ANGLAIS.

1. Closterium.
2. Scenedesmus.
3. Diatom.
4. Amphora (Diatom).
5. Navicula (Diatom).
6. Surirella (Diatom).
7. Diatom.
8. Cymbella (Diatom).
9. Closterium (Chlorophyceæ).
10. Merismopedia (?) (Cyanophyceæ).
11. Microcystis (Cyanophyceæ).
12. Nassula (?) (Infusorian).
13. Botryococcus (Chlorophyceæ).
14. Conferva sp.
15. Sponge spicule.
16. Ulothrix Conferva.
17. Anguillula.
18. Fresh water sponge (?).
19. A Ciliate Infusorian.
20. A Ciliate Infusorian.
21. Protococcus.
22. Cotton Fibre.
23. ——
24. Decayed vegetable tissue.

[*To face p.* 24.

addition to the membrane of each cell, consequently the filaments rarely break up. The ordinary species are T. nivea, T. tenuis, T. tenuissima. Beggiatoa forms colourless motile threads up to one centimetre long, which break up before death. It secretes granules of sulphur. The species are B. alba, B. media, B. minima, B. mirabilis, B. arachnoidea.

The group of so-called "purpur-bacteria" make a reddish-violet matting on the sides of sulphur springs. The bacteriopurpurin they contain may be supposed to play the same *rôle* as chlorophyll does in other plants. Along with this class are found the following other organisms :—

Chromatium Okenii, possessed of only one cilium ; Monas Warmingii, like the former but often occurs in pairs : Spirillum volutans, Ophidomonas sanguinea, and Rhabdomonas rosea.

Soil Bacteria.

The bacterial content of ordinary soil is very large, ranging from 10,000 to 5 millions per gram of soil, while in polluted soil the bacterial contents may rise to 100 millions per gram. These numbers do not continue far below the surface, for at a depth of ten feet there is practical sterility. Waters that have percolated through the upper layers will of course carry off very many of the germs, including pathogenic ones. Of the latter the following are defined :—

Bacillus diphtheriæ, tuberculosis, influenzæ, tetani,* pyocyaneus, typhosus, Gärtner's anthracis, mallei (glanders) ; Spirillum (Vibrio) choleræ ; Frænkel's Pneumococcus and Friedlander's Pneumobacillus ; Spirillum Obermeieri (relapsing fever) ; Micrococcus pyogenes aureus and albus ; Streptococcus pyogenes and erysipelatis ; Bacillus lepræ (not conclusively isolated, perhaps a protozoon) ; and others.

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* Soil penetrating a wound often causes lockjaw.

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CHAPTER III.

SOURCES OF WATER SUPPLY.

Particular Supplies.

MOST houses situated near cities can now obtain a constant supply from the town mains, but there is often an intermediate house-cistern controlled by a ball-cock.

The advantage of a direct supply under pressure is that the pipes are always full of water, leaks are more easily detected, and the pipes, being less subject to corrosion than if they are alternately full and empty, have a longer lease of life. In addition the risk of aerial contamination or leak inwards is avoided. But every house should have a private cistern, with a reserve of at least 100 gallons of water, to provide against emergencies, such as the main supply failing through a break-down at the works, a burst main, a frozen filter, or an extra demand owing to a fire occurring. House cisterns are commonly made of lead, or of "galvanized iron," which consists of iron-plate dipped in, or electroplated with, zinc. New and bright lead is at first rather rapidly attacked by most waters; after a time, however, the surface becomes covered with a coating of insoluble salts, mainly basic carbonate and sulphate, which protect the metal underneath from further attack. New lead cisterns must never be used for drinking water until the incrustation has formed and the water has been proved to be free from lead. Even then they are not safe from risk of "plumbism." Schwartz has proposed to coat the metal with lead sulphide by treatment with "liver of sulphur." This covering is liable to blister, and is acted on by soft water in the presence of air. When cleaning out a lead cistern, care must be taken that the protecting film is left intact. Zinc is also easily attacked by most waters, giving rise to symptoms of irritant poisoning. Slate, Portland cement, and painted cast-iron tanks are also used: the former two are good, but possess the disadvantage of being bulky and heavy, while the paint or oil of the last often contains soluble lead salts.

The authors consider that iron tanks electroplated inside with either nickel or copper, would make ideal storage for many waters, since both these metals possess remarkable sterilising properties, and do not appear to have marked physiological effect as they are not readily acted on by most waters. Such cisterns may be either open or closed. Closed cisterns are advised, since aerial contamination is thereby avoided. The funnel-shaped or spherical so-called self-cleansing cistern does not seem to have sufficient advantages to warrant the extra expense. The weakest points in these house-installations are to be found in the electrolytic action that goes on at the joints of two different metals, such as lead-iron, iron-zinc, zinc-lead, contacts. Remedies for ferro- and plumbo-solvency will be reverted to later. A needful precaution that would prevent much trouble is that all pipes both inside and outside houses should be well protected from frost. Storage cisterns should be placed inside the house.

Few things have been more distinctly proved than that private wells, if they have to be resorted to for drinking water, require as careful protection and supervision as public supplies, and must be frequently controlled by analyses both bacterially and chemically. Even then they are liable to accidental contamination. They have been responsible for much ill health and sometimes acute disease in families, and many of them have been compulsorily closed.

In the first chapter the probable nature of supplies from different strata was indicated. For water to be found in any given spot it is usually necessary that a subterranean water bed or natural reservoir should have formed over an impervious floor such as clay. But since in general these strata are not lying evenly or horizontally, owing to earth movements and other causes, water is often found in a porous stratum below an impervious one, due to an outcrop of that stratum at some point, or to a fault which passes through the otherwise impervious layer.

Wells.

A few words may be interpolated as to early methods of obtaining water artificially from underground.

Primitive man must have very soon discovered that even in apparently dry districts he could find subterranean water by digging for it, and that the character of the liquid so procured would show great differences. Sometimes it was undrinkable through muddiness or smell, but it would require no great ingenuity to cure these faults by settlement and exposure to air. There are very ancient records of the use of astringent or mucilaginous herbs for clarifying and for removing iron, and boiling too is mentioned as a means of rendering water wholesome. Where the liquid was unduly saline, or contained poisonous metals, the evil was then incurable, as distillation was not found out till later, and large tracts of land remained desert. Another very early experience must have been the fevers and unhealthiness caused by drinking raw surface or shallow waters from inhabited spaces or marshy districts, therefore the digging for water must be carried deeper, and the excavation must obviously be lined to keep it permanent, and sometimes covered for protection. Thus populations gathered round wells as a valuable centre.

In certain cases an almost non-porous stratum was dug through, and an imprisoned source underneath was able to rise until it could be easily reached from the top: this was called a dip-well. A "draw-well" required a rope and bucket: very soon a windlass was added.

Subsoil water is in general almost free from living and suspended impurities since it has passed downwards through several feet of filtering soil, alluvial gravel, or sand, overlying the bed-rock or floor, so that the processes of natural purification may have had time to be fulfilled. The surface-pollution must, however, not have been too great, nor must the liquid drain off too fast; otherwise the process will not be complete, therefore it is essential that the product should be submitted to careful and frequent examination.

Porous rocks absorb a varying amount of water up to about 25 per cent. of their weight before they become saturated. When this state is reached the water begins to rise in the stratum resting on the impervious rock or clay beneath, and continues to rise until it finds some outlet for escape either as a visible spring or an underground channel flowing over the impervious layer into a pervious and unsaturated one below it. The height which the water attains is termed the line of saturation or water-line, and is not always horizontal since the resistance of the rock to the flow of water varies from place to place. The excavation or boring must obviously be carried below the saturation line in order that the water may stand up in the well. Pumping will lower the line for a considerable distance around, and not only may drain adjacent wells, but if continued at a rate faster than the surface water can percolate through, may exhaust the entire stratum.

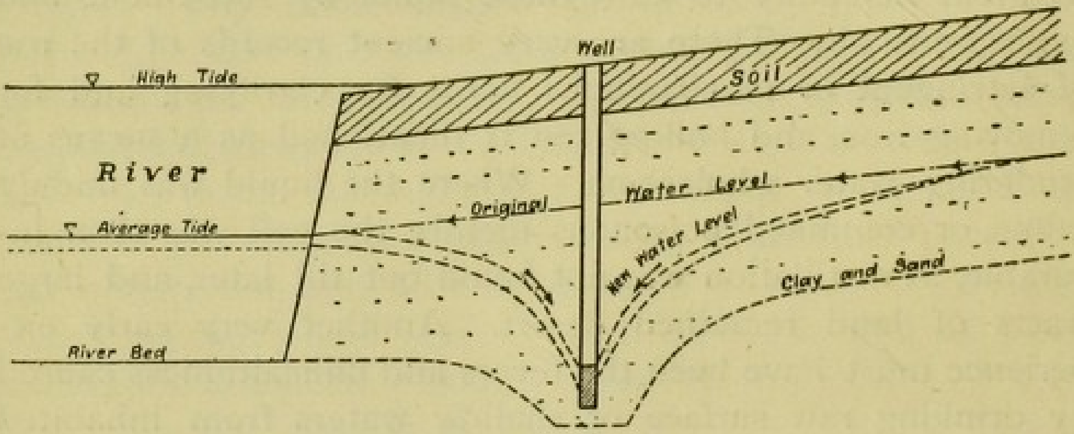

FIG. 1.—A water saturation line; showing how it is lowered by a well.

At one time, water derived from deep wells in the chalk was looked upon as above suspicion, but instances have occurred which have modified this idea, as was shown in the Cambridge County Asylum inquiry in 1905, when such a well 60 feet deep was suspected of causing numerous cases of typhoid. It was proved that the underground supply of the well came partly from sewage irrigation 1200 ft. distant, and that coloured test liquids (see p. 35) could travel that distance in 103 hours (*Trans. Assoc. Water Engineers*, 1907, p. 108). Solid chalk in fact is too dense to allow percolation, so the water is derived from fissures, which are numerous. This confirms what we have previously remarked (pp. 29–30) that the surface pollution must not be too great.

Tube Wells.

(*a*) *Artesian wells.*—French *artésien*, from the province of Artois, where this device came into Western use about 1750. It was employed by the Arabs in the Sahara in very early days; moreover, upwards of 2000 years ago the Chinese bored for water very much in the same manner by percussive action, and also used a tower or standpipe to accumulate the head of water.

These wells are made by drilling, and then carrying down successive lengths of tube, until a deep stratum is reached which holds water under a pressure sufficient to force it through the tube to the surface. Usually, after a time, the yield decreases and has to be assisted by pumping; where the natural overflow is still maintained, the term "boiling wells" is often applied. The subterranean pressure may be caused by the weight of superincumbent rock, by imprisoned gases generated through chemical actions or former fermentations, or by curvature of the formation so that there is hydrostatic pressure from water passing into the upper exposed margin of a natural basin. Diagrammatic sections of the beds under Paris and London are given in Figs. 2 and 3.

The Paris water-bearing strata are at about six times the depth of the London ones. The latter are undergoing serious exhaustion. W. Coles-Finch describes this depletion thus: "Where formerly the water rose above the surface in the lower-lying portions of the Thames valley, now through the multiplication of artesian wells, the amount of water obtained has increased to such an extent that the level has been greatly reduced, until it now stands about

100 feet below the Thames, the percolation of the rainfall on the outcrop being less than the quantity of water pumped. . . . Should these conditions continue, the supply will eventually decrease so much that the amount will be limited to that of the annual percolation ; the accumulation of ages, stored away in the formation which now supplements the supply, will then have been used up, leaving the rainfall only."

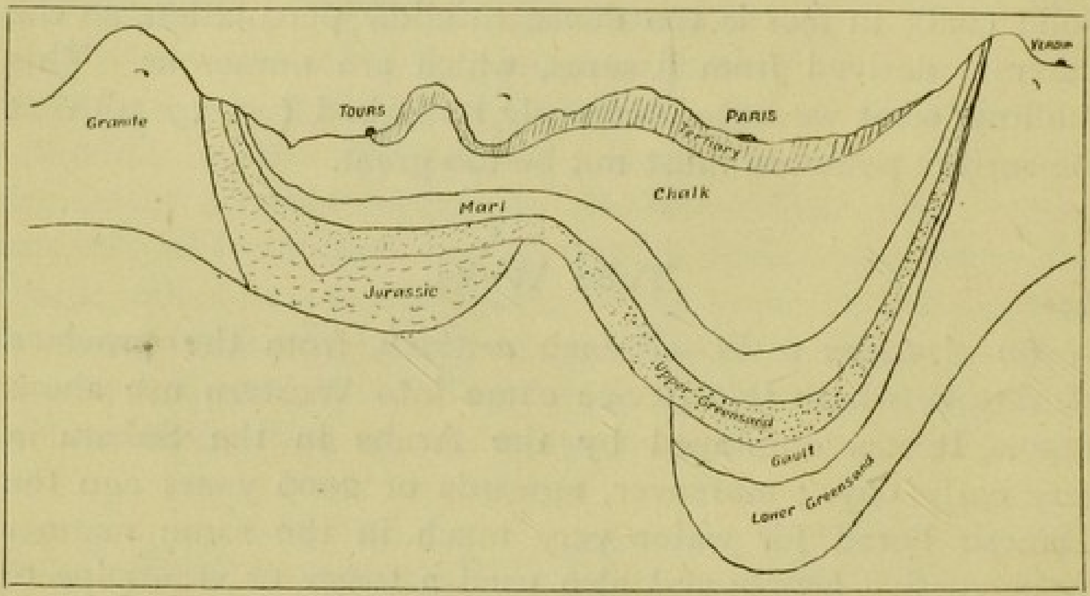

FIG. 2.—Section through the Paris basin.

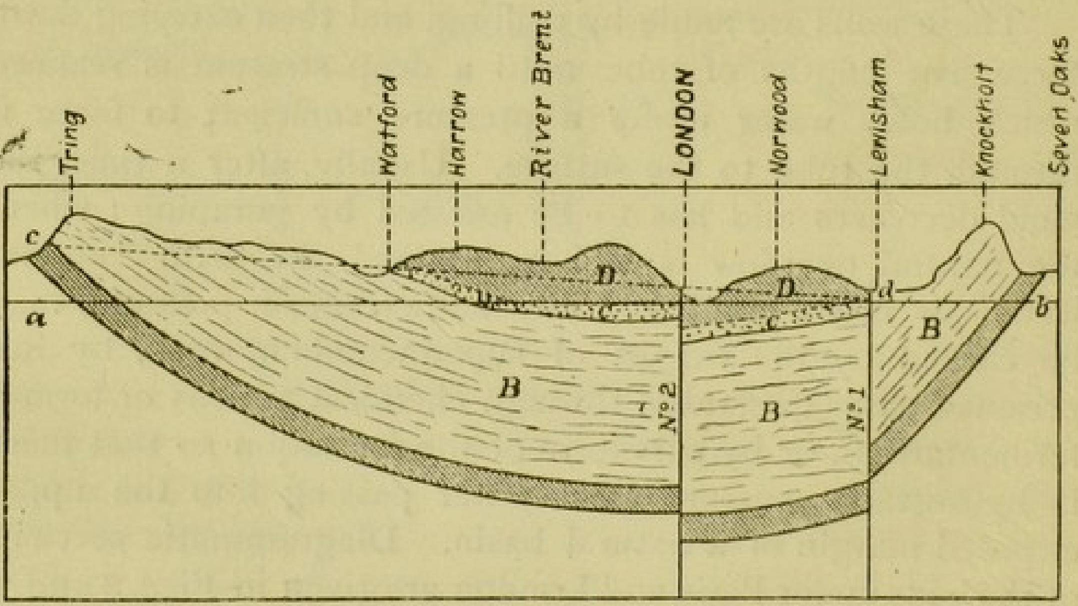

FIG. 3.—Section through the London basin.*

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* *c* Gault clay and B Chalk showing the "fault" between No. 2 and No. 1 ; C London clay ; D Thanet sand. *ab* Level of Thames at London Bridge ; *cd* former saturation line.

The Australian continent practically consists of two large artesian basins; the great Australian basin of about 570,000 miles in area, extending over parts of Queensland, New South Wales, and South Australia, and the Western Australian basin. The effect of this discovery of the possibility of obtaining waters by artesian wells in this continent has been to open up thousands of square miles for development.

A flowing artesian well at St. Louis, Missouri, is 3800 feet deep. The Passy boring near Paris is 1923 feet. Concentric tubes are sometimes used, drawing from different strata waters which often differ widely in composition.

(*b*) *Driven* or Abyssinian (Norton's) wells consist of tubes forced on by successive blows of a ring-weight lifted by pulleys and then let fall. Such a method has the advantage of cheapness, portability and rapidity of construction, and the tube can be taken up and shifted if the first trial is a failure. Their value in military and other expeditions has been very great. Immense regions that would otherwise be desert are now cultivated by irrigation from artesian and driven wells. The words are sometimes used as synonymous, but the essential difference, as we have indicated, is that in the former there is a preliminary boring by steel drills. These are shod with Brazilian black diamonds if the rock is very hard. A more recent, cheaper and very effective tool is the shot drill, which has hard steel shot running loose underneath the crown of the drill. Under the pressure of the weight they cut the rock, leaving a solid core, which is drawn up at intervals, while the finer débris is washed away by a jet of water.

It need hardly be said that in all these wells the tubes must be screwed together tightly to prevent leakage.

Dug Wells.

The shaft is generally cylindrical, and lined with brick or stonework, which must be cemented, and even then will not be safe unless tarred outside to prevent infiltration. At the bottom is a bed of stones through which water can percolate.

The following precautions against contamination are necessary.

1. The shaft should be continued above the ground level.

2. Protection is needed at the top, and a custodian is generally required; periodical inspection and analysis of the water must never be neglected.

3. Instead of the old bucket and pulley a pump should be substituted, and must be so placed that any overflow cannot return into the well, but will pass away through a drain.

4. No dung-hills or other sources of contamination should be allowed to exist near the well.

The problem of ascertaining the size of the danger area round a well is a very complicated one, for not only does it depend on the homogeneity, porosity and state of division of the soil, but the direction of flow of the ground water, as well as the existence of any faults or fissures, also exert a great influence on the liability to pollution. Private wells in kitchens or backyards have often seriously injured the health of families. Such water should not be drunk without precautions.

Testing for the Source of a Pollution

can be done in several ways; one of the simplest is to pour in at the suspected place a strong solution of common salt. If an increase of the chlorine content of the well water (detected by a heavier white precipitate formed on addition of silver nitrate) is noticed after a short time has elapsed, the direction of the contamination is proved.

Other salts may also be employed, such as *Lithium chloride*, which gives a crimson colour to a Bunsen or a spirit-lamp flame (the yellow sodium flame is cut off by blue cobalt glass). Unless the contamination is very gross, the test carried out in this way will often fail, but it is made much more delicate by observing with a spectroscope the flame from a little of the evaporated residue of the water mounted on a clean loop of platinum wire just moistened with hydrochloric acid, when an intense red line will detect one sevenmillionth of a grain of lithium. Prof. H. Robinson,* gives instances of its application. Another test is a solution of *fluorescein*, rendered alkaline by a little soda, which exhibits a strong green fluorescence when the water is made slightly alkaline. This was used by Dr. Thresh in the Cambridge Asylum inquiry, 1905.

It must be remembered that these tests are all liquids, and, except for a certain amount of mordanting or absorption, they can pass through materials which arrest solids such as bacteria; for instance, they can traverse a filter which makes water sterile. Therefore, although a positive result from their use demonstrates a flow between the two spots, it does not actually prove that contamination by *germs* has occurred, since these may have been removed by the soil.

Hence a further test has sometimes been made with an insoluble solid like Prussian blue or starch, suspended in water, but these are liable to deposition; in an important trial using wheat flour at Lausen, in Switzerland, it was proved that the soil had removed starch granules but not typhoid germs. A more conclusive test is to add to the suspected source a culture of characteristic bacilli, like *prodigiosus*, or *violaceus*, and to look for them in the suspected water. Prof. E. Pfuhl, by direct experiment has ascertained that certain bacteria could traverse in one hour eight metres of gravel soil; further that the supply of a tube-well that he tested became contaminated by *B. prodigiosus* when cultures of the latter were inserted into the surface 3·7 metres (12 feet) horizontally from the top.

Springs.—We have seen how the rainfall percolates downwards through porous beds until its course is stopped by strata of clay or dense rock, when it accumulates as a kind of underground reservoir such as is tapped by the various forms of wells we have described. In some places it finds a natural vent as springs, where the end of the stratum has been exposed by denudation, or by a "fault." These are common on slopes and are called land springs. The Bagshot springs furnished London with water for many

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* *Trans. Inst. Mechan. Eng.*, Jan., 1899.

centuries. Nearly all sources of this kind have been abandoned with increase of population, since they are peculiarly liable to be polluted, and they are also apt to fluctuate very much in yield with the seasons.

We have described the conformation of a roof of water-resisting strata overlying a natural reservoir which can be tapped by an artesian well. The roof has sometimes fissures and permits the water to escape in places as *deep springs.* The produce of these is constant and generally of good quality, but is obviously liable to admixture with surface water.

Rain-Water.

In places where water is scarce, the best methods of utilising rain have to be considered. The first fall is more or less dirty from washings of the atmosphere and of roofs, and must be rejected by an automatic tipping separator such as the Roberts' type.

The following is an approximate rule for the amount that can be depended on in temperate countries from this source:—

Area of roof in square feet × annual rainfall in feet ÷ 100 = supply in gallons per day for a very dry year.

Inasmuch as evaporation and absorption diminish the yield, the latter is greatest from high-pitched roofs made of non-absorbent materials. Slates take up only about 1 per cent. of water before they are saturated, while tiles absorb from 3 to 18 per cent. In country districts rain is of considerable purity and is almost perfectly soft, but is not pleasant to most people's taste. It contains varying amounts of ammonia, nitrites or nitrates, according to the electrical condition of the atmosphere. It is peculiarly liable to become foul when stored in tanks, owing to germs carried down from the air. The fine solid matter found as "rain-drop nuclei" (Aitken) usually consists of sandy particles, believed to be meteoric dust.

Small quantities of sodium chloride are derived from sea-spray carried by the winds, the amount varying with their force and direction and the distance from the sea. Professor Church once found in storm-rain many miles from the Bristol Channel as much as 6 grains per gallon of chloride. The average at the Inland Agricultural Station, Rothamsted, is about 2 milligrammes per litre. At Perugia, 75 miles from the Mediterranean, Bellucci found 5 milligrammes per litre. A general record is that the rainfall in winter contains more than in summer. In populous places a certain amount is communicated to the atmospheric washings by breath and skin exhalations, and carries organisms with it. The rain near towns is often unfit to be collected for any purpose, on account of smoke and industrial emissions. Oxidised sulphur from coal-burning renders it acid. As an example of the enormous contamination that may be occasioned, we may quote an instance from the Leeds Experimental Farm, 6 miles from the city, where the rain is periodically collected and analysed.* The total amount of impurities in the Leeds and Garforth rain is given as follows in tons per square mile per annum:—

Insoluble (soot).—Carbon 87·1, tar 42·6, ash 262·5, total 332·2.

Sulphur compounds.—Free acid, H_2SO_4, 8·5. As sulphate 77. In other forms 19·1.

Nitrogen compounds as N. ammonia 4·1, nitrate 0·14, albuminoid 1·0. Total 5·24.

Angus Smith found in London rain-water 2 parts of sulphuric acid per 100,000, in Manchester and Liverpool 4 to 5.

Even ordinarily pure rain rapidly attacks and dissolves lead. Such acid waters as above described may develop a protective coating of basic sulphate of lead, but this cannot be relied upon for safety. On the other hand they are corrosive to iron, zinc, mortar, and most stones and cements, and so give trouble in storage, while the main industrial value of rain-water, its softness, is lost through lime dissolving.

Country rain may contain pollen granules, dried tissue,

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* "Smoke, a Study of Town Air," by J. Cohen and A. Ruston, 1912.

spores of fungi, insects and bacteria, so that it must always be properly filtered if used for drinking.

Rain-water rarely contains less than one grain of solid matter to the gallon, and in towns often 3 or 4 grains, and even more. This is equivalent to 3 lbs. in the quantity of rain falling on an acre of ground during a rainfall of 1 inch as measured by the rain-gauge; which would be a heavy, but not an exceptional shower (Ansted).

Streams and Rivers.

When these are used as a source of drinking water, the latter requires to be carefully purified, on account of invariable contaminations during their flow. We have already alluded to the natural processes of purification, by sedimenting and the action of organisms, which make the water of many rivers seem fit to drink but never make it quite safe. Dr. P. Frankland pointed out that while sedimentation requires rest, moderate agitation followed by quiet intervals is favourable to the growth of purifying bacteria. Therefore the system of constructing weirs on a river, which has been adopted from times immemorial for engineering reasons, is also conducive to the wholesomeness of the water, provided that actual stagnation is avoided. Storms and floods increase pollution, and animals give rise to parasitic contamination. P. Frankland estimated that to allow proper time and the best conditions for self-purification to be completed, a full control over the river for a minimum distance of 12 miles is necessary. The question includes a very large number of subjects, which in England were first systematically dealt with by the Rivers Pollution Prevention Act, 1876, but the law proved to be so complicated that it had to be amended and supplemented by a variety of local acts and bye-laws, and even then there were so many saving clauses and ambiguities that the administration has been almost a failure. A historical account, with instances of litigation, local bye-laws and conditions, is given by S. Rideal.

One of the most important features in the question has been for a long time receiving attention from the Royal Sewage Commission of 1898, namely the discharge of polluted liquids into rivers, especially those used as sources of drinking supplies. In their fifth report of 1908 they find that "it is practicable to purify the sewage of a town to any degree required" (p. 229); and that all trade effluents interfere with or retard purification, but do not make it impracticable to purify the sewage by the various processes (p. 232). The provisional standards they laid down for permissible effluents are generally well known. But in speaking of a Central Administrative Authority (p. 235), they unfortunately repeated the fault of undue elasticity which had made earlier legislation almost nugatory in effect. As continuing :—

"To secure the economical and efficient discharge of the duties of local authorities and others in regard to pollution, and adequately to protect the public health and the amenities of rivers, the statutory provisions in regard to these matters must be of an elastic character." The object seemed to be to remove the matter as much as possible from the jurisdiction of the Law Courts. There was left undecided "the settlement of standards *for different reaches of water*," that is, local standards. But we may remark that if these standards vary for different *places*, they must also vary for different *times;* making the subject simply a matter of discretion. Continued observations were promised and a further report. This appeared in 1912, and rather decreased in definiteness. It is concluded (8th Report, 1912, p. 17) that "the standard should be either the general standard or a special standard which will be higher or lower than the general standard as local circumstances require or permit." The suggested limits of the previous report were rather relaxed: "An effluent in order to comply with the general standard must not contain as discharged more than 3 parts per 100,000 of suspended matter, and *with its suspended matters included* must not take up at 65° F. (18·3° C.) more than 2 parts per 100,000 of dissolved oxygen in five days" (see Chapter XII) . . . "subject to modifications after an interval of at least ten years" . . . "the dilution afforded by the stream is the chief factor to be considered." They state further that if the dilution is over 500 volumes all tests can be dispensed with, and crude sewage discharged "subject to such conditions as the provision of screens or detritus tanks as appeared necessary to the Central Authority."

Public Supplies.

The problem here is only an enlargement of the ordinary one to provide a regular and adequate output of good quality, but there is often difficulty in choosing between alternative sources and methods of collection and treatment.

Wells in all forms must be in such a number that the wide fluctuations occurring in the quantity of water obtainable from this kind of collector will not cause shortage at any time. Widening and deepening do not add so largely to the delivering capacity as does the drilling of adits or horizontal tunnels and passages below the water-level. But although connecting up a set of wells in this fashion greatly increases the yield of water, it has the disadvantage that if *one* well becomes polluted the whole network is liable to receive some of the contamination. The wells can be of any of the types already mentioned, and there are several methods of linking up, by which each unit can be disconnected without affecting the others, while provision is made for drawing off bacterial or chemical samples.

Occasionally compressed air is used for forcing ; this has the advantage that no adjustment of valves is necessary ; but on the other hand the well-chamber has to be made permanently air-tight.

Springs are liable to great fluctuations ; the delivery being occasionally twenty or thirty times the usual amount. As has been remarked they are often highly susceptible to contamination.

A very general source is ground water collected from comparatively low-lying regions such as valleys or from hilly and mountainous watersheds. It is gathered by constructing dykes parallel to the axis of a valley, and advantage is taken of the natural filtration afforded by the strata. The effect of the storm-water rushing down the slopes and causing turbidity may be minimised by planting trees and undergrowth along the banks of each dyke ; foliage must not, however, overhang. On a large scale the protective action of forest areas has been nowhere so well exhibited as in those cases (especially in the United States of America) where, as a result of the removal of a considerable amount of timber without systematic replanting, whole towns and villages have been washed away by floods and rain-storms. Apart from the economic and æsthetic error in the ruthless destruction of forest land, with no provision for the future ; trees affect the rainfall of a country and consequently have great influence on the climate, generally securing the periodicity of showers and making the weather more uniform and equable.

In all systems the collecting ground requires to be carefully guarded against pollution ; sewage or drainage from farms on the slopes being diverted in well-fitting drain-pipes, access of animals prevented, and conduits kept clean and free from leaves, sticks, etc. Caution must be observed in the rate at which the water is drawn, to allow the natural filtration to be gradual enough for efficiency.

Even with all these precautions the above methods of collecting surface water yield a product that has often proved to be dangerous, since infection of the water can hardly be avoided where the site has dwelling houses on it, hence both in this country and abroad collecting areas have been sought where the watershed is uninhabited and presumably unpolluted. The subject will be further discussed in the chapter on Storage.

Rivers as a general rule are so polluted by towns, private houses, or factories, that their direct use as sources of potable water is not feasible. The fault is commonly evaded by drawing from points high up the stream. In the general course natural purification is relied upon to render the water fairly pure, final treatment being afterwards applied at the waterworks either before or after the water is pumped up into the impounding reservoir that supplies the district. In order that natural purification should be effective, it is necessary as we have seen, to take precautions and to have proper control. Factory effluents discharging poisonous substances will have a great retarding influence on the natural improvements. Moreover all effluents must be faintly alkaline or neutral, since acid liquids are harmful and may be fatal to any of the important purifying organisms. Liquors from tan-yards, chemical and gas works, and mine waters are the most generally injurious.

Planting trees along the banks of the protected portions of the river is advised in order both to prevent the entrance of dust blown in and to hinder evaporation, and also to shield the water from the sunshine, since the ultra-violet light in the sun's rays has a powerful germicidal effect on the nitrifying organisms. Aeration and periods of quiet must be provided for as was indicated above, with the same precautions for preventing pollution from the banks. Reservoirs are necessary, since storm-water is always foul and contaminated, and the filter system in use has probably been designed to meet normal flow requirements and consequently cannot deal with the dirtier gatherings.

Distillation of Sea-Water.

The magnitude of the problem of supplying potable water for large ocean-going liners and battleships is frequently not realised. The regular demand may be as much as 5000 gallons per day, and to this must be added the amount required to replace the loss by leakage, due to the exhaust steam from the engines not being all returned to the feed tanks. *Engineering* estimates this latter quantity at about six tons per day per 1000 indicated horse-power. The only feasible process is that of distillation. With due precautions the water may be obtained free from grease and salts of all kinds.

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CHAPTER IV.

DISTRIBUTION.

SETTLEMENTS from the first ages have clustered round sources of water supply, springs, wells and rivers, and the latter for many reasons have gathered the largest and the most rapidly-multiplying populations. As numbers increased, so did fouling of water, and it became necessary to go farther afield for drinking supplies. This involves questions of carriage and distribution ; and water-engineering was almost as prehistoric an occupation as agriculture. In common with most other branches of knowledge, the earliest records of the science come from the Chinese, who laid down conduits from the mountains, chiefly for irrigation, but also for potable supply, and developed taxes and regulations much like modern ones.

In "Bismaya, an account of excavations in the ruins of the oldest of the buried cities of Babylonia," Dr. Banks,* describes their arrangements of 5000 or more years ago. Canals carried the water of the Euphrates far inland from a dam across the river, but as happened in other places similarly provided, the breaking of the dam rendered the country waterless and caused the ruin of dependent communities. Layard found fragments of earthenware pipes at Nineveh, showing that these were employed for distribution in ancient cities.

The huge masonry aqueducts which the Romans built in many countries have been thoughtlessly held as indicating that the use of underground watertight channels was not at that time understood, but there are evidences that the classic peoples appreciated the value of a long transit, exposed

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* E. J. Banks (Putnam, 1912).

to light and air, in naturally purifying the water (Hippocrates and Pliny discuss water characteristics and pollution in almost modern phrases). There were also broad rivers to be crossed, and rocks which were too hard to be tunnelled. A water-tunnel was, however, discovered under Pompeii. This city had an elaborate water system of distribution, with fountains along the streets, fed by pipes made of folded sheet lead, the necessary pressure being maintained by water-towers.

In modern history London was decidedly behindhand in the development of a regular water supply for all purposes; and the first attempt to provide it by mechanical methods was in 1581, the conduits fed by springs being no longer sufficient for the increasing population. At this date, Peter Morris, a German, set up the standard conduit in Cornhill and raised the water by an "artificial forcer" in lead pipes over the steeple of St. Magnus-the-Martyr, thus gaining the requisite pressure at the outlet; at the same time he was granted "the first arch of London bridge for the term of 500 years with leave to erect an engine of his own construction for conveying water into the houses of the inhabitants of the city and for the better service of the city in case of casualty by fire."

In 1766 the London Bridge Waterworks acquired the position, and Coles-Finch, on p. 423 of his book already referred to, gives an interesting account of these early enterprises, of the water-wheels and pumps under the arches of old London Bridge, and of the starting of the New River Company in 1601. The water-pipes in those times were merely trunks of trees roughly trimmed to shape, hollowed, pointed and recessed to fit each other.

It was not until about 100 years ago that rapid progress began to take place in the public water supplies of this country, and, according to Mr. Pickering * (in a paper which gives much valuable information) the main stimulus was the introduction of cast-iron pipes, which permitted greater pressures. Steady advancement has been made ever since, so that few populous places are now without a piped supply. As he says, constant engineering supervision is essential, and

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* *Trans. Inst. Water Engineers*, 1912.

also a systematic and methodical examination of the water by a qualified chemist.

In laying out a scheme of water delivery it is necessary to design the piping installation in such a way as to fulfil the following conditions :—

(1) There should be no dead-ends, since the presence of stagnant water in any part of the system is to be avoided.

(2) The whole must be so linked up as to prevent some portion of the network being starved when water is being drawn off at other points.

Size of Pipes.

It is a mistake to lay down narrow pipes from an idea of economy, since the friction of the water is nearly in inverse ratio to the square of the diameter, which means that a pipe of half the width will have about four times the friction, consequently a greater head, or expensive pumping, will be required to obtain a given delivery. In addition to the effect of friction, the quantity of water that can be transmitted through a pipe in a given time is also limited. Provided a certain speed, "the critical speed," is not exceeded, the flow is steady, in stream lines running practically parallel to the axis; under these conditions scarcely any power is wasted on internal friction. But immediately this critical speed is overstepped by applying more pressure, the current becomes turbulent and the stream lines no longer run parallel to the cylinder axis. The result is that an increase in pressure now by no means gives a proportionately greater yield.

Material of Pipes.

In early times, as we have seen, *wood* was used, and square wooden carriers, or bored trunks of trees, either charred or tarred on the inside are still employed in primitive spots. The durability when made of oak is often very great, but such channels are apt to give the water a colour and taste, besides having other disadvantages. "Salt-glazed" stoneware resists the action of water and communicates nothing to it, but the line is liable to be broken by shocks and vibration from above.

When buried in the earth, metal pipes are subject to corrosion, and can neither be inspected nor repaired without the cost and inconvenience of opening the ground. Therefore municipal deliveries are better laid in the manner now increasingly prevalent, along with gas and electric mains in a common tunnel with inspection boxes at intervals. Occasionally *steel* pipes are laid; they are more expensive but stronger and lighter in proportion. They are objected to by some engineers on account of the thinness of their walls, which would rapidly yield if corrosion set in (*Trans. Inst. Water Engineers*, 1909, p. 213). There are numerous cases on record of their splitting from end to end, and of course wrought iron is liable to this fault along the weld. *Lead* piping is generally used for inside fittings because it is more easily worked, and because narrow iron water-pipes become rusted and clogged.

Several methods have been devised for protecting iron pipes. One largely used is Angus Smith's process of heating the cleaned surface in a mixture of hydrocarbon oil and tar; on the oil evaporating the coating is a protection, but unfortunately it is somewhat easily damaged.*

Attacks on the Delivery System.

1. *Frost* occasioned a water-famine in London in 1895, due to the fact that the street pipes were at that time laid too near the surface; a depth of 3½ feet is considered necessary. House pipes where they run outside should have wooden casings lined with saw-dust or tow.

2. *Corrosion.*—Most waters attack iron pipes more or less rapidly, owing to the solvent action of the dissolved carbonic acid and oxygen, and this is worst in soft waters.

Pliny in *Hist. Nat.* refers to the fear which people had

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* A. Beythien, *Z. U. Nahr. Genussmittel*, 1905, ix, 529, *J. Soc. Analysts*, August, 1905, notes that a water, free from iron as drawn from the well, passed through 1¼ miles of asphalted iron pipe, became filled with filaments of an organism allied to Crenothrix, which he calls *Gallionella ferruginea*.

regarding certain waters and more particularly those that had the power of corroding iron and even copper.

The corrosion of iron by carbonic acid was investigated, among others, by P. Petit.* He found that the waters of the Moselle, which are only slightly calcareous, act energetically on the metal, and sometimes perforate iron pipes or tanks, but a moderate addition of lime causes deposition of a protecting crust of calcium carbonate. Otherwise the iron is dissolved as ferrous carbonate, which is decomposed by air into ferric oxide and carbonic acid, the latter continuing the attack, so that a small quantity of CO_2 can do great mischief, but this is greatly prevented by lime addition. Carbonic acid also promotes the action on iron of certain mineral salts present in waters.

O. Krohnke † found that the very pure and soft town water of St. Johann contained 24 parts per 100,000 of CO_2, and 3 months later only 3·8 parts. The former reduced the bore of an iron pipe from 26 mm. to 7 mm. (from 1 in. to $\frac{7}{25}$ in.) in a short time, owing to the formation of a brown crust, while the metal itself was corroded to a depth of 1 to 3·5 millimetres. He also noted the remedial effect of adding lime.

Waters with little lime but high chlorides act rapidly on iron. Prof. Weber showed that cast-iron under sea water in the course of time is converted into a grey graphitoid mass.

Zinc and tin have been used as linings to iron pipes, but if the lining is not continuous, electrolytic action is set up. This causes the zinc to dissolve for a considerable distance round the exposed area, and then small impurities in the material of the pipe itself cause the metal near them to dissolve away. Tin under the same circumstances accelerates the corrosion, although itself is not readily attacked.

In certain instances where copper-lined pipes are employed, Prinz ‡ has shown that very soft waters and those with a high free carbon dioxide content, readily attack and dissolve copper; once he found 11·8 mgs. of copper oxide per litre.

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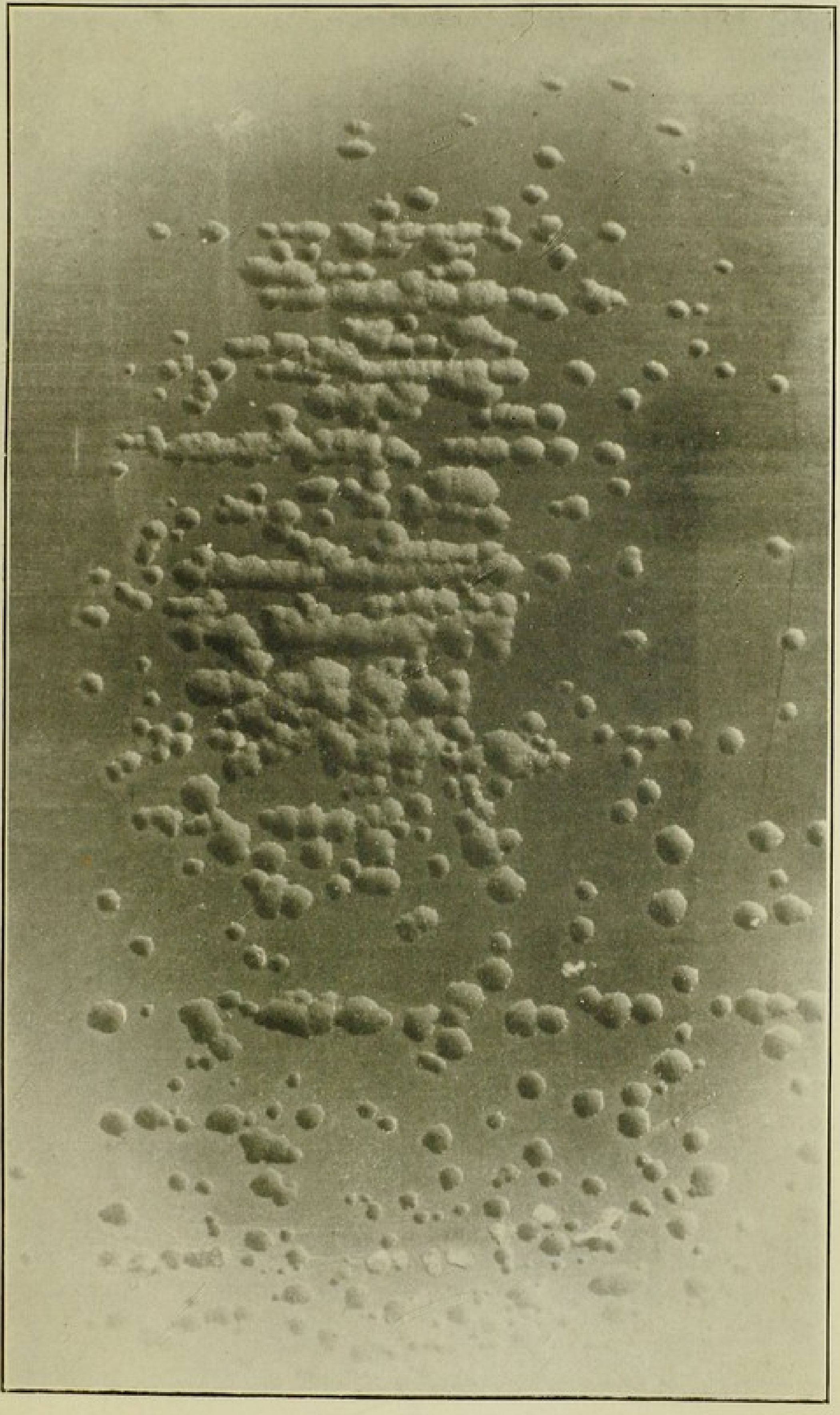
* *Comptes Rend.*, 1896, cxxiii, 1278.

† *Woch. für Brau.*, 1900, xvii, (17), 233.

‡ *Journ. für Gasbel. u. Wasservers.*, 1906, p. 39.

PLATE V.



"Pitting" in a Gun-metal Pump Plunger.

[*To face p.* 48.

Zinc is acted on by many waters, giving rise to symptoms of irritant poisoning.

3. Not only is the pipe attacked from the inside, but foul water in soils is very injurious to the outside. Sulphuretted hydrogen, chlorides, nitrites, nitrates and ammonia have all their special corrosive effects. Pipes traversing infiltrated ground can be protected by a coating of clay, which in several cases has proved effective, by pitch or by asphalt. Slags or cinders often liberate alkali, which corrodes both iron and lead. Slag wool used for packing has been known to corrode wrought-iron pipes. Sulphuric acid in the soil resulting from oxidation of pyrites has frequently caused pitting and rusting in water mains. A proved method of protection is by means of bituminised Hessian cloth, afterwards coated with a bituminous composition (E. Rideal).*

4. Other causes of attack on the piping system have been shown to be present in waters derived from moorlands and peaty sources. Here the water is distinctly acid, owing to the presence of the peat-acids (crenic, apocrenic, and humic are differentiated) to which most of the colour is due. This liquid has a remarkable plumbo-solvent property, and frequently attacks lead more rapidly than iron. The annual report of the Local Government Board for 1908 states that no less than 48 towns in England have plumbo-solvent waters. The exact nature of this property in peat is not at all clear. It has been shown that waters in which free CO_2 is present to the extent of 15 to 40 milligrammes per litre attack lead, iron, copper, zinc, and cement, and that the calcium-hydrogen carbonate in hard waters exerts a protective action. Moor water undoubtedly contains a large quantity of CO_2, formed by oxidation of organic matter, and this adds to its action on metals.

Water can dissolve lead even without carbonic acid; oxygen from the air producing an oxide which passes into solution as lead hydrate, $Pb(OH)_2$. Lead oxide is soluble in

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* More recently cement has been used both for inside and outside protection from corrosion. For many waters the method compares most favourably with others, but several precautions must be taken for good results.

water to the extent of 1 in 7000, or 10 grains per gallon; if the solution is further exposed to air, the atmospheric CO_2 precipitates it as lead hydro-carbonate. The metallic corrosion is very much accelerated by small quantities of acids, as in the manufacture of white lead. In an experiment in our laboratory we found 9·5 milligrammes of oxygen in a litre of distilled water dissolved 120 milligrammes of lead. Nitrates, nitrites, chlorides, and ammonia assist the solution. The metal appears to be most soluble in waters containing oxygen and CO_2 in the ratio of 1 to 2.

Electrical conductivity measurements prove that the peaty acids must be very weak ones, so weak indeed that they have been inferred to consist really of dispersed colloidal matter in suspension, or "sphagnum acids" made up of the cell-walls of that moss (Baumann and Gully).*

Gaertner † proposes to fix a limit for the action of a water on lead—that it shall not dissolve more than 1 milligram per litre after twelve hours' contact. Such a liquid is, however, still dangerous, and it is necessary to totally condemn all lead-containing sources, unless they can be treated to remove the impurity, or the fault can be remedied at first.

Dr. Low ‡ states that in the Heckmondwike district 3 to 6 milligrammes of lead per litre produced plumbism. The requisite treatment for plumbo-solvency will be discussed in a later chapter. A very useful review of the subject is given in H. Heap's "Study of the Action of Various Waters on Lead."

Dachnowsky § investigated the "vegetable toxins" which make moor water injurious to plants and animals. He found that the content varies with the time of year, also that these toxins are removed by absorbents such as quartz sand, kaolin, or carbonate of lime (chalk, marble, limestone), and that the absorptive effect is nearly proportional to the quantity added, and "possibly a function of the surface area of the powder," *i.e.* finer division increases it.

* *Mitt. d. K. Bayr. Moorkultur-Anstalt*, iv, 31, 1910.

† *Viertelj. für ges. Med. u. oeff. Sanit.*, 1910, 40, 104.

‡ *Surveyor*, xxxiv., 517.

§ *Bot. Gazette*, xlvii, 389, 1909.

The action of the peat-acids on metals is prevented by adding a suitable amount of lime or soda, as in the process for water softening. Carbonate of soda, or powdered chalk, will also serve the purpose, and crushed limestone or marble fragments have been used with benefit.

The humic acids combine with calcium ions to form soluble salts which are also coloured. Thus with plumbo-solvent waters containing humic acids a difficulty arises: if we get rid of the colloidal matter without lime, the plumbo-solvency is not removed; on the other hand if we cure the action on lead by adding lime, the latter forms the coloured humic salts alluded to above.

As drinking water is such an important item in public health, it would be desirable that lead should be done away with in pipes and cisterns, and these made of iron protected by one of the known processes. With lead piping, it has been directed that "the water must be allowed to run to waste for a short time before drawing off"—this of course means an indefinite loss of water. It has also been advised that the water should be filtered through charcoal, which absorbs lead; but the power is uncertain and transient.

5. Another very common cause of local attack is of electrical origin. In places where water mains run near electric-light cables, occasionally when the latter become damp the insulation is rendered slightly conducting; this allows a current to flow from the cable to the iron pipe and along it to some other point, where the current can either run to earth or make a more or less good contact with the return cable. When a current flows along an iron water-main, part of the current passes through the water, which acts as an electrolyte, with the result that iron is dissolved from off one part of the pipe and replaced at another point. Solution continues until the iron pipe shows a fracture at a place which represents the positive electrode of the cell that has been thus formed. Since in this case the metal dissolves in water in the ferric state a current of only one-tenth of an ampere will dissolve over eleven and a half grammes of iron in a week.

The earthed return rails of electric trams are a source of stray currents which always cause solution of neighbouring metallic pipes, unless the latter are either :—

(*a*) Sufficiently insulated from wet soil, etc., by means of a protective coating, or insertion in a cement or brick tube.

(*b*) Connected at frequent intervals to the tramway rails themselves by a good conductor, thus making the whole piping system a conductor at the same potential.

The following table shows the potential loss allowed on the return circuits of tramway systems in various European towns.*

Town.	Potential loss on return circuit.	Potential between rails and pipes laid near.
London . . .	7 volts maximum.	Pipe $\begin{matrix}(+1\cdot4)\\(-4\cdot2)\end{matrix}$ volts.
Paris . . .	1 volt per kilometer. 5 volts maximum.	7 volts.
Berlin	No regulations.	1 volt.
Vienna	5–7 volts.	Not observed.
St. Petersburg and Moscow . . .	1·5 volts in the town. 3 ,, ,, suburbs.	— —
Glasgow . . .	7 volts maximum.	1 volt highest observed.
Liverpool . . .	7 ,, ,,	Maximum, 4·5 volts.
Brussels . . .	No regulations.	—
Christiania . . .	10 volts maximum.	Maximum, 5 volts.

A similar phenomenon occurs at all the contacts where different metals are connected, such as the lead-iron or lead-brass-iron joints where a house-delivery is being taken from a main. Electrolytic action also sets in, though with somewhat less activity after two ends of the same metal have been united by solder or brazing, especially when an acid or alkaline flux is used, and is only inappreciable when they have been joined by "automatic soldering" with a special blowpipe. Even then there is slight electrolysis when the metals are of the same name commercially but differ in their impurities, as when cast-iron is joined to wrought-iron or either to steel, or the two are of different hardnesses. Stresses and porosity have also influence. (*Stahl u. Eisen*,

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* *Engineering Record*, lx, 36, 1909.

xxxi, 1485–1493, 1912.) Moreover, thermo-electricity shows that if one part of a conductor is hotter than another a difference of potential is established and a local current, which if water is present must be attended by slight electrolysis, so that electrolytic action can seldom be completely absent.

6. *Obstructions in the Pipes.*—The incrustations found in water-mains may be of either vegetable, animal, or inorganic nature. Vegetable slimes are usually met with in hard waters which contain sufficient food to enable the plants to grow, while soft waters are ordinarily responsible for the rust nodules. Clogging is sometimes caused by animal growths. The *bryozoa* or fresh water polyps often grow in this way, and can only be removed by steaming and flushing the pipes. *Spongilla* and some other organisms produce (see Chapter II) at times partial stoppages, and on decaying make the water offensive. Various fungi, especially the iron group, also cause clogging and contamination. Green algæ cannot, of course, grow in the dark, but are met with in uncovered cisterns. The presence of these organisms in service pipes indicates imperfect filtration or faulty storage, as their spores should not have been allowed to gain access.

Professor Parker [*] has found that a solution of common salt is an effective agent for the removal of sponges from water-mains. Various mechanical contrivances for getting rid of these incrustations without injury to the pipe have been designed and are extensively used in practice.

Besides a matted growth on the walls of pipes, settlement of floating organisms will occur where the current is retarded, and will cause trouble.

7. *Water-Hammer.*—Tap fittings are usually of the screw-down or plunger pattern; this latter type is more to be recommended on the score of economy, since they are not so liable to be accidentally left on over night and at any other times. They have, however, certain disadvantages, the main objection being that they sometimes give rise to the phenomenon of "water-hammer." If such a tap is quickly

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[*] *San. Record*, Aug., 1913.

closed the inertia of the column of water travelling along the pipe sets up a compression next to the end. Thus a wave is set up in the pipe, travelling backwards and forwards between the tap and the other extremity of the pipe where it joins the main or cistern. This wave has a gradually decreasing amplitude, and may move, according to Prof. Joukovsky, at rather more than 4000 feet per second. The pressure is occasionally extremely large, and unless there is some method of gradually slowing down the velocity of the water without suddenly bringing it to a state of rest the water will beat against the tap with a loud noise, and the vibration may cause leaks or loosen fittings. Screw taps gradually closed slow down the water, permitting the back pressure gently to be reduced before the orifice is entirely shut. "Hammer" is sometimes dealt with by having a water safety-valve on the pipe. In Moscow there are over 1500 of these at work, and they are reported to have completely fulfilled their purpose.

The whole subject is well discussed in an article on the "Theory of Water Hammer" by L. Allievi.*

8. In large deliveries the loss through leakage and waste is reckoned as 10 per cent., and even more, therefore in some places an intermittent service is given, and stored in cisterns. But from the point of view of hygiene and of fire-danger, the modern English practice of an unlimited constant supply to houses under a property valuation rate is far preferable, and seems to be better than the Continental system of charging the whole supply by meter like gas. Water meters are expensive, and require frequent inspection: the chief types are the V-notch for open channels, the Venturi, and the turbine.

Deliveries from deep springs and artesian wells have been everywhere credited with uniformity of temperature, but E. A. Martel † has quoted observations to the contrary from reports by Dabat, "directeur général des Eaux et Forêts," and has shown that there are season variations much more

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* *Atti dell' Assoc. Elettr. Ital.*, xvii, 127–150, Feb., 1913.

† *Comptes Rendus*, March 13, 1913.

considerable than had been previously recognised. A number of springs in the Gironde fluctuate from 6° to 14° C. according to the time of year; in the Nord department they range similarly from 6° to 13° C. About Douai and Cambrai many springs have a varying temperature, which, however, is generally 6° to 8° below the local annual mean. He arrives at the law that "the temperatures and delivery vary equally, and the more variable these are the more uncertain is the purity, for the filtering power is a function of the speed of transmission." This combined with the results of geological observation is of the greatest importance from the point of view of sources of drinking water supply. "The constancy of temperature exists only in the continuous sources from sand and similar material, or artesian supplies from great depths, slowly and regularly maintained."

The advantage of more than one source of water supply and of its abundance, to a city in case of war or serious accident has been many times evidenced in history. Ancient Rome with its eleven aqueducts is said to have served its inhabitants at the rate of over 300 gallons per diem for each man, woman, and child, partially explained of course by the much greater consumption in bathing: we moderns have to be content with a far less provision, as will be seen in Chapter V.

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CHAPTER V.

STORAGE.

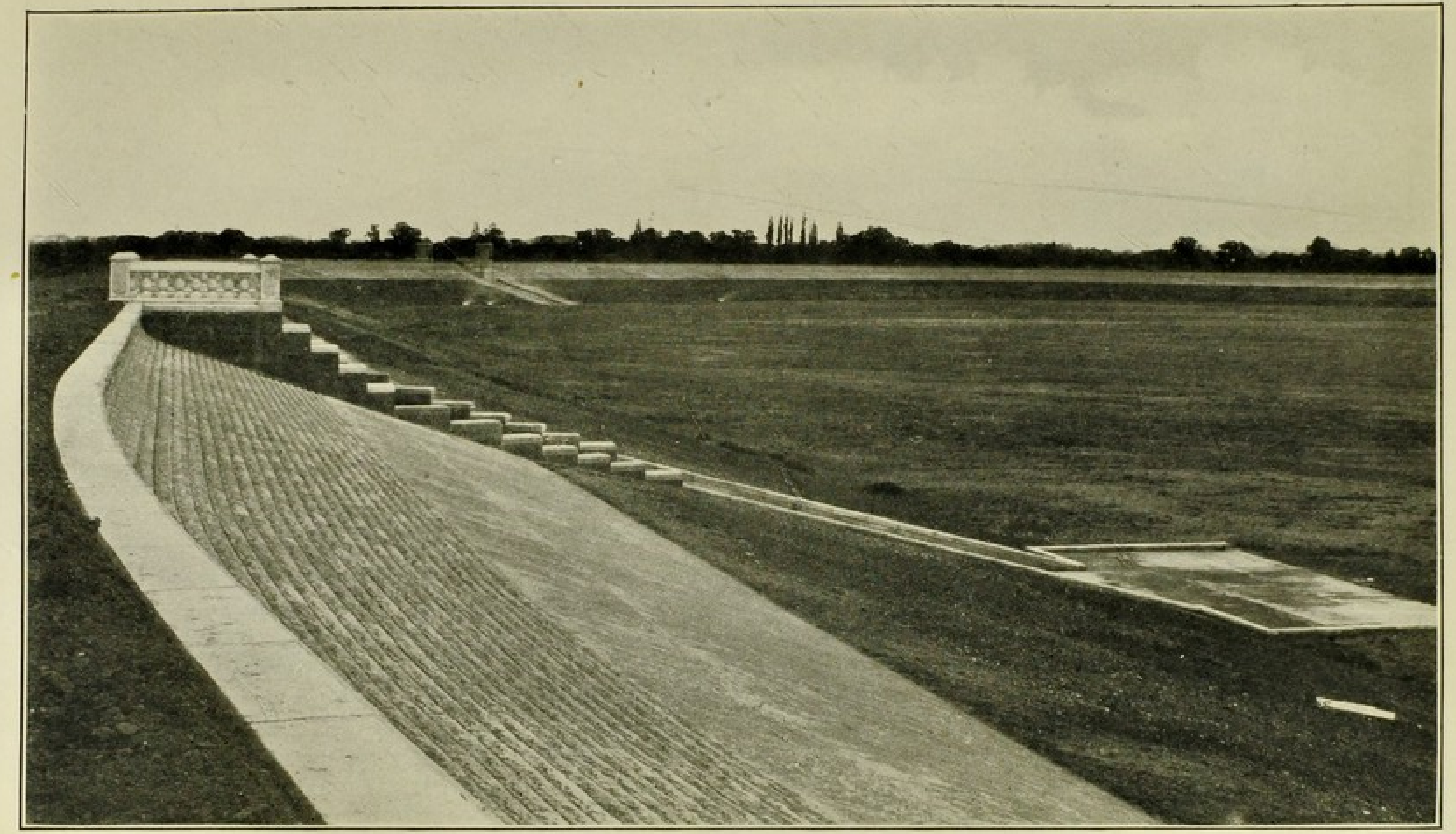
THE practice of storing large volumes of water, with a knowledge of the improvement that could be thus effected in its quality, is traced in very early Egyptian records, but Humboldt points out that remains of numerous tanks and cisterns in India are of still more remote antiquity. Jerusalem was famed for its reservoirs and pools of clean water, mostly of the age of Solomon. In modern countries systematic storage is of quite late date ; we have already noticed in Chapter IV the beginnings of a complete system in London.

The average allowance of water per inhabitant varies greatly in different localities ; in America it is much larger than elsewhere, as the following approximate figures show : Buffalo 250 gallons per day, Philadelphia 211, Chicago 169, New York 120, Berlin 28, London, 35, Madras 25.

English practice usually reckons 30 gallons per head per day ; Germany 22 to 33 gallons with a maximum hourly consumption per day of 2 gallons. These figures include street watering and household consumption, but an additional quantity has to be supplied for public lavatories, baths, laundries, parks and gardens, besides local industries that require special provision.

London was formerly served by a number of separate companies and undertakings, but in 1902, following the example of other cities, these were all placed under the administrative control of a new central elective body, the Metropolitan Water Board. Their report of February, 1914, shows that they are now serving a population of nearly 7 millions on an area of about 537 square miles, with 238 million gallons of water per day, equal to about 35

PLATE VI.



Chingford Reservoir, North Side.
(London M. W. Board.)

[*To face p.* 56.

gallons per head. Of this 55 per cent. is derived from the river Thames, 25 per cent. from the river Lee, and the rest from wells and springs in Kent and Hertfordshire. Almost the whole (99·2 per cent.) of the supply is on the constant system, which is proved to have such great advantage as regards purity, not to mention emergency requirements. For storage of the raw water there were then 47 reservoirs holding nearly 9000 million gallons, with 15 smaller ones for smaller non-domestic supply. Two new reservoirs have since been added, Island Barn 1000 million gallons, and Chingford (1913) 3000 million gallons. The latter has quite a new departure in raising the water by the Humphrey apparatus with explosion chambers instead of ordinary pumps. The London total storage will furnish sufficient water for 57 days' consumption.

New York is now constructing large works to provide a new supply from mountain sources on four watersheds having an area of 900 square miles, calculated to yield 770 million gallons daily, with reservoirs in each basin, connected by aqueducts, and many "syphons" for passing rivers. The largest of these is the one under the river Hudson, and the borings showed that great depths would have to be reached before rock was met with sufficiently solid and free from seams to keep the tunnel tight. Finally a shaft was sunk on each side 1100 feet deep, with a horizontal tunnel between. On account of the depth, the pressure in this is 40 tons per square foot. The Ashokan reservoir and its connections in the Esopus watershed deal with 250 to 500 million gallons daily, delivered to Croton Lake; the Kensico reservoir, chiefly fed from the Catskills, has a capacity of 40,000 million gallons, of which 29,000 million gallons, or 60 days' continuous supply at 500 million gallons daily, will be available for New York. The average depth of the water will be 100 feet. Nearer the city is the Hill View reservoir of 900 million gallons. At present the Croton system can provide 350 million gallons per day. At the Ashokan and Kensico reservoirs *aerators* are built, consisting of rectangular basins, 500 × 250 feet, with 1800 nozzles through which the water will issue in a fine spray.

Utility of Aerators.

As we have seen, some waters are habitually, and others become occasionally (especially during the summer months) deficient in dissolved oxygen, and aerators start a natural improvement by supplying it, in the same way as waterfalls, rapids, and weirs on rivers; moreover, aeration often causes a decrease of odours and colours, and much oxygen is required for oxidation of ammonia and other nitrogenous matters by nitrification. The jets are made removable in case of clogging or freezing.

In all reservoirs the inflowing water should be roughly strained ; the inlets and outlets should be as far as possible apart, and so arranged that there is no direct crossing of water from inlet to outlet leaving other parts stagnant. Construction in compartments, as frequently practised in America, has the great advantage that it gives better opportunities for uniform mixture as well as rest and sedimentation, and also for cleaning out in sections. Cleansing must obviously be done in all cases at intervals longer or shorter according to the amount and nature of the deposited matters. This will of course affect the time required for the settlement of which we shall speak further presently.

In Chapter II it has been shown that although the majority of living plants increase the amount of dissolved oxygen in waters, their growth in reservoirs must be discouraged for the following chief reasons, apart from obstruction of circulation :—

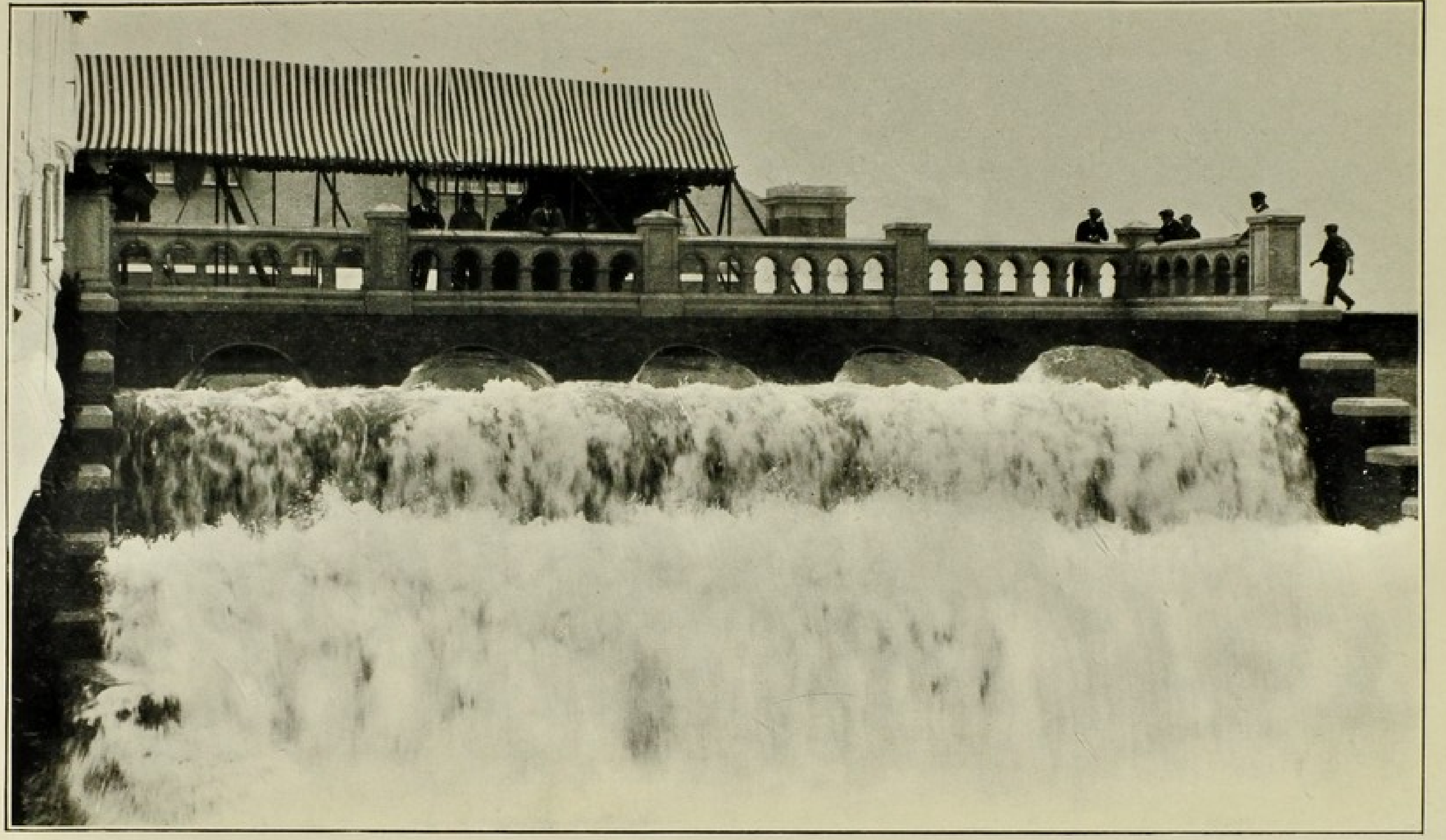
(*a*) The gas-bubbles they disengage prevent sediment from settling.

(*b*) In life they often cause odours, and after death they decay and foul the liquid.

In March, 1913, the water in the Staines reservoir of the Metropolitan Water Board had a peculiar aromatic "geranium" taste which gave rise to complaints. On investigation Dr. Houston discovered that the taste was associated with a marked growth of Tabellaria, with some Asterionella.

Some elementary points must be here noticed. All

PLATE VII.



HUMPHREY PUMPS: WATER ENTERING THE KING GEORGE RESERVOIR.
(London M. W. Board.)

[*To face p.* 58.

animals and plants tend to sink if left at rest, because the cellulosic and albuminous materials of their bodies, as well as the outer envelopes and skeletons, have a higher specific gravity than water (the only exception being the minor quantities of fats and oils). They can be kept in suspension in three ways—

(*a*) By motile organs, in which case they subside when dead.

(*b*) By agitation or currents.

(*c*) By air or other gases contained in their cavities or adhering to their outer surfaces. Organisms will often be seen rising with the gas bubbles and falling when these become detached or dissolved.

As essentials, green plants require light and carbonic acid; animals require oxygen. The gases dissolving from air penetrate in time to any depth by diffusion, but light is soon cut off by turbidity or colour. Hence while animals are found at great depths, *e.g.* at the bottom of oceans, green plants do not thrive in deep water. To hinder vegetation, therefore, it has been laid down that reservoirs should not be less than 25 to 30 feet deep (most of them are about 50 to 100), and that the sides should be as nearly as possible perpendicular.

In fixing the site of a new reservoir a variety of factors have to be primarily ascertained, among which are—

(*a*) Available yield from each feeder, and the quality as determined by a sufficient number of analyses both bacteriological and chemical, to determine what sources must be excluded or separately purified.

(*b*) Rainfall.

(*c*) Dry weather flow.

Each of these items is apt to vary enormously, and it is not permissible, as has sometimes been done with grave results, to take averages without considering aberrations, since the latter have occasioned in the case of (*a*) epidemics of acute disease, and in (*b*) and (*c*) floods or conversely, water famines. Other considerations are elevation and distance, nature of intervening ground, and in many cases a very serious item is the redemption of private claims.

It has been well said that gravity feed to the distributing area should always be made use of if obtainable, since it is much more economical than pump feed, which is not only expensive in upkeep but generally irregular in its action: this irregularity may be overcome by the use of small impounding reservoirs. The whole of the watershed supplying the collector must be carefully and periodically inspected, and the district or municipality supplied should acquire rights over the collecting area.

Changes effected by Storage

depend greatly on the character of the supply.

When this yields normally a very good water, as with many upland sources and deep wells or springs, it is clear that, except for reserve purposes, there is no advantage in storage, which is liable to cause deterioration instead of improvement. It is noticed that if pollution once occurs in a water of this kind, the entering bacteria, including pathogenic ones, multiply with extraordinary rapidity, probably from their having a free field. A typical observation by Dr. Miquel in the Vanne Spring water at Paris was a rise of bacterial content from 150 to 30,000 per cubic metre in 20 hours. Dr. Kruger * found in another case that at 10° C. a maximum was reached when the number of bacteria had risen to five times its former amount.

Direct sunlight is capable of killing nearly all bacteria. Dr. Currie † finds that it is most quickly fatal to the fæcal species, but that diffused light has no influence. (See Chapter XI.)

When, however, storage is applied to waters of the common class (such as those derived from rivers or shallow wells), which contain large numbers of organisms of all kinds, the effect is usually quite different. There is sometimes a rise at first, but this is followed by a decline, and the pathogenic species tend to disappear. Part of the suspended matter, together with some bacteria, is taken out by

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* *Z. f. Hyg.*, vol. 7.

† *J. R. I. Public Health*, xxix, 214, 1911.

sedimentation, but this has limits, as shown by the appended curve, illustrating what happens in a natural water.

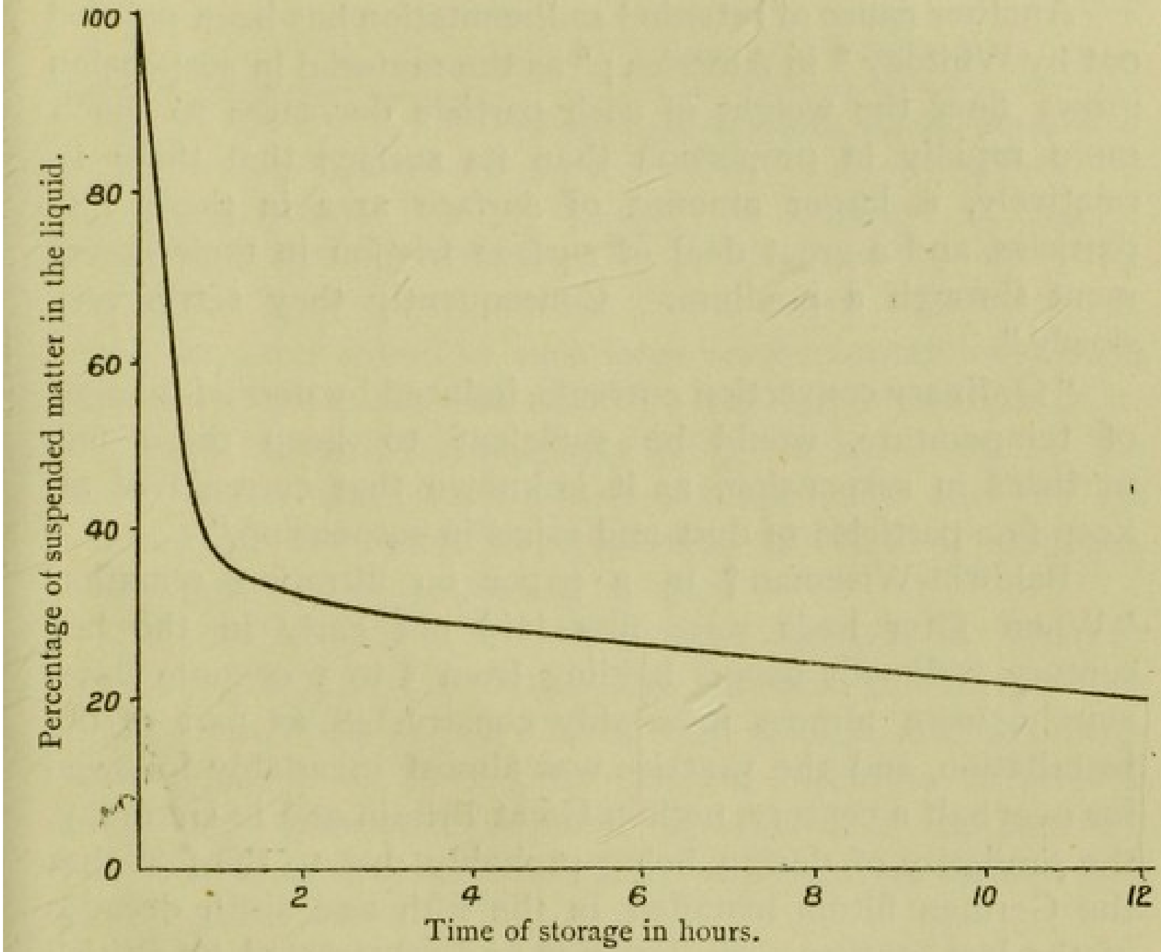

FIG. 4.—Sedimentation-Time Curve.

The following figures, based on Flad's observations of the rate of settlement of silt in Mississippi water, extend over a longer time. (Fuertes.)

Time of storage in hours.	Percentage of suspended matter left in the liquid.
0	100·0
24	5·5
48	3·3
96	3·0

It will be seen that the curve tends to become parallel to the base, because a percentage of these matters remains suspended for an almost indefinite time. They are partly of colloid nature, and require coagulants or filtration, or perhaps both.

Another cause of retarded sedimentation has been pointed out by Whitney * in America ; " as the material in suspension grows finer the weight of each particle decreases so much more rapidly in proportion than its surface that there is, relatively, a larger amount of surface area in these fine particles, and a great deal of surface friction in their movement through a medium. Consequently they settle very slowly."

" Ordinary convection currents, induced by normal changes of temperature, would be sufficient to keep these fine particles in suspension, as it is known that currents of air keep fine particles of dust and ashes in suspension."

Baldwin-Wiseman † in a paper on filtration remarks: "When filter beds were first laid out early in the last century, sediment basins holding from 3 to 5 or more days' supply, were almost invariably constructed as part of the installation, and the practice was almost invariably followed for over half a century, both in Great Britain and in Germany, the similarity of design being probably due to the fact that the German filters installed in the fifth and sixth decades of the last century were designed and constructed by British engineers. Subsequently German engineers have not increased the storage capacity of the settling basins to keep pace with the increasing daily supply, but have in many cases decreased that capacity in order to provide an additional area for filter beds, and they have maintained the hygienic standard of the filtered water by filtration or some other process.

"On the other hand, British engineers have constructed more and more storage reservoirs, aggregating in the case of sixty-seven of the principal British water supply authorities, some of which have no need to filter their supply, a capacity of nearly 105,000 million gallons of the water. In the case of London alone the storage has been increased in the ratio

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* Wiley's *Agricultural Analysis*, i, 180.

† *Inst. Civ. Engineers*, 1910.

of 1 to 6·3 in 24 years, as shown in the following statement:—

Year.	Authority owning the works.	Capacity in millions of gallons.		
		Storage reservoirs.	Service reservoirs.	All reservoirs.
1884	Eight companies . . .	1290	154·5	1444·5
1908	Metropolitan Water Board	8913·6	243·1	9156·7

"The water stored in such large reservoirs not only parts with much of its silt, but also with the larger portion of its contained bacteria, the majority being carried down by the silt to which they have attached themselves, and the remainder for the most part perishing for lack of adequate food supply and subsequently sinking."

So that a main difference between British and German practice, according to this author, is that the former has relied more upon sedimentation and storage, and the latter upon filtration or some other process. Neither is reliable unless the "some other process" consists of a real sterilisation (see Chapters XI and XII), which saves storage and simplifies filtration.

In the United States, where the substances are particularly slow in depositing, sedimentation is helped by adding some chemical, which by coagulation and agglutination of the refractory matter produces more or less rapid precipitation, and the settling basin with its chemical tank is an almost invariable adjunct, not only of American sand filters but also of the high-pressure types.

Fate of Bacteria in Storage.

Besides through sedimentation, bacteria disappear in the following ways:—

1. By acting as food to other organisms. Many common and vigorously-growing harmless forms of life rapidly exterminate disease germs: the protozoa are specially active in this respect, as shown by Russell in soils.

Hautemüller [*] actually observed the ingestion of living typhoid bacilli by flagellate protozoa; while Hörhammer [†] has observed a similar phenomenon in the case of certain crustacea such as cyclops. The same has been proved by Stokvis and Swellengrebel [‡] for ciliate infusoria on micro-organisms.

2. By exhausting their food supply and suffering starvation.

3. By poisoning themselves with their own excretory products.

Some of these toxins have been isolated, and prove to be also poisonous to higher life. This is a point that is sometimes forgotten, and shows why the mere mechanical removal of bacteria from polluted water does not render it undoubtedly wholesome.

According to the experiments of Horrocks,[§] and Gordon, Russell, and Zeit,[||] as well as those of Russell and Fuller,[¶] the life of typhoid germs is shorter in water containing large numbers of other bacteria than in water that is sterile, or contains but few organisms, although sufficient food, oxygen, etc., may be present to sustain growth.

The pathogenic organisms which thrive best at blood-heat are specially susceptible to the above adverse influences, since the temperature is lower, and the medium weaker, than in their natural habitats in living bodies, as has been remarked by numerous observers.

With regard to the effect of temperature of storage on the number of bacteria present in water; while most bacteria are capable of multiplying in a fairly wide range of temperature, each organism has an optimum at which it grows most vigorously, and a few degrees above or below this cause a

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[*] *Archiv. f. Hyg.*, liv, 89, 1905.

[†] *Ibid.*, lxxiii, 183, 1911.

[‡] Stokvis and Swellengrebel (*Journ. of Hyg.*, xi, 481, 1911).

[§] Horrocks (*Journ. Roy. San. Inst.*, xx, 664, 1899).

[||] Gordon, Russell, and Zeit (*Journ. Infect. Diseases*, i, 641, 1904).

[¶] Russell and Fuller (*Trans. Amer. Public Health Assoc.*, xxxi-ii, 1905).

marked diminution in the rate of growth. For most organisms the point lies between 20° and 40° C. Exceptions include among others the thermophilic kinds, which thrive at a temperature of 50° C. and upwards. The optimum temperature for the majority of organisms present in natural water, especially those rapidly liquefying gelatine, is below 30° C., while pathogenic and sewage organisms generally grow most rapidly at blood-heat. In the bacteriological examination of drinking waters, advantage is taken of the above fact for the elimination of the common water bacteria, and the numbers of organisms producing colonies of growth at "room temperature" (20° C.), and at blood-heat (37·5° C.), are separately determined, the latter being only a few per cent. of the former in potable waters.

Although it might be expected that water would contain more bacteria in warm weather than in cold, this is not always the case. With warm storage of a polluted water the optimum temperature of growth for the putrefactive organisms may be approached, so that their multiplication will become very rapid, causing a crowding out, and eventually an actual diminution in the total numbers occurs.

Another reason is that in summer there is a greater multiplication and activity among the larger organisms, such as the protozoa, paramœcia, rotifers, volvox and others, which eat up bacteria, and are hardly seen in winter.

An example is given by P. A. Maignen from a very large number of analyses of the water of the Lower Roxborough settling reservoir fed by the Schuylkill river. In winter the average count of total bacteria at the inlet was 60,000, at the outlet 90,000; in summer the corresponding numbers were 6000 and 3000.

Although many bacteria are not killed even by extreme cold, their vitality is sooner or later impaired by prolonged incubation much below their optimum temperature, some of their characteristic reactions disappear and many pathogenic organisms lose their virulence.

Dr. Houston, in his series of annual reports to the Metropolitan Water Board, has published the results of his very will deteriorate in quality. A striking example is given by F. P. Stearns :—

CHANGES IN GROUND WATER DURING OPEN STORAGE.

Parts per 100,000.	Albuminoid ammonia.		Nitrogen as nitrates.
Time of storage in days.	Dissolved.	Suspended.	
0	·0016	None.	·06
2	·0054	·0170	·045
7	·0082	·0406	·004
35	·0128	·0060	·003

"The nitrates here represent food; the suspended albuminoid, the algæ, and other organisms, and the dissolved albuminoid, an extract of dead organisms with perhaps, in addition, the excreta of live ones." At the end the algæ were dying because they had exhausted the nitrates.

3. There is usually a decrease in the hardness. Waters containing bicarbonates of lime and magnesia have always a tendency to evolve CO_2 by diffusion at their surface, at the same time depositing the earthy carbonates and becoming softer. Also a large number of plants and animals absorb lime and other hardening substances in the growth of their structures.

4. The free and saline ammonia (Chapter XII) diminishes in several ways. (*a*) If excessive, it passes into the atmosphere. (*b*) A good deal is *absorbed* by ferruginous deposits or even by mud. (*c*) Plants can take up dilute ammonia and its salts in their feeding. (*d*) Organisms like *Nitrosomonas* and *Nitrobacter* turn it with the aid of dissolved oxygen into nitrites and nitrates. These in turn serve as the food of plants, along with the nitrates originally present.

5. Consequently there is an eventual decrease in the oxidised nitrogen (Chapter XII), and generally a total disappearance of *nitrites* by oxidation.

We found the following instance of the removal of ammonia and the production of nitrites (though not to an equivalent extent), in the great natural purification of a very bad water by the concurrent action of light, air, and organisms.

The original sample on August 18th was brownish-yellow in bulk, and flocculent matter was present ; it had a sewage, and also fishy, odour. It contained in parts per 100,000, total solids, 80·2 ; chlorides as chlorine, 10·9 ; nitrates, absent ; nitrites, heavy ; free and saline ammonia, 2·35 ; albuminoid ammonia, 0·70 ; organic nitrogen (Kjeldahl), 1·15 ; oxygen absorbed from permanganate in 5 minutes, 0·646 ; ditto in 2½ hours at 80° C., 2·50.

It was exposed at the ordinary temperature for 18 days to air, while protected from dust ; having diffused light in the daytime, and occasional sunlight. The odour and colour gradually diminished at about the same rate as a sediment of green algæ formed with continuous evolution of gas bubbles. The deposit contained an abundance of flagellate infusoria with a few ciliate, and large numbers of very active amœbæ, with Daphnia pulex and rotifers. The main part consisted of small green algæ, desmids, and diatoms. The liquid was now clear, with a faint greenish tint and no odour ; there were still no nitrates, but the nitrites had increased ; the free and saline ammonia had fallen to 0·2, the organic nitrogen to 0·78. The evaporated solids, which at first were light brown, now appeared nearly white.

Impounding and Service Reservoirs.

The former are for raw water, the latter for water variously purified before delivery.

In populous countries it is imperative that all impounding works should be designed so as to utilise the yield of a watershed to the best advantage. A paper by Mr. W. J. Binnie and Dr. H. Lapworth,* read at the Wakefield meeting of the Institution of Water Engineers in 1913, discusses formulæ for the capacity of impounding reservoirs. The earliest is Mr. Thomas Hawksley's, $N = \frac{1000}{\sqrt{R}}$, where N

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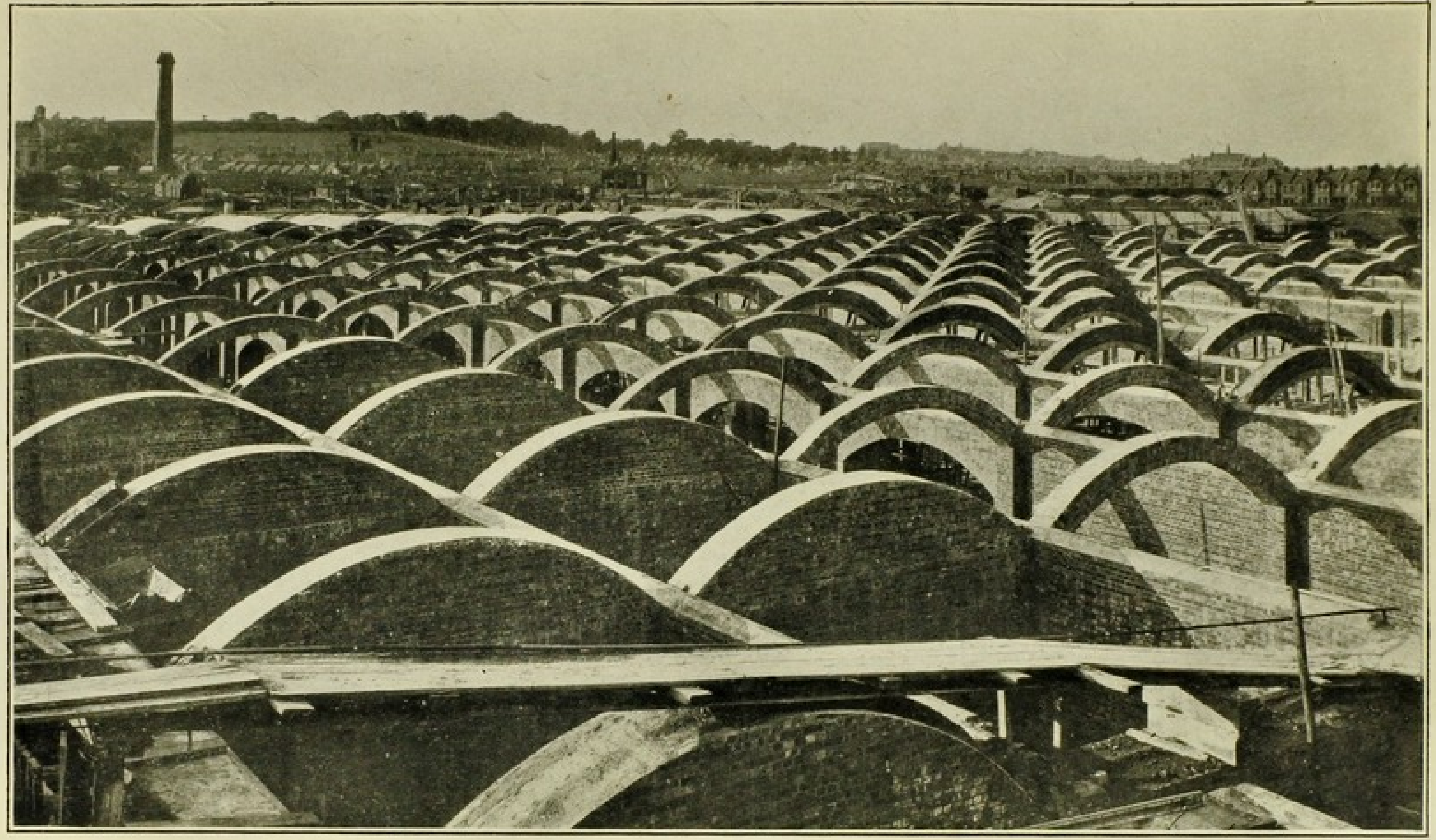
* "Reservoir Storage in Relation to Stream Flow."

represents the number of days' storage and R the mean annual rainfall of the three driest consecutive years. This holds very well for many drainage areas, but is not of much help in those cases where only a portion of the flow is abstracted during the driest seasons. Mr. R. E. Middleton's formula is $N = \frac{500}{\sqrt[3]{r}}$, where r represents the average annual run-off during the three driest consecutive years; here evaporation and absorption are taken into account. Binnie and Lapworth suggest as an approximate rule in determining the amount of storage for reservoirs up to, say, three-quarters of the total yield, the expression $S = 15\frac{(n-d)^2}{r^{1 \cdot 85}}$; where S is the number of inches' storage required to supply n inches per annum to be drawn constantly for supply from the rivers, d is the minimum dry weather flow of the river in inches per annum, and r is the mean run-off in inches per annum. They rather doubt, however, whether the refinement of adopting the fractional index to the value of r is justified with the present data available, and offer for practical purposes the formula $S = a\left(\frac{n-d}{r}\right)^2$. The value of a varies with the run-off thus: when $r = 9 \cdot 4$, $a = 21$; when $r = 23$, $a = 24$; when $r = 50$, $a = 27$. The paper shows the application of this formula to watersheds in this country and abroad.

Service reservoirs are generally of moderate size, allowing special care in construction, and in carrying out the necessarily greater precautions for avoiding contamination. The sides of impounding reservoirs are commonly sloping, and can hardly be kept free from plant-growth. When the water fluctuates in level it acquires a margin of decaying vegetable matter. Service reservoirs should have upright or nearly vertical sides, and bottoms artificially prepared. Some of the very earliest ones, as those of Carthage, had an arched covering. As we have seen, full exposure to light and air has advantages in the destruction of bacteria, but it encourages the growth of algæ and animals (see Chapter II). It is a good practice to plant near the banks a belt of trees,

PLATE VIII.



Relieving Arches, North-East Reservoir, Honor Oak.
(London M. W. Board.)

[*To face p.* 70.

selecting such species as are not liable to drop their leaves into the water, *e.g.* conifers.

Lakes of course are natural reservoirs, and furnish the water supplies of many large cities. As a rule they are obviously subject to much greater pollution than artificial reservoirs, and George R. Whipple, of Harvard University, Cambridge, Mass., says of them in a paper on "Sanitary Protection of the Water Supplies taken from the Great Lakes," read at the Eighth International Congress of Applied Chemistry, Washington and New York, Sept., 1912 :—

"More than five million people live in cities and towns near the shores of our Great Lakes. Most of these communities take their water supplies from the lakes and discharge their sewage into them. Except where the water supply has been purified before being used, this practice has very seriously affected the health of the lake cities and has been the cause of much loss of life. With our present sanitary knowledge it seems strange that such a filthy practice should have been ever tolerated. It is still more strange that raw lake water should continue to be used in cities which are doing so much in other ways to improve public hygienic conditions."

The paper shows the effect of the use of raw contaminated lake water on public health, especially in regard to typhoid and allied diseases, pointing out ways in which improvement has been or can be achieved.

The watersheds together have an area of nearly 300,000 square miles. The following table gives particulars :—

Lake.	Land surface.	Water surface. Square miles.	Total.	Mean elevation above sea level at New York.	Maximum observed depth. Feet.
Superior . .	48,600	31,800	80,400	602·28	1012
Michigan .	45,700	22,400	68,100	581·36	864
Huron . .	52,100	23,200	75,300	581·41	750
St. Clair .	6,335	495	6,780	—	—
Erie . . .	24,480	9,932	34,412	572·62	210
Ontario . .	25,720	7,260	32,980	246·2	738
Total .	202,935	95,037	297,972		

The pollution is gravest at the south end of Lake Michigan, where several cities, including Chicago, are near together on the shore. The depths vary very much, Erie for instance has an average of 63, and a maximum of 210 feet.

The water away from the shores is generally of very good quality, but near the land it is often exceedingly bad. Barnard and Brewster at the south end of Lake Michigan found the following numbers of bacteria in 1908 :—

Distance from the shore in miles.	Average number of bacteria per cubic centimetre.
0 to 1	174,000
1	15,000
2	6,600
3	5,800
4	4,400
5	1,000
6	200

The amount of organic matter in the *broad* waters of the lakes is very small. They have a low colour, are tasteless, inodorous and comparatively soft. The following are given as representative analyses compared with the St. Lawrence river at Ogdensburg :—

	Superior.	Michigan.	Huron.	Erie.	St. Lawrence.
Dissolved solids, pts. per 100,000 . .	8·7	11·8	10·8	13·3	13·4
Total hardness, degrees Clark . .	3·2	6·9	6·2	7·6	7·5
Permanent hardness, degrees Clark .	0·15	0·52	0·45	0·94	0·87

The number of bacteria is almost invariably small : the counts are below 100 per c.c. for most part of the year, and in summer much below.

Most of the intakes are run a long distance out ; those at Cleveland and Chicago are four miles long. But it is considered impracticable to extend pipes or tunnels to points where the depth much exceeds 75 feet, so that the best water of the lakes is not used for supplies. Moreover the water is always in motion through currents caused by winds and disturbance by the numerous passing vessels, as well as changes of temperature, so that the inflowing sewage becomes mixed with the liquid and dispersed.

Lakes of moderate size in mountain districts can be properly guarded, and furnish very good water to large districts in many countries. As an example, Loch Katrine, 40 miles from Glasgow, supplies that city by a closed conduit with clear and soft water of a faint brownish tint: an analysis shows in parts per 100,000: total solids, 3·28; organic carbon, 0·256; organic nitrogen, 0·008; free ammonia, 0·002; oxidised nitrogen, 0·031; chlorine, 0·25; $CaCO_3$, 0·36; hardness, 0·5° Clark. The high relation of carbon to nitrogen indicates that the organic matter is of vegetable origin. Some of these lakes, such as Loch Katrine and Thirlmere, which supplies Manchester, have been enlarged by erecting a dam across the valley. Such a system demands the greatest care in construction and watching, as was emphasised by accidents like those at Holmfirth, Yorkshire, and Johnstown, U.S.A.

Dr. Thresh properly points out that where a natural lake has been converted into a storage reservoir, boats and steamers plying thereon should be under the supervision of the water authority.

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CHAPTER VI.

PRELIMINARY PURIFICATION.

SPECIAL methods of purification are required by some waters in place of or supplementary to the ordinary processes of storage, filtration, and sterilisation.

Assisted Sedimentation.

In the last chapter attention was drawn to the form of the sedimentation curve. It was shown that the deposition of suspended matter from some waters takes a considerable if not indefinite time to complete itself, and one reason for the delay is the semi-colloidal nature of a percentage of the suspended matter. If we add a substance that precipitates itself from the water in a short time, it drags down with it much of this suspended matter, and, especially if in addition the newly-added substance is to some extent colloidal, it also carries down adhering organic matter, and organisms which become entangled in the filmy surface of the precipitant. On the other hand, substances with a colloidal or semi-colloidal surface take a longer time to subside than non-colloids. On the action of colloids in attracting bacteria more details will be given in the next chapter.

Primitive tribes were aware that certain plants or their products had the power of making foul waters fit to drink. The action may be classified in three principal groups:—

1. Mucilaginous kinds, like quince and sweet almond seeds, many bulbs, barks such as elm, and exuded gums like tragacanth. Although a strong mucilage prevents clearing, when used in an appropriate small quantity it tends to clot together and sink with most of the impurities, partly as isinglass does in fining liquors.

2. Species containing vegetable acids or compounds which form insoluble precipitates with the earthy salts in waters. A type that has for very long held a high reputation and extensive use over a wide area is the "clearing nut" of India, which is actually mentioned in some Eastern pharmacopœias. It is the fruit of a large tree growing in Southern India, Burmah, and Ceylon called *Strychnos potatorum* (Linn.),* and is not poisonous, but only mildly medicinal, although it is botanically a close relative of *Strychnos nux-vomica,* which furnishes the drug strychnine. Roxburgh in his splendid work, "Plants of Coromandel," (published by order of the Honourable East India Company under the direction of Sir Joseph Banks in 1795), describes and figures both species. As to the former he says: "The ripe seeds are dried and sold in every market to clear muddy water. *The natives never drink clear well water if they can get pond or river water,* which is always more or less impure. One of the nuts is rubbed very hard for a minute or two round the inside of the vessel, generally an earthen one, and the water left to settle; in a very short time the impurities fall to the bottom, leaving the liquid clear, and so far as I have been able to learn, perfectly wholesome. These nuts are constantly carried about by the most provident of our officers and soldiers in time of war, to enable them to purify their water; they are easier to be had than alum, and are probably less hurtful to the constitution." Col. Drury † says the seeds are devoid of all poisonous properties. "In clarifying, their gelatinous matter first mixes with the water, then combines with the lime salts; both becoming an insoluble precipitate and carrying with them the matters held in suspension."

Powell's "Punjaub Products" states that almonds used in a similar way will clear water. They belong to our first group.

3. Those which are astringent and tanninoid, including a number of leaves, roots, barks and woods, among which the

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* Trimen's "Flora of Ceylon," 1895, p. 176.

† "Useful Plants of India," 1873, p. 408.

species of Cinchona, "Peruvian Bark," have been employed from antiquity by the South American Indians. Many of the group have value in precipitating iron, lead, and heavy metals generally, along with colouring and other matters. The almost universal use of tea, coffee, and their allies is kindred to this section.

A passage in Exodus xv, verse 23, runs as follows: "And when they came to Marah, they could not drink of the waters of Marah, for they were bitter. . . . (v. 25) And the Lord showed him (Moses) a tree, which when he cast into the waters, the waters were made sweet." Natural causes of bitterness in waters of the region are magnesia, iron, and alkalinity. The first and second could have been remedied by plants of the above groups 2 and 3, while alkalinity could be neutralised by the acid juices of plants, such as Burkhardt in his *Syria* records as growing abundantly near the spot. A great number of vegetable substances have of course been used simply with the object of disguising faults, without any idea of purifying.

Dr. Percy Frankland* describes his experiments on assisted sedimentation with various powders, passed through a sieve of 40 meshes to the linear inch and then sterilised. Polluted water was shaken for 15 minutes with one-fiftieth of its weight of the substance, and allowed to subside until the liquid had become clear. His results can be tabulated as follows. We must remark that neither the efficiencies nor the times would be always in the same order.

Powdered substance.	Time allowed for settling.	Organisms per c.c. at first.	Organisms per c.c. left in liquid at end.	Percentage reduction in number.
Spongy iron, first trial .	30 minutes.	609	63	90
,, second trial	30 minutes.	155	10	93
Ordinary wood charcoal	27 hours.	3000	120	96
Chalk	5 hours.	8000	270	97
Animal charcoal . .	nearly 5 hrs.	8000	60	99
Fine coke	48 hours.	Too numerous to count.	None.	100

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* "Micro-Organisms in Water," p. 193.

China clay, brick dust, plaster of Paris (this of course is somewhat soluble), oxide of manganese, and some other substances were tried, but yielded less satisfactory results.

He also tabulates Kruger's investigations with potter's clay, chalk, infusorial earth, alumina, powdered brick, vegetable charcoal, fine coke, and sand. These experiments included an examination of the water at the top, middle, and bottom of the vessel, after two, 20 and 50 hours, as well as observations on the rate of clearing. It must be noticed that Frankland employed a quantity of the precipitants much larger than could be applied in ordinary practice, namely 20 grammes per litre, while Kruger experimented with $\frac{1}{10}$ and $\frac{1}{40}$ of this amount. Kruger's bacterial reduction is greatest in the middle layers and at 20 hours. Curiously enough he succeeded best with powdered brick and potter's clay.

Every one who has examined the process either on the small or large scale will conclude :—

1. That the removal is fractional, and subject to irregularity owing to there being so many variables. It is affected by temperature, quality of liquid, proportion of precipitant, and its fineness and gravity, quantity of organisms and their character.

2. That while inert matter may be removed permanently, organisms, by their motility rise again from the sediment and re-commence propagation in the liquid. This is specially favoured if the precipitant contains food matters, such as the phosphates of animal charcoal, or the organic impurities of many other materials.

3. Therefore the water must be at once decanted as soon as settled clear.

4. Precipitants should be washed free from dust, and preferably sterilised by heat.

5. By causing disengagement of the natural gases present in water, the method produces a flat taste, and some substances such as clay are apt to give a faint earthy flavour and smell.

Evidently the process can only be regarded as an occasionally useful preliminary to other methods.

It will be noticed that some of the above agents begin their action by forming insoluble compounds with substances in solution in the waters, afterwards carrying them down with other matters in the deposit. The same is the case with ordinary inorganic ✓

Chemical Coagulants.

Soluble *Aluminium salts* react with the carbonates of calcium, magnesium and ammonium (or sodium and potassium when present) in the following typical way:—

$$\overset{\substack{\text{Aluminium}\\\text{sulphate}}}{Al_2(SO_4)_3} + \overset{\substack{\text{Calcium}\\\text{carbonate}}}{3CaCO_3} + 3H_2O = \overset{\substack{\text{Aluminium}\\\text{hydrate}}}{Al_2(OH)_6} + \overset{\substack{\text{Calcium}\\\text{sulphate}}}{3CaSO_4} + 3CO_2,$$

forming gelatinous insoluble hydrated alumina which combines with colouring and other matters and carries down with them the suspended impurities. The carbonic acid is increased, therefore the water is so far made more sparkling and piquant. At the same time, conversion of the earthy carbonates into sulphates, that is, of "temporary" into "permanent" hardness, leaves the latter of the same number of degrees, and of a character more objectionable for boilers. The method, however, is of great value for making coloured and turbid waters potable, and is a usual preliminary to mechanical filtration, which will be described in Chapter VIII.

The most familiar aluminium salts are potash and ammonia *alums*, double sulphates of aluminium and of the alkali, but these after the precipitation leave behind in solution the sulphates of K or NH_4. Therefore sulphate of alumina is used, and it is also more economical. The quantity must be regulated so that no Al remains in solution, and can be calculated from the temporary hardness (see Chapter XII). The atomic weight of Al being 27·1, the molecular weight of anhydrous Al sulphate is 342·2, and this in the above equation reacts with $3CaCO_3 = 300$. *Crystallised* aluminium sulphate is $Al_2(SO_4)_3$, $18H_2O$, and is soluble in twice its weight of cold water. As the commercial article is liable to vary in composition, it should always be purchased with an analysis, and it should not be basic or too dry, or it is less easily soluble, and it should be fairly free from excess of acid. The quantity of the reagent is calculated in practice from its total content of SO_3 and the alkalinity of the water reckoned as $CaCO_3$; 80 of the former = 100 of the latter.

The finished clarified water must also be regularly tested as to its freedom from alumina: this is easily done by adding a drop of logwood tincture, which gives a purple tint with a mere trace. Iron gives a deep, dull blue.

Natural aluminium sulphate, and alums, are rather widely distributed as minerals, being formed by the decomposition of pyritous clays, and their use for water-purifying is believed to have been very anciently discovered. The properties of alum are described by Columella, and by Pliny,* who calls it "salsugo terræ," and speaks of "aqua aluminata." Vitruvius mentions "aluminosi fontes." MacPherson states that from the earliest times the Egyptians and others filtered their water through porous earthenware containing alum. Alumina would be precipitated within the interstices, and its action might last for a long time. The Japanese and Chinese are also credited with the application. Two powders now used by the former people for purifying waters were found by one of us to have the following composition:—

(1) A mixture of about 0·2 per cent. of potassium permanganate which had partly decomposed into manganese oxides leaving 0·1 per cent. undecomposed, with potash alum, and about 35 per cent. of china clay; (2) a mixture containing 75 per cent. china clay, with chloride of aluminium, a little carbon, and a small quantity of some vegetable tanninoid extract.

Coagulants must be mixed with water as quietly as possible, to avoid entanglement of air-bubbles, which very much hinder the settlement. It is impossible, however, to entirely prevent this, since some dissolved air is continually being disengaged from ordinary water owing to changes of temperature and pressure. Therefore it is generally found that a kind of scum of coagulated matter mixed with air-bubbles collects in small quantity at the top, but clear

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* *Hist. Nat.*, lib. xxxv, cap. 15.

water can as a rule be drawn from a little below the surface, and the exit should always be provided with a strainer. With some waters, mere decantation is efficient in from 12 to 24 hours; anything not deposited then is very difficult to get rid of. Some river waters, especially in Western America, seem to be of such a nature that nothing else but sulphate of alumina can deal with them. Dr. Kemna has used it at Antwerp regularly for many years past, rather for decolorising than clearing, and finds it an effective remover of the humic bodies (Chapter II). He describes interesting experiments illustrating this action of alumina (*Trans. Inst. Water Eng.*, 1912, pp. 218, 253, 260).

With coloured waters which are very soft, like some from moorland sources, an equivalent of lime is used with the aluminium sulphate. Prof. Leeds found that by the addition of ½ grain of alum per gallon and settlement the organisms in a water were reduced from 8000 to 80 per c.c.

Just as with sewages, "aluminoferric," a mixture of the sulphates of iron and aluminium, in which the proportion of iron salt is usually small, has been used with benefit, as also *ferric sulphate** itself, or the chloride (in conjunction with lime), for very foul waters: the iron compounds have the advantage of additionally removing sulphides, but are liable to contain traces of arsenic.

Metallic Iron has long been known to exert a certain amount of purifying action on water (see p. 76). It dissolves slowly, evolving hydrogen, and reducing to ammonia any nitrates present; the liquid is also deprived of its dissolved oxygen, and acquires an unpleasant taste and distinct odour. The action is injurious to organisms and can kill most of them. The metal dissolves to form with the carbon dioxide of air, *ferrous* bicarbonate, and this in its turn oxidises to *ferric* hydroxide, liberating the CO_2, which further renews the attack until the iron is all rusted away. The ferric hydroxide has also a sterilising influence, and much of it

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* *Ferrous* sulphate, green vitriol or copperas, $FeSO_4, 7H_2O$, is used in some American towns for reasons of cheapness, but is much less satisfactory, since strong oxidation is wanted to throw down the iron.

precipitates as an ochreous deposit carrying down impurities and organisms ; the latter being poisoned or enfeebled have not the same tendency to rise again and multiply as with other precipitants. But a part of the oxide remains suspended in a colloid form (including probably a basic ferric carbonate, since Findlay and Hardy [*] found that ferric hydrate increases the solubility of CO_2 in water), necessitating subsequent removal by another coagulant, like alumina and lime, or efficient filtration. Anderson and Ogston in 1885 patented a horizontal revolving drum fitted inside with longitudinal curved shelves, which raised from the bottom a quantity of iron turnings, and then dropped them across a current of water filling the chamber through the axis at one end and passing out slowly at the other. Cascade aeration, settlement and filtration through sand followed.[†] The apparatus was adopted at Worcester (England), Choisy-le-Roi, Antwerp, and other places, and gave better purification in all respects than sand filters alone. Metallic iron treatment has been applied successfully to several turbid river supplies in America, Uganda, Mauritius, and on the Nile. But, however much the water is improved, the process is expensive. See U.S. Consular Reports, July, 1906, p. 571.

Manganates and permanganates, the active constituents respectively of Condy's green and red fluids, have been used from time to time for very foul waters. The former decompose very readily, thus giving off oxygen :—

$$(1)\ \overset{\text{Sodium manganate}}{Na_2MnO_4} + 3H_2O = \overset{\text{Caustic soda}}{2NaOH} + \overset{\text{Manganic tetrahydroxide}}{Mn(OH)_4} + O,$$

the liquid becoming alkaline, with a deep brown precipitate.

With a *dilute* acid, even carbonic, in excess, they yield a permanganate :—

$$(2)\ 3Na_2MnO_4 + 2H_2SO_4 = \overset{\text{Sodium permanganate}}{2NaMnO_4} + Mn(OH)_4 + 2Na_2SO_4.$$

The permanganate renders the solution pink, and afterwards further changes as shown below.

The ordinary commercial salt, *potassium permanganate*,

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[*] *Chem. d. Kolloide*, 1908, iii, 169.

[†] *J. Soc. Chem. Ind.*, iv, 1885, p. 544.

$KMnO_4$, although rather expensive, has the advantage of being a pure, easily kept, and fairly soluble solid. With organic matter it decomposes similarly to the manganate but yields more oxygen :—

$$(3)\ 2KMnO_4 + 5H_2O = 2KOH + 2Mn(OH)_4 + 3O.$$

The action is hastened by dilute acid :—

$$(4)\ 2KMnO_4 + H_2SO_4 + 3H_2O = K_2SO_4 + 2Mn(OH)_4 + 3O$$

(also see Chapter XI).

The green manganate solutions of commerce always contain excess of alkali (soda). Permanganate when used alone produces an equivalent of caustic potash (equation 3). In both cases the water is rendered alkaline and may have to be neutralised by acid. In equation (4) it would generally be made acid, and would require neutralisation with lime or soda.

The hydrated peroxide of manganese formed in the above reactions has much less clarifying power than alumina or iron, and has less value in curing turbidity. Manganates and permanganates by their oxidising action destroy organic matter and remove colour and most odours, but there are better and cheaper ways of doing this.

Lereboulet applied permanganate on a large scale to the French soldiers' drinking water in the war of 1870, and Hankin used it extensively in India for wells and tanks, which were regularly "pinked" by officials as a defence against cholera. It was soon found, however, that the germicidal action of these manganese compounds is feeble and uncertain. (See S. Rideal's "Disinfection," p. 364.)

In Belgium permanganate has been successfully used as a part of the *Linden* processes, which employ also lime, salts of iron, and carbonic acid in a patented apparatus. The system includes utilisation of the precipitated mud for the recovery of ammonia and the manufacture of cement. It has been adopted by the town of Ghent to purify for distribution as a drinking supply the water of the river Scheldt, which is particularly foul and polluted, and had previously been considered intractable. Official analyses by Drs. Van Ermengen and Van de Velde show great chemical improvement, and also sterility (or at most 2 colonies per c.c.), in the finished water, but we must again notice that permanganate is only a part of the process. It is reported that the price is very little higher than the other waters used by the town, which require only pumping.

Sodium phosphate, in conjunction with lime, has a high clarifying and decolorising power, and therefore has been used with temporary success for clearing waters, but a serious fault is that difficulties occur from aftergrowths owing to traces of phosphates left encouraging the growth of organisms. They are introduced for this purpose in some bacteriological culture solutions.

Treatment of Iron-Containing Waters.

At p. 7 of Chapter I we have noticed the different states of combination in which iron occurs in natural waters. Its amount varies from the ordinary mere trace to from 30 to 70 milligrammes per litre (parts per million) in sources that have been used as potable: higher quantities are medicinal.

It is fortunate that iron in small quantities has no marked effect on health, as besides being contributed by soils or rocks, it is also often added by being dissolved from pipes and tanks. Dr. Thresh * remarks, "Although I have never heard of any ill effects following the continued use of a water containing a trace of iron, I should expect headache and constipation to be produced amongst those unaccustomed to its use." To ascertain whether the ferruginous character is natural or accidental, a sample must be obtained direct from the source; in the case of deep wells, by pumping vigorously for some time.

To lay down permissive limits for its quantity in supplies involves not only considerations of potability, but of industrial applications, since it affects many dyes and natural colours, and is injurious in several manufactures. In washing, besides acting as hardness and using up soap, it stains the clothes with the so-called iron-mould. It also stains paper and other light-coloured materials. Speaking on all the aspects, H. Schwers †

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* "Water and Water Supplies," p. 84.

† *Rev. d'Hyg.*, xxx, 11, 1908.

observes that "inconveniences from iron appear sometimes to commence when the content reaches 0·1 part of Fe per million; commonly, however, when it rises over 0·2 to 0·3 part. With 0·1 to 0·3 part, a deposition of iron hydroxide occurs on standing, and this concentration is found most favourable to the growth of iron bacteria which may block up the pipes"—this has occurred at Rotterdam, Berlin, and elsewhere—"also at this point the water takes up a chalybeate taste, and becomes unsuitable for washing and many industries." Therefore he considers that iron removal begins to be necessary at a content of 0·1 to 0·3 part of Fe per million, according to the water. In America, Hazen's permissible limit for public supplies is 0·5 part of Fe per million.

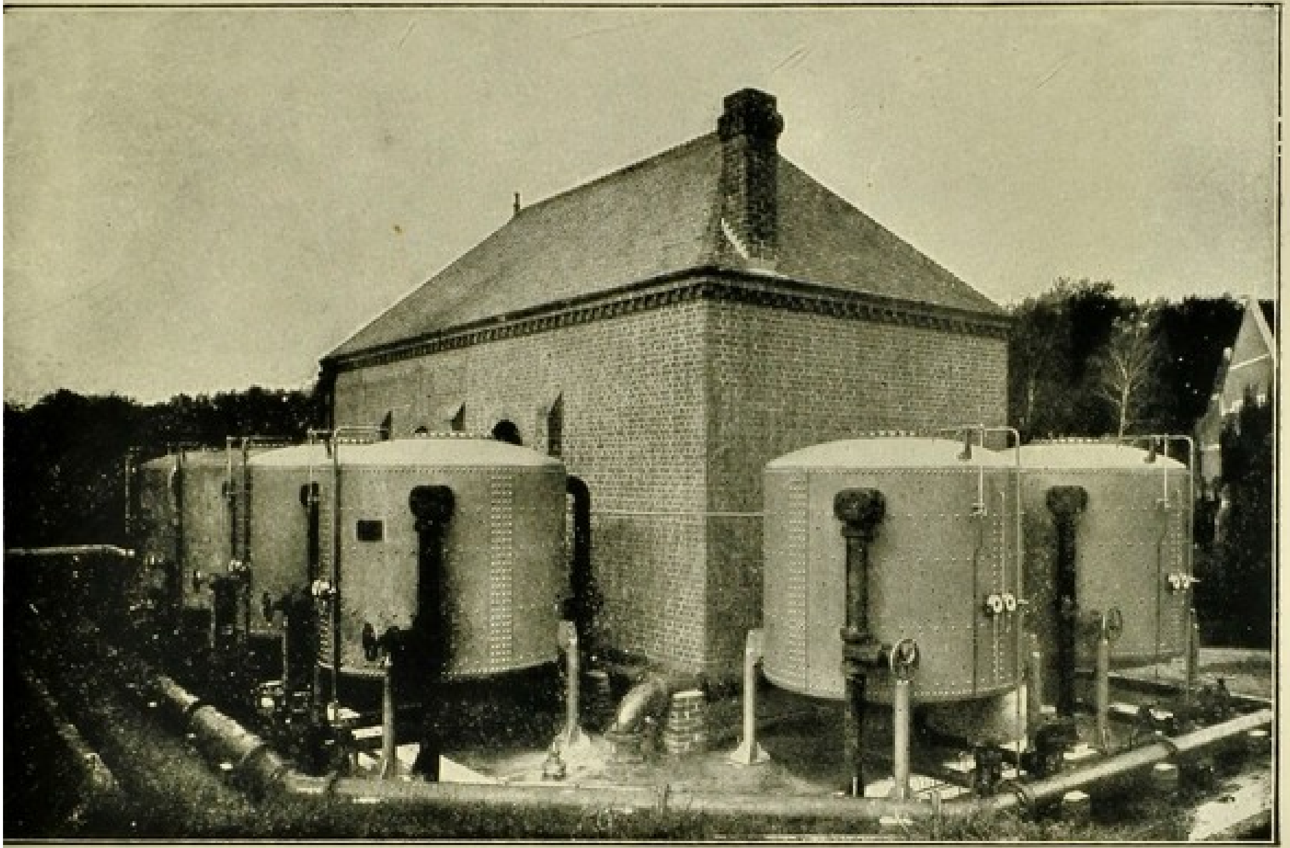
O. Spitta says, "when iron is over 1 part per million most people can taste it very distinctly." Trials in our laboratory confirm this taste limit. Only one out of seven persons could notice any difference of taste with water containing 0·5 part per million of iron, but one part per million was distinctly perceived by all, particularly in the aftertaste.

Iron can be thrown out of solution by the action of atmospheric oxygen on the ferrous bicarbonate, which is the form commonly present. Darapsky shows that this action takes place most readily, and possibly only to any extent, in the presence of a catalyst. The best catalyst is some finely divided absorbent surface. These conditions are completely fulfilled by the so-called "oxidising filters" (Chapter VIII), which are consequently used for treating ferruginous waters. There are other types of apparatus which are exclusively employed for removing iron.

The behaviour of the iron depends greatly on other substances accompanying it in waters, which sometimes much increase the difficulty of separation. Schwers lays down the axiom that "if the electrolytes present do not vary, then the same deferrising process will free water from varying amounts of iron."

The facility in treatment is often much greater with highly ferruginous waters than with those containing only

PLATE IX.



Oxidising Filters for removing Iron at Tunbridge Wells, Candy System.

[*To face p.* 84.

small quantities; it depends mainly upon the state of combination. Accordingly, deferrisation processes may be classified as (A) those adopted when simple aeration is sufficient; (B) classes where lime has to be used as an adjunct; (C) colloidal removal by agglutination. On account of the fineness and colloidal nature of a part of the iron precipitate, simple settlement takes such a long time that filtration is an ordinary sequel of all the processes.

A. It is a common observation that when a ferruginous brook enters a larger body of water the iron is rapidly oxidised, and is thrown down as an ochreous deposit entangling impurities, and many rivers in upper regions purify themselves in this way. Artificially the process is assisted by passing the water over step-cascades, by showering through perforated plates, or by centrifuges. Another device is a specially constructed pump, called in Germany a "bastard pump," which delivers a mixture of air and water at the same time through a small sand filter.

Schreiber* pronounces this a very good apparatus for precipitating the iron on the surface of the sand as ferric hydroxide. Dunbar uses an iron cylinder containing sand in grains of 1 to 1·5 millimetre diameter, repeatedly emptied and filled; he finds that when once the sand grains have obtained a thin coating of ferric hydroxide the filter prevents any more iron passing through. The filter must be emptied every night to admit of air circulation among the interstices of the sand grains. The principle includes *agglutination*, further utilised in our class C. Similarly, coarse filters, made as beds or towers, filled with coke-breeze, remove iron, probably by accretion to the iron compounds already contained in the coke (see J. New England Waterworks Assoc., xi, 278), and the use of other materials, such as clinker or wood shavings, is more or less successful. In some places the air is forced in under pressure in a closed chamber, with the advantage that the solution is more rapid, and the water is protected.

Ozone has been employed for rapid oxidation, but its

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* *Mitteil. Wasservers.*, 1906, vi, 52.

cost is prohibitive unless it is required for further purification (Chapter XI).

B. The dissolved iron may be in combination (1) with mineral acids as in some mine waters and trade effluents; (2) with organic bodies and acids of the humic group, as in peaty sources; or there may be a large excess of carbonic acid. The reaction in aeration is:—

$$\overset{\substack{\text{Ferrous}\\ \text{bicarbonate}}}{2Fe(HCO_3)_2} + O + H_2O = \overset{\substack{\text{Ferric}\\ \text{hydroxide}}}{Fe_2(OH)_6} + 4CO_2$$

According to the general law in such changes, soluble products tend to retard the reaction, and if there is already a large excess of carbonic acid in the water, the iron precipitation will be correspondingly hindered.

In each of the above cases slaked lime must be added along with the aeration (not forgetting the effect on the hardness), and has a certain amount of agglutinating power as seen in the "excess lime" process and in methods of softening (Chapter IX).

C. Special agglutinants or coagulants such as those described earlier are sometimes required for deferrisation; the iron is here removed by adhering to the gelatinous precipitates of hydrated alumina or of iron hydroxides. At several places *chalk* has been used instead of lime, but with bad results, due mainly to the consequent liberation of carbonic acid as seen in section B. above. Kröhnke states that he obtains the best results with *ferrous* chloride, $FeCl_2$, and lime.

Hess and Linde use a deposit of hydrated oxide of *tin* on wood as a mordant and carrier of oxygen.[*]

Humous bodies can themselves act as agglutinants, and for this purpose Wernicke and Weldert[†] mix the ferruginous water with a suitable (?) quantity of a brown peaty water. A number of details as to the working of the above processes are given in Don and Chisholm's "Modern Methods of Water Purification," pp. 332 *et seq.*

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[*] *Die Reinigung des Wassers*, Stuttgart, 1900, v, 55.

[†] *Mitteil. Wasservers.*, 1907, viii, 176.

E. M. Mumford[*] has lately isolated an iron bacterium possessed of some salient characters from the Bridgewater Canal tunnels at Worsley, Lancs. It precipitates iron as a mixture of oxides corresponding to bog ore. An enzyme has been separated from it and produces all its chemical reactions, but requires the presence of nitrogen in the medium. The organism itself is a short, round-ended bacillus, size 2 × 4 microns, motility varying; it forms endospores and involution forms. It grows well on ordinary media at an optimum of 70° C., the greenish-brown nodules on potato being characteristic. Most of these features would make it difficult to get rid of, but it would yield to hypochlorite.

Manganese is very generally diffused, and its hydrated oxides accumulate as *bog ores* in many parts of the world. In the drainage the manganese dissolves just as iron does, hence most ferruginous sources contain it in distinct amount. As with iron, no special toxicity is observed, but it causes similar inconveniences, and its removal by the ordinary processes is slower and more difficult, because, as is known in analysis, it is less easily precipitated by alkaline reagents. Dr. Kemna,[†] in his paper read before the Institution of Water Engineers in Dec., 1912, cites the case of Breslau, where the water in 1906 contained in grammes per litre 0·6 of iron and 0·4 of manganous sulphate.[‡] The iron even in that large quantity was easily removed by the very effective system employed, but the manganese remained, and gave a deep brown stain to everything with which the water came in contact. Besides the discoloration and turbidity caused by manganese hydroxides (being here a hydrate of the sesquioxide, Mn_2O_3), they encourage the growth of a *Crenothrix*, in this case the sub-species or variety *manganifera* (p. 22). At Cheltenham Dr. Garrett recorded in June, 1912, that although filtration in great part removed the organism, the dirty sand

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[*] *London Chem. Soc. Proc.*, 1913, xxix, 79.

[†] *Trans. I. W. E.*, 206.

[‡] Thresh found 0·4 part per million of manganous bicarbonate in the Buxton thermal water: this, however, is not used as an ordinary potable supply.

of the filters had a very unpleasant odour, while the water pipes were obstructed by growths that had escaped the filters and produced red-brown zooglœa filaments, and reddish spores. The visitation lasted six weeks, and then spontaneously abated.

Peters * states that 50 milligrammes of Mn per litre give water a *green* colour deeper than the tint with an equal quantity of iron. Possibly in his case a green alga might have been encouraged, unless he is speaking of the delicate *manganate* colour, which is only produced artificially in pure alkaline solutions, and then disappears on simple dilution, giving the brown hydroxide as in equation (1) above.

"Demanganisation" requires more intensive treatment with lime and air than deferrisation, and can hardly be effected without heating or the addition of some assisting chemical. Lately the "permutit" system has been applied with great success to the removal of both iron and manganese, see Chapter IX. As to the action of waters on other metals, and their removal if present, see Chapters I and IV.

Nuisances from Living Growths in Reservoirs

have been alluded to in Chapter II. They reside not only in obstruction, but also in tastes, odours and colours produced by water organisms in growth or decay. On the continent and in America several State Commissions have had to deal with this subject. The causes, as we have seen, may be either animals or plants, but by far the most usual are algæ. To destroy, or at any rate to inhibit these, copper salts have been successfully used as "algicides," the poisonous metal being subsequently precipitated as a basic salt, the coagulating effect of which often renders the water clear and bright. Even metallic copper, in presence of water, produces a colloid solution which, as shown by von Nägeli,† Galeotti, Israel and Klingmann, and S. Rideal, is sufficient to make the water

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* *Z. f. Hyg.*, 1908, xli, 112.

† *Neue Druckschriften d. allgem. Schweiz. Ges.*, 1893, xxxiii; S. Rideal, *J. R. San. Inst.*, 1904, p. 593.

toxic to many forms of algæ and bacteria. The action of copper salts on bacteria has been investigated by numerous observers (see Chapter X), but it was not until the beginning of the present century that they became widely used as algicides with care as to quantities. At Ben, Virginia, in 1901 a destructive growth of the Conferva-like alga *Spirogyra* in the watercress beds was got rid of by adding 0·02 part per million of copper sulphate. In 1904 the Department of Agriculture at Washington issued their Report on Moore and Kellerman's trials of this salt on the large scale.[*] It had been proved that doses of from 0·02 up to 1·0 part per million were required in different instances according to the character, numbers, and vigour of the organisms, while some waters did not seem amenable to the copper treatment. The worst tastes and odours were most susceptible.

It follows that Moore and Kellerman found a serious element of uncertainty in the treatment, and this is borne out by other investigators. Trials by the Massachusetts State Board of Health in 1903 and 1904 gave conflicting results. Clark and Gage[†] found copper sulphate rather uncertain in its action, sometimes as much as 3 in 1000 being required to ensure sterility. Phelps, Kemna, and S. Rideal have shown at different times that the low algicidal value occasionally obtained with copper salts is due to their being immediately precipitated as basic cupric carbonate by the high amounts of calcium or magnesium carbonate present in very hard waters.

At Minneapolis, Minn., Dr. Corbett[‡] treated the supply of that city from the Mississippi river in the two reservoirs of about 47 million gallons each, with 50 lbs. of copper sulphate, equal to 0·064 part per million (a U.S. gallon = $8\frac{1}{3}$ lbs.), applied three times a week. "As a result the plankton was decreased 80 per cent. at the end of 30 days, during July and August, the usual time for these organisms to be on the increase. Bacteria were reduced about 40 per

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[*] *Bulletin* 64, *Bureau of Plant Industry.*

[†] *J. Infect. Diseases*, suppl. 2, p. 175, 1906.

[‡] Report Water Committee, March, 1910.

cent., turbidity about 20 per cent., while the colour was slightly reduced."

In general experience it is better to make periodic small additions, as in the above trials, than one or two larger ones, although this portion of the service is thereby thrown out of use for a longer time. When filter beds are treated with water containing one part per million of copper sulphate for two days, and then for five or six days with 0·5 part per million, the algæ will be practically all destroyed. The copper sulphate is here added in two strengths for the sake of economy, since some algæ absorb copper much more readily than others: the former are first removed and then the reagent has a better chance of reaching the others. An example of the gradual removal is quoted by Baldwin-Wiseman * from Hanover, U.S.A.: 0·25 part per million removed 90 per cent. of the organisms in 24 hours, a further 8 per cent. in the next 16 hours, and the remaining 2 per cent. in 20 hours more, but it must be remarked that such a complete final success is very rare.

The use of copper sulphate at the Brisbane waterworks led to a marked improvement in the quality of the water. But the official report was unfavourable as to a continuance of the method, remarking "our experience is that while the copper sulphate treatment temporarily removes a large number of the minute organisms to which the salt is fatal, it thereby opens the way for a subsequent increase in the numbers of other organisms—not necessarily of a harmful nature—whose development is favoured by disturbing the previous balance of life in the water." This, it is understood, is also the experience in other lands where this method of treatment has been tried. It is, however, helpful as an aid to intermittent sand filtration, by preventing a too rapid choking of the filter. (See Chapter VII, p. 98.)

To mix evenly a small quantity of a chemical with a large body of quiet liquid is obviously not easy, particularly when, as in this case, the solution is heavier than water. The usual practice with copper sulphate and other solids has

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* *Proc. British Institution of Civ. Engineers*, 1910.

been to suspend them in bags of coarse canvas dipping in the water and dragged by a boat all over the surface. Probably a better method would be that of spraying a diluted solution proportionately over the surface, taking the depth into account, and mixing with paddles. Unequal distribution has certainly been one cause of failure.

A water engineer tells us that he has sometimes observed the production of a nearly black colour instead of a greenish blue, this can only be due to the formation of copper sulphide from sulphuretted hydrogen or a sulphur-containing organic compound in the dead or living impurities in the water. The removal by the copper salt of such a source of smell would be an important advantage.

Great trouble is often occasioned by higher fresh-water algæ that cannot be properly called "plankton," because they are originally fixed by root-like organs (rhizoids), though floating fragments are commonly met with. Some species, such as *Chara fœtida*, give an objectionable odour and taste, which was observed in America by Forbes, and has caused trouble in several places in England, notably in one of the supplies at Cheltenham. Here Dr. Garrett [*] has lately tried the effect of adding one part per million of copper sulphate *on only one day* (Oct. 4, 1912). On cleaning out in next April there was no harvest of weed to remove, whereas in the companion reservoir, to which no copper had been added, the growth was flourishing. Therefore he concludes that "the copper did in the end kill the weed in great measure." With regular treatment, as we have described above, this encouraging result would doubtlessly have been followed by extermination.

That single applications of very small quantities at considerable intervals can be, however, an effectual remedy, is proved by the success at the Isthmus of Panama.[†] Here the conditions were so favourable to the growth of algæ that as early as January, 1907, the potability of the water

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[*] *Public Health*, June, 1913.

[†] Kellerman and Meadows, *Amer. J. of Public Hygiene*, Aug., 1910, p. 658.

supplies was seriously menaced. In the Rio Grande reservoir (497 million U.S. gallons), the numerous diatoms gave the liquid a brownish colour; *Chara fragilis* was growing rapidly; Anabæna, Oscillatoria, and their kindred, were also offensive by odour and taste. The Brazos Brook reservoir (641 million gallons) was nearly as bad. 0·15 part per million of copper sulphate was added in February, 1907, with the result that in 7 days the Chara had become white and flaccid, in 10 days it was decaying, and in 17 days there were only a few fragments visible in the first reservoir, in the second none. By March 4 both waters were biologically in a satisfactory condition. It has since required very little copper to keep the algæ in subjection, and the Chara has not reappeared. Similar histories are given for two other large reservoirs in the State, previously infested with Anabæna and Gleotrichia.

Incidentally it is mentioned that a less distinct odour than that due to algal pollution gave trouble during 1907 and 1908. It was caused by stratification and stagnation of the lower layers "in which the rather high organic content and the uniformly high temperature furnish suitable conditions for a slow putrefaction." * The fault was remedied by blowing compressed air through the water before it entered the mains.

Kellerman, at the International Congress of Applied Chemistry, New York, September, 1912, gave a table "of the occurrence by States of the 12 genera of algæ most frequently reported to me during the last eight years as troublesome." These are "Anabæna, Beggiatoa, Asterionella, Chara, Cladophora, Clathrocystis, Conferva, Crenothrix, Fragillaria, Navicula, Oscillatoria, Spirogyra." He also gave the following experience:—

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* This particularly occurs where before the construction of the reservoir the ground has not been cleared, or "stripped" from impure soil, vegetation, etc. On a bed so cleaned the water keeps clean much longer.

TABLE SHOWING QUANTITY OF COPPER SULPHATE REQUIRED TO KILL VARIOUS FORMS OF ODOUR-PRODUCING ORGANISMS.

Copper sulphate expressed as parts per million :—

Anabæna	·09
Asterionella	·10
Beggiatoa	5·00
Chara	·20 to 5
Cladophora	1·00
Cladothrix	·20
Clathrocystis	·10
Cœlosphærium	·30
Conferva	·40 to 2
Crenothrix	·30
Euglena	1·00
Fragillaria	·25
Hydrodictyon *	·10
Kirchneriella	5·00 to 10
Leptomitus	·40
Microspora	·40
Navicula	·07
Oscillatoria	·10 to ·40
Peridinium	2·00
Scenedesmus	5·00 to 10
Spirogyra	·05 to ·30
Ulothrix	·20
Uroglena	·05
Volvox	·25
Zygnema	·70

TABLE SHOWING SAFE LIMIT FOR TREATING WATER WITH COPPER SULPHATE WHEN CERTAIN FISH ARE PRESENT.

Copper sulphate expressed as parts per million :—

Black Bass	2·10
Carp	·30
Catfish	·40
Goldfish	·50
Perch	·75
Pickerel	·40
Suckers	·30
Sunfish	1·20
Trout	·14

We shall defer consideration of hypochlorites to Chapter XI, *Sterilisation.*

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* This alga is useful in forming a straining film over sand filters, and does not produce odours while living.

CHAPTER VII.

SAND FILTRATION.

IT has been shown that while properly conducted sedimentation greatly improves most waters, the method by itself is naturally incomplete for want of time, with other reasons. The duty of a sand filter is to further the purification, sterility being practically unobtainable by any system of sand or mechanical filtration on a large scale. But apart from the historic examples at Hamburg, Altona, and other European localities, the good that can be caused is forcibly illustrated by the New York Health Records, giving the typhoid mortality in the cities of the State during the ten years up to 1911, with a special comparison of the rate per 100,000 in 1907 with the average of the whole ten years. In ten of the cities the rate was lowered 24 to 78 per cent., by the provision of improved water. At Albany, for example, typhoid mortality per 100,000 was 88·8 before the introduction of sand filters, and 23·7 afterwards. All cases which had made no change in water-supply methods showed little, if any, improvement as to typhoid, while where sand filters had been adopted the reduction in typhoid was always distinct. To tabulate the general results :—

Nature of supply.	Typhoid mortality per 100,000.	
	Average of 10 years.	In 1907.
Lake water unfiltered	27·6	26·8
River water unfiltered	57·7	57·7
Filtered water without any improvement in method throughout the ten years . . .	45·8	45·1
Filtered water introduced since 1902 . .	59·7	37·8
Spring or well water introduced since 1902	36·3	4·35

Still more striking evidence is recently given in a very complete study by Dr. Allan J. McLaughlin * of the death-rates from typhoid fever and other diarrhœal diseases in the cities which take their water supplies from the Great Lakes. The tables show that the rates in cities that do not filter their water are very high as compared with European and American cities which do use filters. He points out that in the Lake cities that use unfiltered water the typhoid fever rate is exceptionally high during the winter season, "thus affording additional evidence that this disease is more often transmitted by cold water than by hot water." He also shows that intestinal diseases classed as diarrhœa and enteritis, and infantile diseases, are exceptionally prevalent in the Lake cities using unfiltered water, and that they are too liable to occur under the name "winter cholera." The lesson has additional significance from the fact that it has been attempted throughout to obtain relatively clear water, and avoid local sewage pollutions by drawing at a great distance from land, and below the surface. Thus the intakes of a number of cities are a mile to a mile and a half long; at Chicago and Cleveland they are 2 to 4 miles. The depths of intake straining cribs below the surface are in feet, Chicago 27 to 40, Milwaukee 60, Toronto 68 (proposed to be eventually 100), Oswego 83, and are rarely less than 50, while it is sometimes impracticable to construct them below 75 feet deep. Yet all this expense without filtration has failed to be a guard against water-borne disease. It is true that other considerations induced this construction of the intakes, to avoid pack-ice, passing vessels, and silting and clogging through movements of the sand. Many breaks have occurred in the pipe lines or tunnels, and in several instances have caused epidemics through the entrance of polluted shore water. More information on the subject will be found in a valuable paper by Geo. C. Whipple.†

With reference to the exceptional improvement observed

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* *Bulletins* 77 and 83, U.S. Pub. Health Dept., 1912.

† *Internat. Congress of Applied Chem.*, 1912, p. 271.

in the last line of the table we have quoted above (p. 94), Dr. Kemna * remarks that although underground waters have been preferred from very ancient times, not only on account of their abundance in many cases (and we may add that they would be more secure in times of war), but also because of their usually constant temperature and their general purity in those days; yet it was wrong to pronounce this the only permissible source of public water supply. In France the purity of springs was once considered unquestionable, but the frequent recurrence of typhoid epidemics in Paris was finally traced to contamination at the sources, and similar experience was obtained at other places. A comparison between the health-statistics of towns supplied from springs and from filtered surface-waters resulted in favour of the latter, and a change of opinion took place between 1895 and 1905. In Germany, however, there was a change in the opposite direction, and several large cities replaced their surface supplies by underground sources, not always with advantage. In most cases the former had been well filtered, and the general health had been good, while the results of the costly alteration were indistinct hygienically, and often disappointing as to quantity and quality. The majority of the underground waters in the German or Baltic Plain are chalybeate, and however easy it may be to remove the iron, the process involves trouble and expense. Dr. Kemna instances Breslau, where the original supply was sand-filtered from the river Oder, and the health was normal. Under a new scheme 300 wells were sunk in a region believed to be inexhaustible. But the yield, instead of the daily 60,000 cub. metres expected, was only 40,000, and was proved to come from a limited and rather shallow basin, absolutely dependent on local percolation, so that the reliance was now on the obscure purification by the strata, instead of by the controllable sand-filters. In March, 1906, a part of the district was inundated, and the underground supply suddenly decreased. For 36 hours nothing but air could be pumped from the wells, and when the water came back it

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* *Trans. Inst. Water Engineers*, 1912, p. 206.

was found to contain 0·6 gramme per litre of iron and 0·4 gramme manganous sulphate. The iron, even in that large proportion, was easily removed, but the manganese remained, blackening everything with which the liquid came in contact. Recourse had again to be made to the river and the sand filter, which fortunately had not been displaced.

Surface water supplies have the advantage that the quantity can be correctly estimated, and there is another safeguard, that being always open to contamination, they must be treated as contaminated, and purification is indispensable.

Methods of filtration were used in very early times. Bolton in "Ancient Methods of Filtration," * mentions among them the siphoning of liquid from one vessel to another by the capillary action of porous material, such as a strip of cloth or a skein of wool, and it was even observed that an asbestos skein can be cleaned afterwards by heat.

About 1810 slow sand filter beds were beginning to be installed in Lancashire and Scotland, and in 1828 a Royal Commission conducted an inquiry into the condition of the London water, and recommended that steps should be taken to improve it. Mr. James Simpson, engineer to the Chelsea Waterworks Co., made a tour of inspection of the northern works, and on his return installed the first filters in London for the Chelsea Co. He provided decanting basins in duplicate, and a sand filter of about the same area as each, *i.e.* 1 acre.

The results were so good that the method was soon adopted for the whole of the London supplies. It rapidly spread over the world, and is often known as "the English system." The original practice was generally followed, by allowing the raw water to settle for 12 to 24 hours in reservoirs, then drawing it off from near their surface by means of floating arms, and discharging on to sand filters of about half the area of the settling basins.

The method proved adequate for the mere clarification which at that time satisfied requirements, and later it also

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* *Pop. Science Monthly*, xvi, 495.

met, as a rule, the new hygienic examination. Koch took up the question from a bacterial standpoint, and introduced rules for the management of filters; he proposed the limit of 100 microbes per c.c., but of course this, although a good guide as to the state of the filters, is not safe without a consideration of the nature of the organisms escaping retention. Therefore a *coli* limit, and other tests, were also introduced.

In 1885 when Dr. Koch's new bacterial water tests were introduced, it was found that the filtration process had removed about 99 per cent. of the total number of microbes present in the unfiltered water. As Mr. Andrews observes, it is rather amusing that the public, instead of being reassured, were considerably alarmed at this news, and a fall occurred in the stocks of most of the water companies. The public at that time knew very little about what are now termed waterborne diseases, and that germs could be present in drinking water at all was the alarming part of the news. In 1892 the outbreak of cholera in Hamburg and Altona brought the matter to the front again, and supplied the most convincing proof of the advantages of sand filtration. These two cities both drew their water from the river Elbe, but Altona drew its water below the city of Hamburg, that is, after it had received the sewage from a population of 800,000. Altona filtered its water through sand, and its cholera death-rate was 221 per 100,000. Hamburg drew its water above the city, *i.e.* before it had polluted the water with its own sewage, and although, no doubt, there was some pollution from places above the Hamburg intake, still it had a raw water comparatively pure compared with Altona; but Hamburg neglected to filter its water, and its cholera death-rate was 1250 per 100,000, or nearly sixfold that of Altona.

The London Metropolitan Water Board's report of 1913 gives the number of microbes per c.c. as :—

	Thames.	Lee.	New River.
Raw water . . .	5250	9263	2172
Filtered water . .	16·1	30·9	14·1
Per cent. reduction .	99·7	99·6	99·3

These results are effected by the following plant:—

	Number.	Area in acres.	Capacity in millions of gallons.
Subsiding and storage reservoirs for unfiltered water . . .	64	2030	12,976
Filter beds	172	170·7	—
Covered storage reservoirs for filtered water	85	—	314

giving a daily supply of 229 million gallons (including 20 million gallons from deep wells in the chalk, which is not filtered); equal to 34·27 gallons per head per day. Although about 80 per cent. of the London water supply is derived from sewage-polluted rivers, the reports published monthly of the regular bacteriological and chemical analyses, show that the finished product of this slow sand filtration is on the whole satisfactory. A great part of the purification occurs, however, in the storage reservoirs.

General Theory of Sand Filtration.

Formerly it was thought that a filter bed was most efficient when new, but it is now known that clean sterilised sand, beyond straining out some suspended matter, exerts no purifying effect. Atmospheric oxygen has little or no action on the organic matters ordinarily present, without the assistance of organisms, or of some active oxidising agent.

In a new filter the suspended matter gradually blocks the upper layers, and the passage of liquid becomes slower, but at the same time the clarification is more complete. The "active volume" of the filter bed is chiefly confined to the first few inches. From this fact some filters, especially in Holland, have been made very thin. Mason points out that although much of the actual work is done by the upper layer of sand, yet if the thickness be unduly reduced, that portion of the water which is in the act of being delivered will bear too large a ratio to that filling the lower interstices; as a result, currents will be established and ruinous channels be quickly worn in the uppermost stratum. This is the case when a thin layer of sand is laid over a bed of coarser material. When the fine sand is of such a thickness and so supported that the water passes evenly and slowly through it, a film, the so-called "Schmutzdecke," or dirt-cover, forms on the upper particles, and is the chief seat of activity. The time interval elapsing between the first use of the bed and the attainment of proper efficiency is termed the "filming-time." The other sand grains in the body of the filter also gradually acquire a similar coating of slime, and act in removing impurities. Thus Reinsch at Altona found the raw water to contain per c.c. 36 thousand organisms; after passing the upper film it still retained 1876, but after traversing the entire bed there were only 44 per c.c.

The Nature of the Colloidal Matter.

Besides the suspended solids such as sand, hair, etc., and dissolved substances such as urine, lime, etc., there exists another class half-way between, named the colloids. Fine colloids approach, and finally merge into the state of real solution; coarse colloids, on the other hand, come into line with suspended solids.

Colloidal matter is in general electrically charged, since it wanders under the influence of the electric current either to the cathode or to the anode. This phenomenon is termed "cataphoresis." W. Biltz and O. Krohnke * have shown that the major part of the putrescible matter in water is of a colloidal nature, and further belongs to the negative group of colloids, since cataphoric action leads it to the anode under the influence of the electric current. Other negative colloids important for our purpose are iron, aluminium, and chromium hydroxides. (See R. Spurr Weston, *Proc. Amer. Soc. of Civil Eng.*, iii, 1324 and 1393, 1908). One method of freeing water from colloidal matter is therefore by means of the electric current, as described later (Chapter XI). Common methods of precipitation involve the same principle. All

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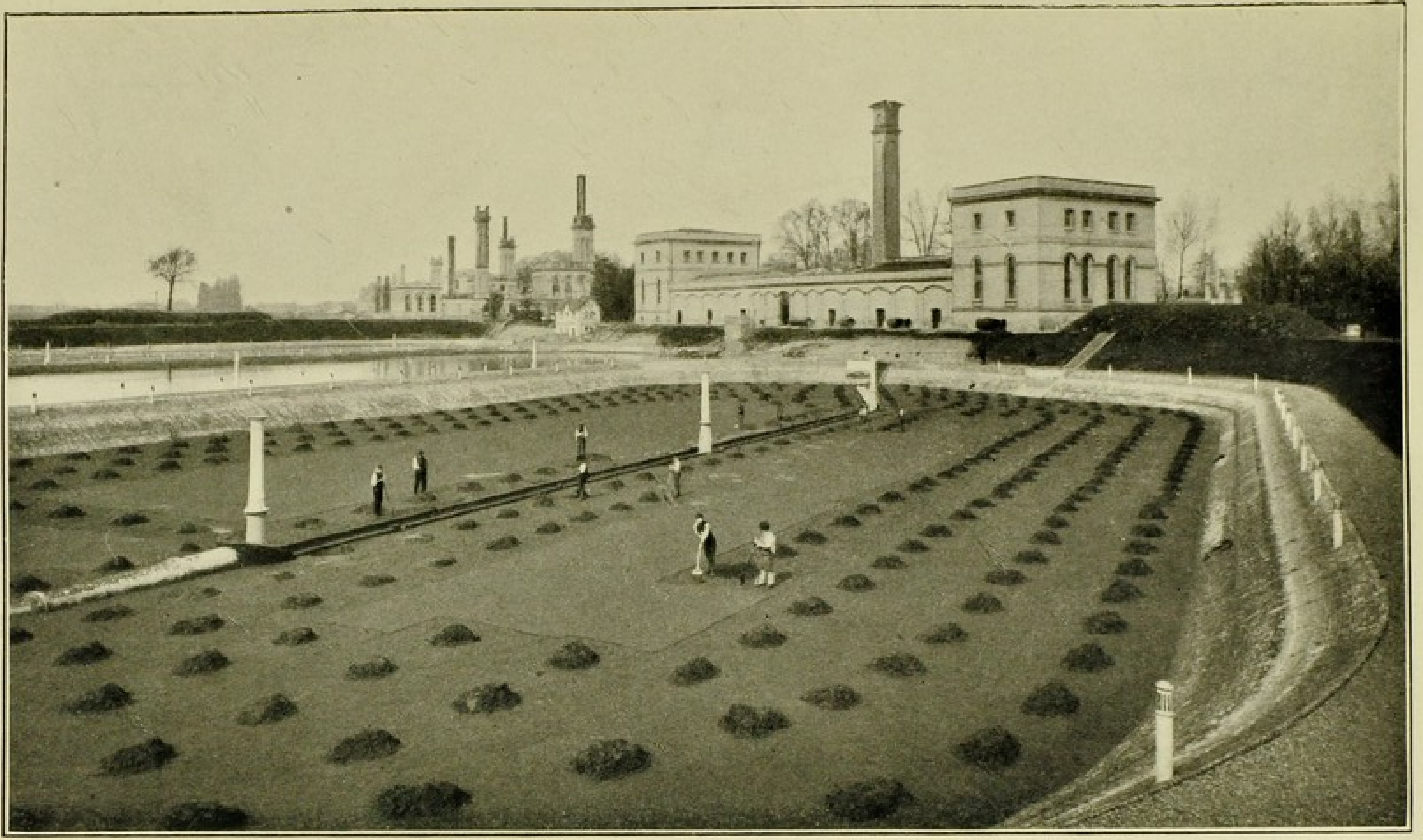
* *Berichte*, xxxvii, 1745 to 1754, 1904.

PLATE X.



Removing the “Schmutzdecke,” Hampton Filters.
(London M. W. Board.)

[*To face p.* 100.

these bodies can undergo coagulation, which is sometimes a reversible and sometimes a non-reversible process. We may regard coagulation as the desideratum of the water engineer, for in this way only will colloidal matter come out of solution as a precipitate. This state is most conveniently brought about by taking away the electric charge, thus bringing it to the so-called "iso-electric point" (Hardy [*]), where it exhibits no cataphoric action. A good example of the phenomenon is furnished by white of egg. A trace of soda present makes the albumen wander to the acid under the influence of the electric current, while a trace of acid makes it wander to the cathode; in a neutral solution the iso-electric point is to be found, where the colloid remains stationary under the influence of the electric current. Billitzer,[†] and previously Linder and Picton [‡] have shown that this neutralisation is probably due to the absorption of ions or masses of opposite charges to their own, until a neutral conglomeration occurs, when coagulation and precipitation is most likely to occur. This oppositely charged body may be another colloid, or it may be the ion of a salt. Whetham has shown that the coagulating power of an ion is not a constant factor, but depends on its valency. Thus if a univalent ion such as *sodion* (sodium-ion) precipitates n parts of the negative colloid, a divalent ion such as *barion* (barium-ion) will precipitate n^2 parts of the colloid, and a trivalent ion n^3 parts, and so on. Thus our ideal coagulant must consist of either an oppositely-charged colloid or a polyvalent ion. On this principle a theory of sand-bank formation has arisen. It is suggested that colloidal silica is carried down stream to the sea; here it loses its charge owing to ionic absorption of *sodions* if the silica happens to be negatively charged, and *chlorions* if it is positively charged. When neutral the silica is deposited. However, the reduction in the carrying power of the stream, by the retardation of its velocity when it enters the sea, probably plays a leading part.

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[*] *Zeit. Phys. Chem.*, 385, 1900.

[†] *Ibid.*, 307, 45, 1904.

[‡] *Phil. Trans.*, 67, 63, 1895.

One of the most important properties of colloids from our point of view is the great power of *absorption* they show. This property permits of many interpretations, in terms of surface-tension, electrical charge neutralisation, formation of solid solutions, or of complex compounds on the surface of the absorbing mass, and other hypotheses, but probably no theory quite fits the facts, since the adsorption of, *e.g.* iodine, methylene-blue, and bacteria by charcoal needs a great deal of explanation. One can only say that the process of absorption is necessitated by the tendency for the absorbing systems and the absorbed systems to reduce their mutual free energy to a minimum. This is not an explanation of the process, but simply regards it from a stand-point of thermodynamics.

If we add to a water a small amount of coagulant we may precipitate the colloidal matter together with many of the bacteria. On filtration this coagulated colloidal mass will settle out and form an artificial film on the filter medium. In fact, artificial filming economises time to a great degree, and is occasionally employed for ordinary sand purposes, *e.g.* at Reading. Such artificial films usually consist of alumina. When either a natural or an artificial film has been formed, the efficiency of the filter is raised, bacteria and algæ no longer pass through in large numbers, and the period of proper filtration begins. This can be continued till either the film is destroyed through mechanical or chemical rupturing processes, or until the film becomes so thick that the rate of filtration is made uneconomically slow. In the whole process of sand filtration the part played by the film is of the greatest importance, and the actual mechanism of its action is worth investigation. Reinsch, from observations at the Altona waterworks, first drew attention in 1894 to the fact that the beds coated with algæ removed many more bacteria than the clean beds.

The Film.

In natural filming the basis is mainly organic, since at the stage where bacteria and algæ are partly retained, the skin has been thickened by means of the crude suspended matter, mainly of a semi-colloidal organic nature, in the water. Retention is effected by the partial blocking of the waterway, and by the attachment of the bacteria and algæ to the filter-particles as "zooglœa colonies." These grow quickly since they receive the full food-value of the organic and inorganic constituents of the raw water. Some of them soon intermesh, and form a slimy gelatinous layer, which is in reality a small cultivation-bed. Here peptonisation and hydrolysis of the albuminoids take place by means of the organisms growing and retained in the filtering skin. At a level below, nitrifying bacteria flourish on the ammonia, nitrites, and soluble organic products from the layer above. For the nitrification abundant dissolved oxgen is of course required. There are some indications that species exist which can convert albuminoid substances directly into nitrates, but they have not yet been isolated. The film thus resolves itself into a gelatinous, semi-colloidal partially organised layer, strengthened by a network of algæ, and supported on a stratum of decomposing organic matter and underlying sand. In this jelly are contained the saprophytic organisms that split up the complex albuminoids into their simpler constituents, and lower down, the nitrifying bacteria. For the activity of these latter, oxygen, as we have seen, is essential, therefore the filter-bed must be kept well-aerated, and the aeration is assisted by the algæ on the surface which by means of their green chlorophyll contents liberate oxygen in the sunlight (this action will be further discussed subsequently).

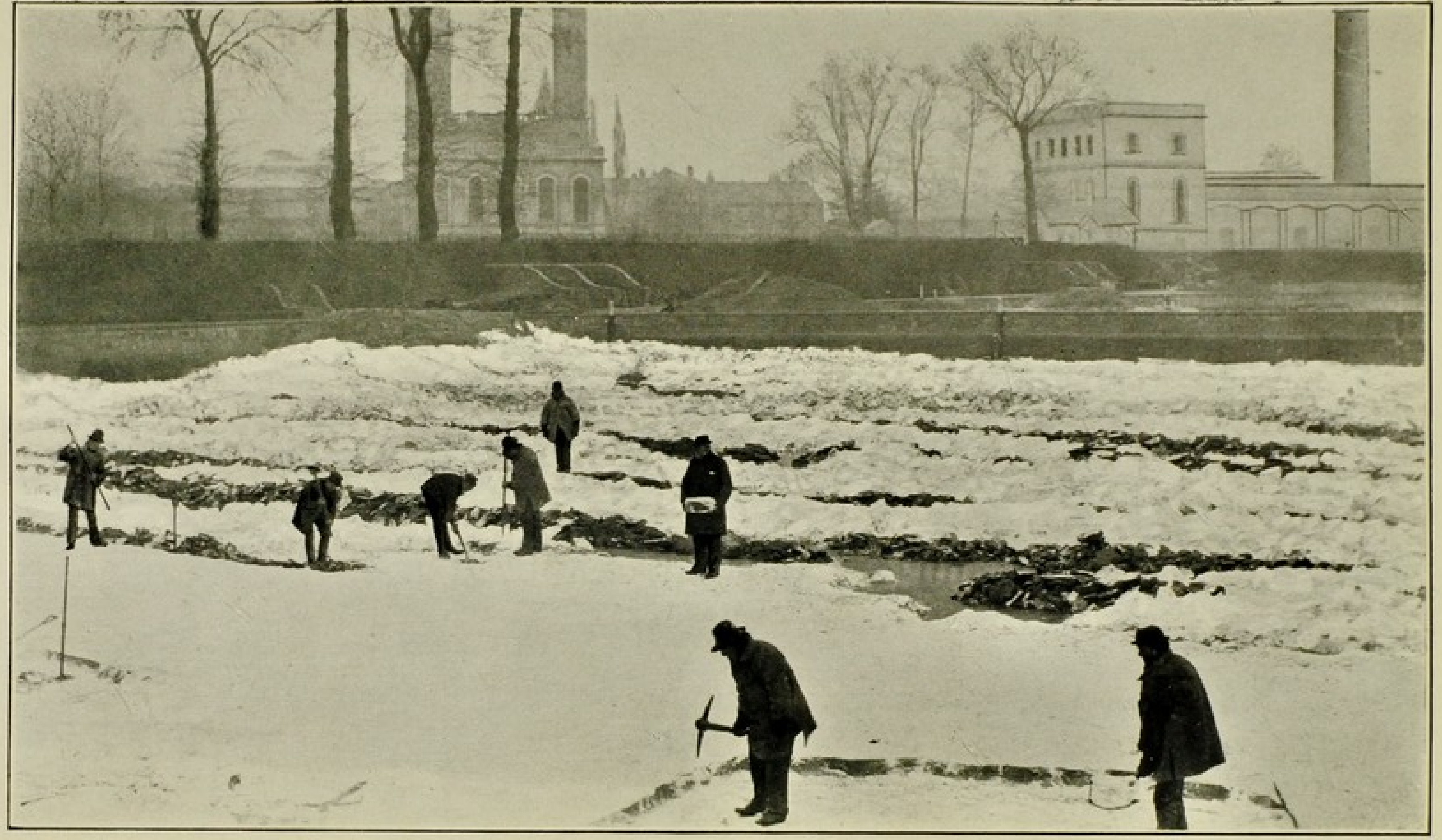
We should infer from the above, not only a removal of organisms by adherence to the film, but also a decrease in the nitrogenous organic content as measured by the albuminoid ammonia, and a nearly corresponding increase in the nitrate. Apart from the algic and bacterial action, a certain amount of simple oxidation takes place at the colloidal surface of the film, possibly owing to the formation of ozone or hydrogen peroxide by surface condensation, or feeble electric currents, or due to the production of some unstable intermediate oxide acting as an oxygen-carrier, the catalytic effect of colloidal platinum and similar substances making such an action probable. In any case it has been shown that a change of the kind occurs in so-called mechanical oxidising filters (Chapter VIII).

The main activity of the filter-bed being centred in the organic stratum of gelatinous consistence, attempts to make an artifical film are only successful when a body of colloidal nature is used, such as gelatinous silica, alumina, or ferric hydroxide. The first of these is the least efficient, and we obtain better results from sand containing compounds of iron or aluminium which can give hydroxides with water. The entire group when baked lose their gelatinous coverings of coagulated hydroxide, and their utility as films is thereby destroyed. The entangling properties of a film have been familiarly compared to those of a fly-paper.

A number of soluble bodies are also retained in a filter-bed, and we must conclude that they are assimilated or broken down by the organisms, or that they are absorbed by the colloids either mechanically or owing to some residual charge being still present on the particles. Further research on the point is advisable, but the action of the organisms must be the chief beneficial agency, since mere mechanical surface absorption is apt to soon come to an end, and even to reach a point where the absorbed substances are again liberated in quantity. Such an occurrence has actually been observed in filters, when the effluent for a time has been rendered in some respects worse than the raw water. On the other hand, the life of a properly-working sand filter is protracted.

Great advances in filter construction have arisen from scientific work as to absorption and oxidation at the surfaces. Therefore the absorptive power of colloids, both for soluble substances and also for colloidal and small suspended particles, such as bacteria and the like, must be thoroughly studied both from a theoretical and practical point of view. When ferruginous silica is used to make up a sand bed, proper filtration will often ensue without the apparent formation of the ordinary film, and this has been held to show that

PLATE XI.



REMOVING ICE FROM SAND FILTERS.
(London M. W. Board.)

[*To face p.* 104.

absorption-oxidation as just described is not indispensable. But in this case the film is already present, not limited to the first few inches of the filter-bed as in the time-filmed ones, but spreading throughout the mass on each granule of sand that has a ferric hydroxide coating, consequently the filter acquires its efficiency almost at once, but its value comes to an end sooner. Various disturbances are met with when a filter-bed is in action; these can be put down to a number of separate causes as follows.

Influence of the Algæ.—The algic growth naturally varies in different filters according to the properties of the water, the climatic conditions, and the species of organisms prevailing: the weaker kinds are eliminated by competition. The colour is variable, and is usually bright green in summer and of a more bluish tint in autumn, the periods of greatest luxuriance respectively of the groups Chlorophycaceæ and Cyanophycaceæ (Chapter II). Some forms produce a rough network up to twelve inches in thickness, that can be rolled up like a carpet. Of special interest is the green alga *Hydrodictyon* (Chapter II), which has a very strong hexagonally-meshed structure, and has been found to be a most effective strainer, giving a film that admits of rapid cleaning by rolling and raking. Here practically the whole of the upper filtering layer is incorporated with the algic growth. This species should be tried on all self-filmed beds by inoculating the surface with its active growths, since it spreads rapidly and furnishes a good skin in a short time, if it finds the conditions to its liking.

More investigation is needed as to whether the algæ liberate active oxygen, *i.e.* ozone, or nascent or ionic oxygen, that would assist in the oxidation of the organic matter *per se*, and not through the intermediation of organisms or some chemical oxygen-carrier.

During the period of maximum growth when bright sunlight occurs, more oxygen is sometimes disengaged than is desired, and the bubbles of liberated gas disturb the film and may perhaps rupture it. Such an accident means a breaking down of the filtering system, or at least entails cutting out that filter. After the prolific growth of summer months the algæ begin to decay, and aromatic and fishy-smelling oils are liberated ; the colour of the water is also affected. For these two reasons alone we must have some method of retarding the algic growth at will. This can be accomplished by the partial exclusion of light (as at Warsaw), but owing to the expense of such a proceeding the method is not often made use of. Good results without large expenditure are obtained by the addition of chemicals. The only two chemicals of importance as algicides at the present time are copper sulphate (blue vitriol) and sodium hypochlorite (chloros, electrolytic bleach).

(*a*) *Copper sulphate* (see Chapter VI, p. 88).—Disadvantages in its use as an algicide are :—

1. On the death of the organisms their oil-sacs are ruptured, and the contents swept away with the water, which is rendered for some time unfit to drink.

2. The starting of a new film is often difficult, owing to the inhibitive action of the copper carbonate which is precipitated by the earthy carbonates of the water and retained in the filtering mass.

3. This copper carbonate is slowly redissolved by the carbonic acid in the water, hence the filtrate may contain copper for weeks after treatment.

The method is found to disable a filter for at least ten days. Kemna and several American observers, in using copper salts to get rid of algæ, have observed that for some time the filtrate contained many more bacteria : they would not only fail to be strained off, but would multiply by feeding on the dead organisms.

(*b*) *Sodium hypochlorite*.—A solution containing about one part of " available chlorine " (see Chapter X) in one million parts of water is found to be of suitable strength for this purpose as in the case of copper sulphate. It is run in straight from the electrolyser, or from a storage tank at the main inflow, either by means of an injector, or simply at a constant measured rate from a tap. The use of this chemical instead of copper sulphate has the following points of preference.

1. If it is intended to afterward sterilise the water subsequent to filtration, by means of sodium hypochlorite (Chapter XI), practically no extra cost is entailed.

2. The hypochlorites destroy other organisms besides algæ, consequently when the film breaks they neutralise the effect of a penetration of organisms into the lower strata of the filter. Copper sulphate fails in this respect in the strength used.

3. Hypochlorites are strong oxidisers, so that the nuisances from oil-sacs and decaying bodies of algæ are obviated almost immediately.

4. The growth of a new film is not impaired, and the chemical disappears in a few hours, leaving only oxygen and a little common salt as residues.

Along with these merits there is only the objection of instability. For efficient use the solution must be made on the spot and kept in the dark; also it must not be applied in bright sunshine since it is rapidly decomposed by strong light.

When treated in this way, completed in the following manner, a filter need not be thrown out of action except when the water is turbid with inorganic suspended matter. On a new film being required, add to the incoming water enough hypochlorite to make the effluent sterile; the old film will be harmlessly oxidised away. Now apply the solution *after* the water has gone through the bed and not before. This allows a new film to form, while at the same time a sterile water is obtained. Of course more of the agent must be employed on the non-filtered water than on the water that has already passed through a bed in good working order; therefore the quantity of solution required to be added on the discharge side of the bed will at first be a maximum, decreased day by day until a definite quantity of chemical need be added every day: this occurs when the bed is working at its maximum efficiency.

Influence of Animal Life.—Injuries to the film may be caused by several of the smaller kinds, such as little eels, worms, water-boatmen, sticklebacks, larvæ of Chironomus, and other water insects, and by various members of the plankton groups (Chapter II).

Influence of the Size of the Sand.—Since large-grained sand allows rapid percolation, while small grains easily clog up, the size has an important relationship to efficiency and the cost of upkeep. The most complete set of experiments on the subject were made at Lawrence, Massachusetts, and published in the reports of the Massachusetts State Board of Health, 1890, etc. (that for 1892 describes the methods for mechanical sand-analysis, and is abstracted in Hazen's "Water Filtration"). The "effective size" of sand is defined as "that diameter than which 10 per cent. by weight of the particles is smaller and 90 per cent. larger." This is based on the observation that 10 per cent. of fine sand has as much influence in the filter-bed as 90 per cent. of the coarse sand. The finest sand used in Holland has an effective size of 0·17 to 0·19 millimetre or $\frac{1}{150}$ inch approximately. At the Metropolitan Waterworks it has a value of $\frac{1}{70}$ inch ; at Berlin, Hamburg and Altona it is slightly less ; at Antwerp it is $\frac{1}{64}$ inch. If the effective size of the grains is below $\frac{1}{150}$ inch, the filtration becomes uneconomically slow. The mechanical analysis of a sand is based on the weight of different fractions that have passed through standard-meshed sieves (Baldwin Wiseman).* J. M. Penninck at the Amsterdam Waterworks has shown that the whole filtering system must be uniform as regards frictional resistance, otherwise the film is likely to be weaker at one place than at another. It is clear that since the surfaces of the filter-beds are horizontal the surfaces of equi-pressure must be horizontal as well. As the pressure-difference between any two strata depends on the nature of the sand, to preserve uniform pressure-difference we should require uniform sand. To meet as far as practicable this ideal requirement a coefficient of uniformity has been introduced (Allen Hazen), which is defined as the numerical value of the ratio :—

$$\frac{\text{diameter of grain such that 60\% of sample is finer than itself}}{\text{diameter of grain such that 10\% of sample is finer than itself}}\cdot$$

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* *Proc. Inst. Civil Engineers,* 1910.

Influence of the Depth of the Sand.—The working of slow sand filters being so closely associated with the top skin, we should not expect the depth of the bed below to have much influence, except in the case of ferruginous sand as mentioned above. But if the film breaks in a shallow filter the water will run through at too great a speed, moreover organisms are often trapped by sand-particles quite low down in the bed. For these reasons it is not advisable to have the depth of sand below 2 feet. On the other hand a great depth retards the velocity of filtration. The Lawrence formula for frictional resistance of sand closely packed and with the pores completely filled with water, disregarding the action of the film and assuming a uniform flow-gradient, is :—

$$V = cd^2 \frac{h}{l} \frac{(t^\circ + 10^\circ)}{60}$$

where V is the velocity of the water in cubic metres per square metre per day (equal approximately to a million gallons per acre daily) ; d = the effective size of the sand grain in millimetres ; h = the loss of head in filtration (measured by the difference of water-level in tubes sunk to the bottom and top of the sand-bed); l = the depth of the sand-bed ; t° = the temperature in degrees Fahrenheit (increase of temperature diminishes viscosity of liquid, therefore increases rate of filtration) ; while c is a so-called constant, or rather a multiplier, which differs according to the condition of the sand—it is estimated to have a value of 850 *plus or minus* 150, that is, to range from 700 to 1000, for new sand, and from 500 to 700 for sand which has been in use for some years, the lowering of the figure being presumably due to increase of film-resistance. The value of c also decreases as the uniformity coefficient increases.

W. H. Burr considered this formula to be only of use in cases where the "effective size" of the sand lies between 0·1 and 3·0 mm. (=0·004 to 0·12 inch), with a uniformity coefficient not greater than 5. Baldwin Wiseman, in the valuable paper quoted above, to which reference should be made for further details, concludes the formula "incapable of universal application for want of a more rigid and precise definition of the coefficient c than that customarily given." He made careful experiments with a large number of different sands, and found the rate of delivery to depend essentially on the surface area of the sand particles and the thickness of the adherent water-film. These were estimated from the number and size of the grains and the weights when dry and when wetted. He deduces the formula

$$Q = \frac{e^{vf}}{a} \times \frac{h}{l} \times \frac{t^\circ + 10^\circ}{60}$$

where Q = the discharge in cubic feet per square foot per hour.
e = the base of the Napierian logarithms = 2·7183.
v = the percentage porosity of the sand, or the volume of the retained water per unit volume of the sand in its most compact condition, multiplied by 100.
f = the thickness in inches of the film of retained water of the sand, or the volume of retained water per unit volume of sand, divided by the surface area of the grains per unit volume of the sand in its densest condition.
a = the surface area of the grains per unit volume of the sand.
h = the head of water in feet inducing the flow.
l = the thickness of the sand-bed in feet.
t° = the temperature in degrees Fahrenheit.

According to his tables the rates calculated from this formula run fairly parallel with those actually observed, but there are variations needing further investigation.

Don and Chisholm * remark that, as might be expected, the rate of percolation is inversely proportional to the area of the granules.

Distribution of the Bacteria in a Filter-bed.—The number stopped by the thick and clearly visible film is about 71 per

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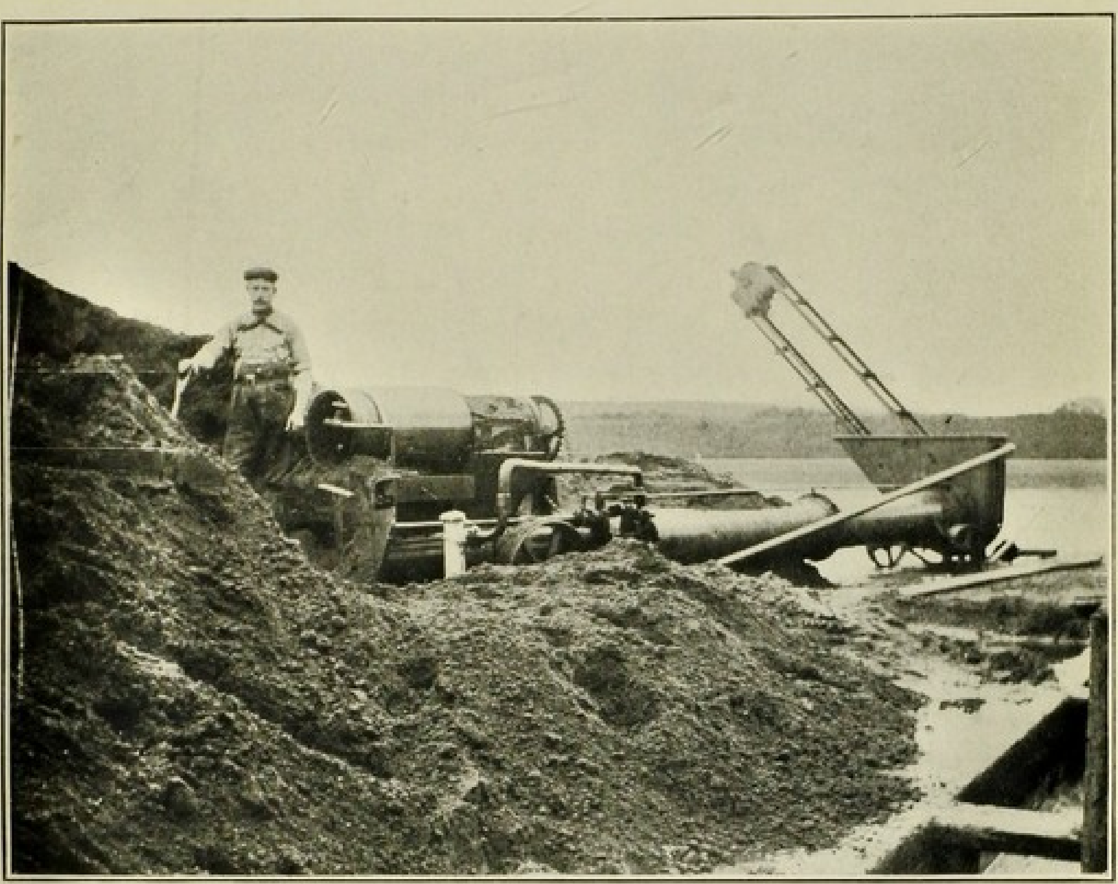
* "Modern Methods of Water Purification," 1911, p. 100.

PLATE XII.



Hydraulic Sand Washer, Hampton Filters.
(London M. W. Board.)

[*To face p.* 110.

cent. (Reinsch).* In addition to this, the stoppage at a depth of 40 centimetres below the skin was 28·9 per cent., indicating that the separating power is not restricted to the upper layer. Schuckmann † investigates seasonal variations in the purity of filtrates, in great part due to differences in the work done by the filtering skin. The bacterial content of the finished water does not change quite proportionally to that in the raw liquid, but there is an immense reduction, from say 200,000 to 100 per c.c., averaging 98 and 99 per cent. Such statistics, to be useful hygienically, must also record the *character* of the organisms left. A removal of 99 per cent. from a water rich in bacteria may still leave tens or hundreds per c.c., including perhaps pathogenic species.

Several researches have been made on the diffusion of bacteria through sand and soil. Kruse ‡ found that *B. prodigiosus* passed through 50 metres of sand, but only one per cent. of the organisms remained. Proskauer's Muggelsee § experiments gave a similar result. Kabrhels || finds that under ordinary conditions the vertical penetration rate for bacteria is 0·3 to 0·5 centimetres per day, while they travel very much quicker horizontally. Therefore, the layers of filtering material soon attain bacterial equilibrium.

The limitation to the life of a bed comes from the fact that organic liquefaction and destruction is slower than organic accumulation, while the material also becomes silted up more or less rapidly with inorganic suspended matter. The period of use is extended by scraping the top surface, or by the methods of treating it that we have described, but sooner or later the whole mass becomes clogged and the material has to be taken out and washed or replaced by fresh.

Sudden alterations in the head of water have a bad effect on the purity of the effluent, and even the increase of pressure rendered necessary by the rise of skin-resistance tends to

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* *Centralblatt f. Bakt.*, 1894, lxvi, 881.

† *Inaug. Dissert. Breslau*, 1900.

‡ *Zeit. f. Hyg.*, lix, 6, 1908.

§ *J. Gasbel. u. Wasservers.*, 574, 1908.

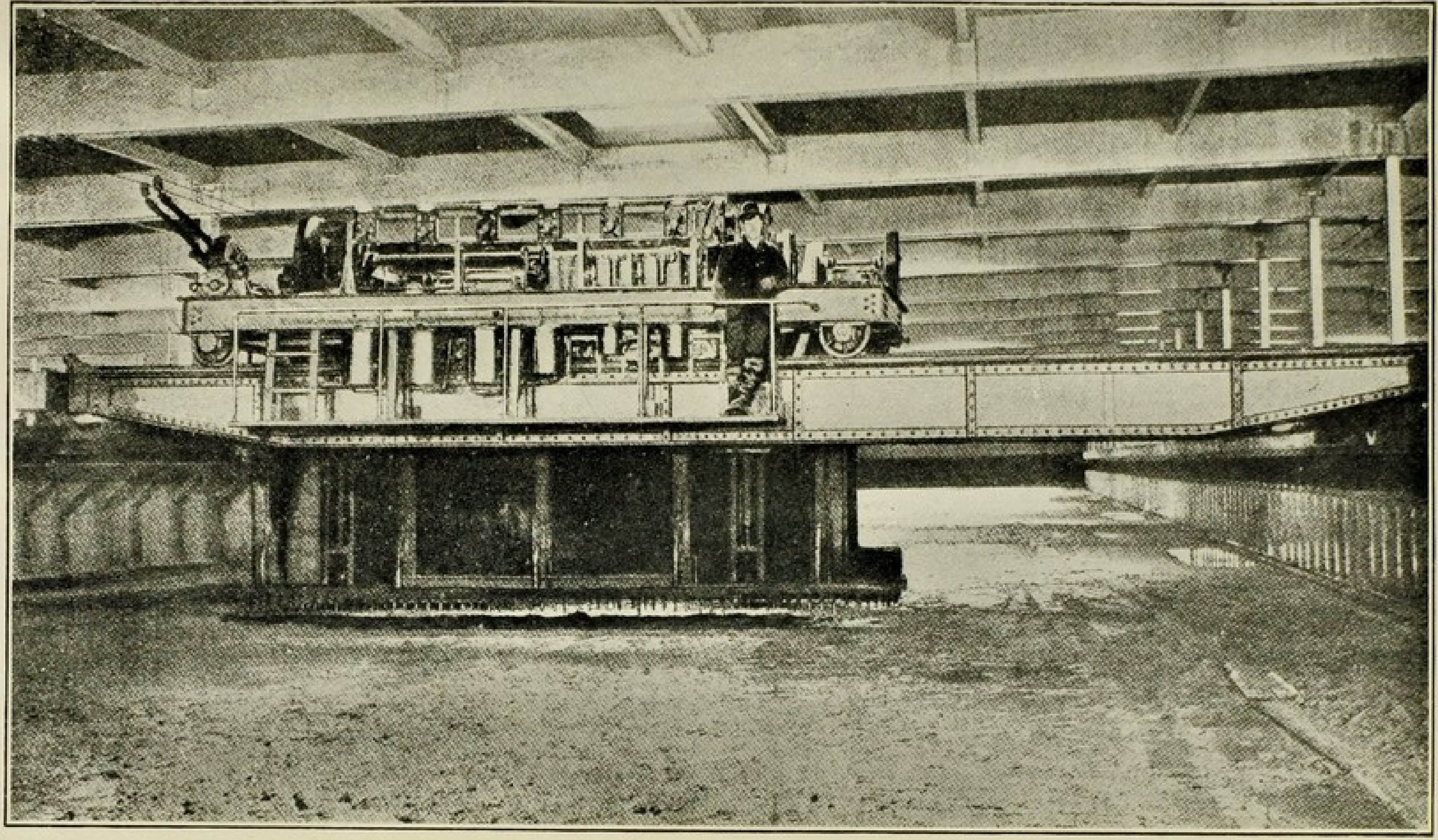
|| *Arch. f. Hyg.*, lxiv, 295, 1908.

diminish bacterial purification. When there are variations of speed there is a tendency for channels to be formed, through which unpurified water is swept. (See Penninck on "Sand Filtration," *Die Ingenieur*, xvi, 1908.)

The rate of filtration by ordinary sand filters is generally, in Great Britain, from 2 to 3 million gallons per acre per day, indicating a downward travel of the water equal to 4·6 inches, or 11·7 centimetres per hour. In America it is 1 to 2 million gallons per acre per day. In Germany the velocity of descent is restricted to 10 centimetres per hour, equal to 2·4 cubic metres of water per square metre per day (about 2·4 million gallons per acre). The head required varies between 60 and 100 centimetres (2 to 3½ feet).

Sand Filters without a Top-film: Non-submerged.—Some experimenters, particularly in France, have contended that it was better to work quite differently from the ordinary English method. The presence of plankton was to be avoided, and the upper layers kept well-aerated, by sprinkling the water over a clean surface of sand at a rate equal to the escape from the bottom, so that the bed never became entirely filled. Janet and Robert's preliminary experiments were carried further by Miquel and Mouchet, and on a larger scale by Baudet at Chateaudun, as described in his book *Filtres à Sable non-submergé*, Paris, 1908. He uses a bed 1·3 metres (4¼ feet) deep of fine sand, 0·5 to 1·5 millimetres in grain. 60 per cent. is less that $\frac{1}{30}$ inch in diameter, and the remainder averages $\frac{1}{20}$ inch. The water is sprinkled from fine nozzles, 16 to the square yard, and percolates at a rate of 6½ inches per hour. The installation is covered. The filter gives at first an effluent rich in bacteria, but Miquel found that in 16 weeks they had gone down to under 100 per c.c. Baudet, with his slower rate of filtration and finer sand, reached efficiency much sooner, "in a few days." Cleaning is necessary once a year, and there is no film. Miquel and Mouchet observed that to a depth of 30 centimetres there was an increase in numbers of bacteria, after that a decrease. *B. coli* was present in the raw, but not in the filtered, water, though it was found in the sand at 50 centimetres. *B. typhosus* does

PLATE XIII.



Blaisdell Sand Washer, Wilmington, Del., U.S.A.
(G. A. Johnson.)

[*To face p.* 112.

not pass through. They say that the speed of filtration must not be great, but "may be two or three times higher than that of ordinary sand filters." Gaultier, in *La Technique Sanitaire* supplement, p. 113, 1908, and p. 27, 1910, recommends these filters and describes various forms. They generally take a long time to get into order. This, in conjunction with Miquel and Mouchet's observations quoted above, and also the fact noticed at Bedford that the sand is white at the surface but discoloured some inches below, prove that the ordinary top-film is replaced by deeper filtering growths of zooglœa nature, which will be less easily disturbed, but more difficult to manage and clean. The French Conseil Superieur d'Hygiène authorised an installation of non-submerged filters with 300 square yards filtering surface at Chateaudun. The raw water there is clear and almost free from sediment. Turbid water, according to M. Baudet, would require pre-filtration. Non-submerged filters with sprinklers are used at the Bedford Waterworks.

Stage or Successive Filtration.—Instead of relying on storage and sedimentation, time is shortened by first straining turbid waters through beds of coarse, gravelly sand (pre-filters), which effect considerable improvement in other respects besides clearing, greatly prolong the life of the final filters, and allow them to be made more efficient by using finer sand, even while giving a higher delivery. A consideration sometimes very important is that the output of an existing waterworks will be greater, or the area required for a prospective one will be less. Much credit is due to Goetze in investigating and applying the advantages of double filtration with pre-filters.* He gives the following details of the plant at Bremen †:—

	Area in square yards.	Thickness in inches.	Delivery inches per hour.
Pre-filter . .	2775	47·5	2·0
Final filter .	777	44·9	7·9

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* *J. Gasbel. u. Wasservers.*, 965, 1903 ; 105 and 128, 1907. *Berichte*, 14th Intern. Congress of Hygiene and Demography, III, 152, 1908.

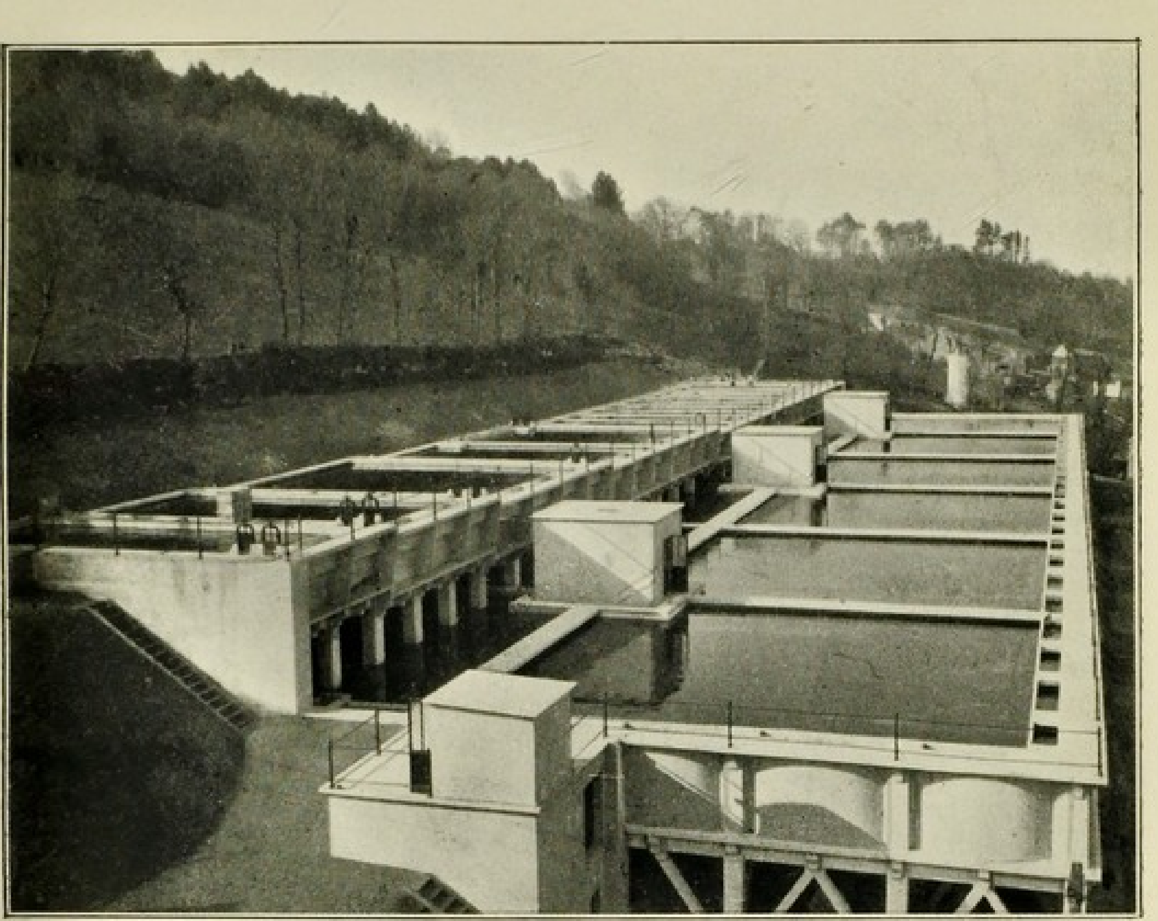
† *Water*, vi, 19, 1904.

Concurrently, trials by Dunbar, Kemna, Chabal, and others led them to advocate an expansion of the system into *multiple filtration.* Dunbar's researches showed that the removal of impurities, especially colloids, by sand-filtration became proportionally much greater the less of them there were present. Thus a one per cent. impurity does not fall below a half per cent. in a single filtration, but the latter strength may become reduced to a twentieth or a fortieth per cent. by a second filter. So that multiple filtration can effect practically complete purification. This is the basis of the

Puech-Chabal System of Multiple Filtration (Armand-Puech patents), which is in use at a number of waterworks in France and other countries, and in a modified form at Sunbury-on-Thames, Bamford (Derbyshire), and elsewhere. The water passes at a decreasing speed through a series of "dégrossisseurs" of successively smaller gravel, from the size of walnuts to that of small peas; then in most cases through coarse sand pre-filters, and the process is completed as usual by fine sand-beds. The Mont Valérien plant, Paris, dealing with 10 million gallons daily of very foul water pumped from the Seine below the city, has four dégrossisseurs, each consisting of four compartments side by side. The dégrossisseurs are arranged in steps, with their straining material progressively 12, 14, 16 and 16 inches deep, and their surface areas nearly proportional to the numbers 1, $1\frac{1}{2}$, 3, and 5 (the first compartment being 146 square metres = $392\frac{1}{2}$ square feet). Through these changes, and the diminishing size of the materials, the water slackens in speed and more time is allowed for deposition as it advances. The twelve pre-filters of coarse sand are erected over the eighteen fine sand-filters, part of which are themselves built on the roofs of three-storage reservoirs, together holding 19,000 cubic metres (about 4 million gallons). The speed of the final filters is limited by the Government regulations to 75 gallons per square foot per 24 hours, equal to a vertical fall of 6 inches per hour.

It is said that "the total time of treatment of the water at these works occupies forty-two hours, which has been found sufficient to eliminate the free ammonia by nitrification."

PLATE XIV.



Multiple Filtration at Cherbourg, France, Puech-Chabal System.

[*To face p.* 114.

Some also disappears in the evaporation from the thin films over the stones and in the cascades. Analyses of the finished water are made weekly at the Montsouris Laboratory, and published in the *Bulletin Municipal Officiel.* The results show a good and uniform purification, and the daily tests for seven years record that *B. coli* was always absent from the final filter effluent. The issue of July 13, 1913, giving the last year's mean results for the different Paris waterworks, states that the Seine water at the intake of the Mont Valerien works showed an average of 77,940 germs per c.c. after an incubation of fifteen days, while the Puech-Chabal filtered water averaged only sixty-nine. Later results for six months give for this system :—

	Total bacteria per cubic centimetre after 15 days' incubation.		
	Average.	Highest.	Lowest.
Raw Seine water	53,533	144,300	4500
Filtered water (mains) . .	33	82	6

The similar Cherbourg installation gives the following figures :—

	Area in square yards.	Successive percentage removal of bacteria.
Dégrossisseurs . . .	378	86·5
Pre-filters	400	91·8
Fine sand filters . . .	2444	99·7

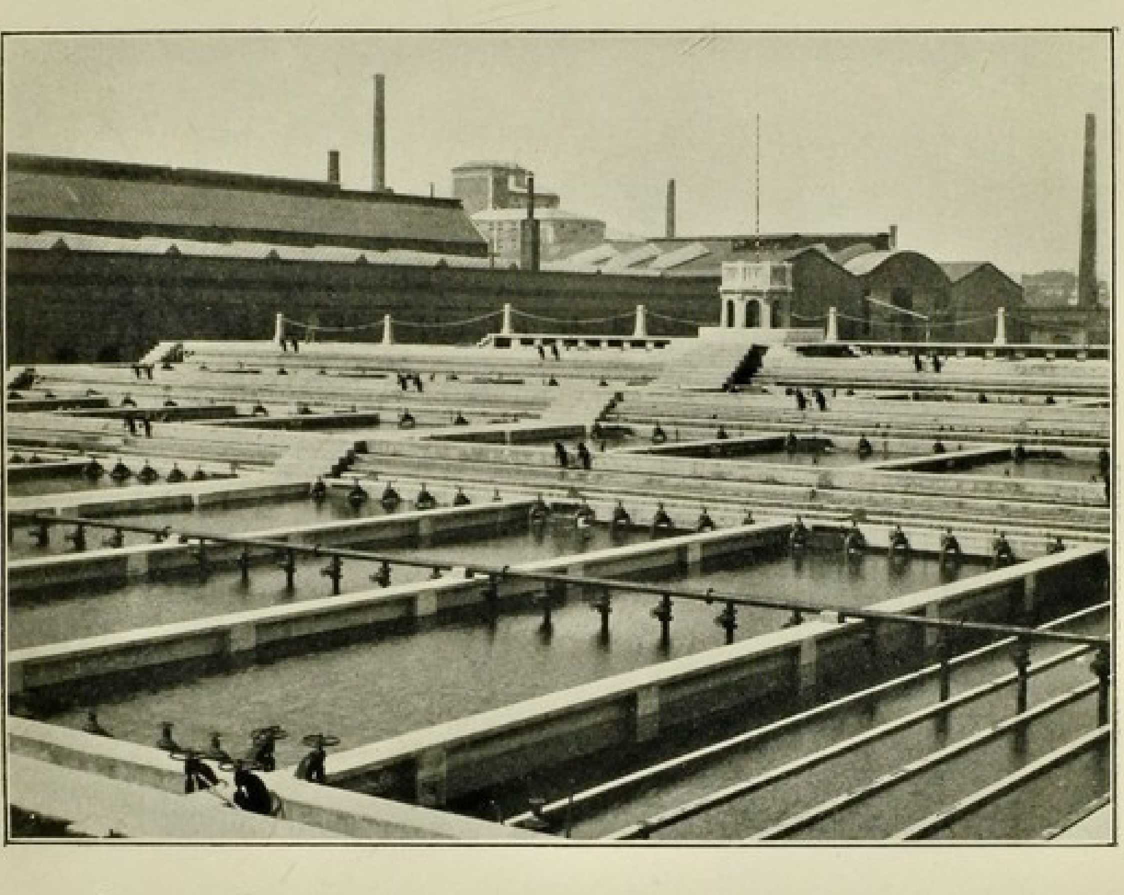
At first it seems difficult to understand how what appears to be mere straining arrests such a large proportion of minute organisms, but it is explained by the fact that besides the coarser particles strained out in the dégrossisseurs, a quantity of the finer suspended matter is retained by sticking to the slime-coating that forms on the gravel, just as it forms on the sand-grains of a fine filter. It must be remembered that many organisms are smaller than the interstices between the grains of the finest commercial sand.

At Magdeburg, Germany, the filtering plant formerly consisted of (1) decanting or sedimentation basins; (2) coarse sand pre-filters; (3) fine sand filters. The pre-filters rapidly became blocked, and the sand filters also gave much trouble; accordingly, in 1908, the whole was reconstucted on the Puech-Chabal principle, the decanting basins being replaced by four dégrossisseurs in series of eight basins each, with an elaborate system of intervening cascades for aeration. Previous to 1911, when the arrangement was covered in, trouble was experienced from frost. The raw water from the Elbe is highly polluted, contains factory and other refuse, and is always turbid. *Engineering*, January 13, 1911, gives the Magdeburg Municipal Laboratory's report on the bacterial results for the whole of the filters in November, 1910, comprising 454 samples from the eleven sand filters and the multiple filters. The average number of bacteria per c.c. in the raw water was over 43,000; in the Puech-Chabal final effluent it was under 6 per c.c., and *B. coli* was not found. The following table of details can be compared with those we have already given:—

	Total bacteria per c.c. after 48 hours' incubation.			Successive percentage removal of bacteria.
	Average.	Highest.	Lowest.	
Raw Elbe water .	43,523	144,000	4200	—
Dégrossisseurs .	3,771	10,000	1500	91·33
Pre-filters . . .	636	1,900	130	98·51
Final sand filters .	5·65	18	1	99·987

In *Trans. Inst. Water Engineers*, 1911, will be found a diagram of the working of one of the largest sand filters, 13,350 square feet in area, for six months before, and twelve months after, the change to the Puech-Chabal system. Previously the filter had to be cleaned every ten or fifteen days, and yet gave bad results, while afterwards, although already partially choked, it was able to remain in work for nearly four months longer, and after it had been recharged with fresh sand it continued passing a full quantity for the remaining eight months of the period with very little loss of head and excellent results as to removal of bacteria.

PLATE XV.



General View of Dégrossisseurs at Magdeburg, Germany.

[*To face p.* 116.

As to aeration we have already spoken in Chapter V. Cascades evidently require a height, and ordinarily involve extra pumping and expense of construction, hence this feature of the system is sometimes omitted.

Cleaning.—The latest and most approved method of cleaning the dégrossisseurs is as used at Roubaix and at Cawnpore, by forcing air with the water upwards through them by means of fixed vertical pipes arranged in rows with cross connections. At Magdeburg the first series of dégrossisseurs is cleaned on an average every three days, the second every week, the third every ten to fourteen days, and the fourth every two or three weeks.

The pre-filters were at first cleaned in the ordinary way by scraping ; this is done at Magdeburg every week. At some recent installations a vacuum cleaner or suction dredger called the Boistel apparatus is used. It requires rails to be fixed to carry the travelling bridge. The pre-filters are cleaned in rotation, so that only one is thrown out of work at a time.

See also *Trans. Assoc. Water Engineers*, 1907 (Dr. Kemna and others) ; *Trans. Mech. Eng.*, 1909 (M. Puech) ; an article by Walter Clemence in *Engineering*, vol. 89, and an interesting pamphlet by him on "Sand Filtration," published in 1912. The most recent information is contained in an illustrated report of personal inspection of European installations on this system, made to the Indian Government by F. O. Oertel, Sup. Engineer, Allabahad, in 1913 (Vacher, Westminster). He considers it more suitable for use in India than mechanical filters.

Maignen's "Scrubber" Filter.—This was introduced at the South Bethlehem, Pennsylvania U.S.A. Waterworks in 1905 (*Water*, vii, 437). The pre-filtration is *upwards*, at a rate of about 200 gals. per square foot per day, through scrubbers 38 by 16 feet in area and 6 feet deep, of the following construction. On a base of perforated terra-cotta pipes is a 9 inch layer of 3 inch pebbles, and then 9 inches of egg-sized coke. Next come four rows of slates, separated by small coke, each row sloping slightly in herring-bone fashion, in an opposite direction to the last, the whole slate stratum being 2 feet thick. Above this is a layer of sponge 18 inches deep, held down by wooden laths. The partially-purified water now passes downward through fine sand filters. These only require cleaning four times a year, and although the rate of filtration is high, the bacterial results are said to be satisfactory. Two claims for this apparatus are :—

1. That the scrubbers remove much dissolved air, which by forming bubbles frequently interferes with the action of a slow sand filter.

2. That the scum rising to the top of the scrubbers is used at times for starting the surface film of the fine filter.

In America it has been long recognised that rough filtration has many advantages over large sedimenting reservoirs, for the preparation always advisable, and often absolutely necessary, before slow sand filtration. The settling basins are costly and occupy a large area of ground : their efficiency is often impaired by changes of temperature giving rise to currents, or from disturbances through winds or other causes, so that the clearing by gravity is arrested, and the sediment may be stirred up again, even in reservoirs of considerable depth. Periodical cleansing is more costly and troublesome than the rapid methods used for roughing filters such as we have described, and frequent small quantities of dirt are easier of disposal than the enormous accumulations of mud from reservoirs, just as at Antwerp the three sedimentation basins each occupied twenty-five men for two days twice a year for clearing away the mud, which generally filled the reservoirs to about one-third their capacity.

James H. Fuertes,* in a paper on the Steelton Waterworks, Pennsylvania, designed by him, draws special attention to the use of coarse-grained filters instead of subsiding basins "for preparing the raw water for slow sand filtration, by removing therefrom enough of the turbidity and bacteria to permit the slow filters to be operated at a relatively high rate, yielding a water of reasonably good and constant

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* *Amer. Soc. Civ. Eng.*, Oct., 1909. See also Hazen, "The Filtration of Public Water Supplies," New York.

character throughout the year." He emphasised the small area required, and the long runs of the final filters without cleaning. In the discussion, G. W. Fuller observed that the Steelton plant accentuated the advantage of applying to a sand filter an effluent substantially free from turbidity, in line with experience and practice since 1899 at various places, notably Zurich, Switzerland; Philadelphia, Pa.; Washington, D.C.; Albany, N.Y., etc. "Incidentally it is true also with respect to the benefit secured from adequate preparation of the unfiltered water in the case of mechanical filters."

In his early report on *The Purification of the Ohio River Water at Louisville, Kentucky* (Van Nostrand, N.Y., 1898), he had dwelt (p. 386) upon the economic value of sedimentation as a preliminary to filtration of very turbid waters.

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CHAPTER VIII.

MECHANICAL FILTRATION.

In this country open sand filters still retain the most general favour. The substitution for them of mechanical filters operated at high rates has been in the great part influenced by questions of cost. We know that to form slow sand filters a considerable acreage of land has to be purchased, since, depending almost wholly on a sand layer a few feet deep, and working under a small head, they must be of large area to furnish the required delivery. Within the last ten years the merits of mechanical filters, combined with apparatus for adding suitable chemical solutions, have gradually become more recognised in Great Britain, and in many places installations of this type are superseding the old system. The advantages of the new methods are thus stated :—

1. Discoloration can be more easily removed.

2. Acidity can be neutralised, removing or reducing metallic solvency and corrosion.

3. "Cost of construction and upkeep, and area of works, are less than with the slow filters."

4. Rate of filtration is much higher.

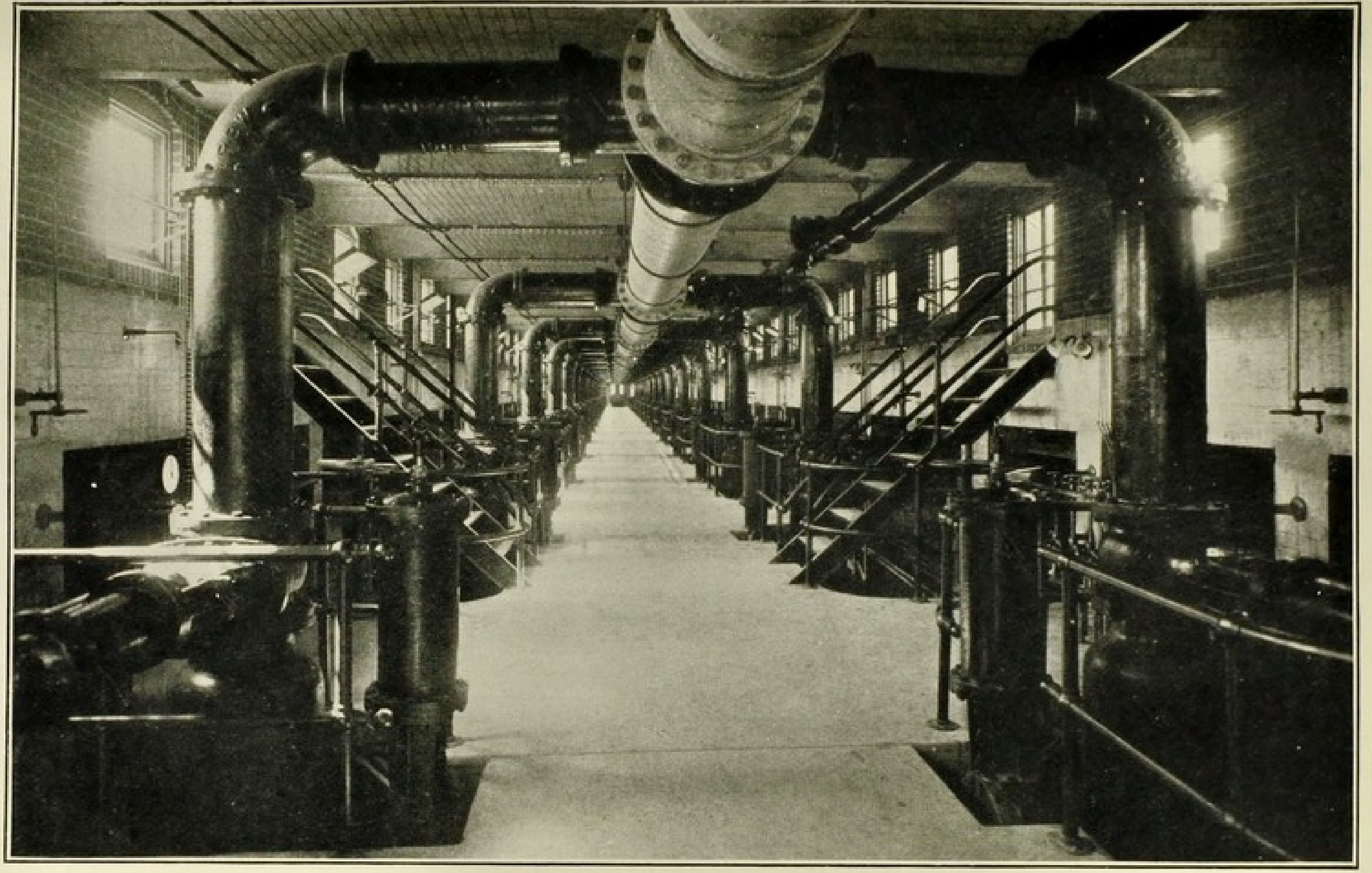
5. Less water is needed for washing the filtering material.

6. Contamination from the air, and the encouragement of algæ by light, are avoided.

7. The whole can be protected from frost.

8. In the old sand filters the bacterial purification is subject to irregularities from the causes mentioned in Chapter VII ; in the present method it can be made more uniform, and in many cases higher, and "it is not unusual to obtain a sterile water." On this point a comment must

PLATE XVI.



Operating Gallery, Prefilter House, Torresdale, Pa., U.S.A.

[*To face p.* 120.

be emphasised. When after the addition of coagulant, the water is run into sedimenting tanks before filtration, there is always some danger of the organisms again ascending into the supernatant liquid. It must be remembered that the bodies of most species have a natural gelatinous envelope, by which they may adhere to suspended matter or to sand grains, but when this happens they can generally detach themselves at will and resume their usual motility. Therefore, the efficiency of the subsequent sand filter must always be guarded as the final reliance.

The term "mechanical filters," although of course arbitrary, is well understood to denote the class which do not mainly depend for their efficiency upon the formation of films by living growths. They might almost be called "inorganic" filters. The distinction has only arisen since the agency of the ordinary plankton films has been discovered. These are replaced in the modern "mechanical filters" by artificial filming with inorganic colloids. As Allen Hazen remarks, the principle had its origin in the United States from a wider application of the iron or wooden cylinders filled with sand which were used in paper-mills to remove from the large volumes of water required the comparatively large particles which would otherwise affect the appearance and texture of the paper. The water was forced through at rates of 100 to 200 million gallons per acre daily, which was 50 to 100 times the general speed of sand filters. In their earlier forms they were quite inadequate to remove the finer particles, such as bacteria, or even turbidity. By improvements, particularly the use of coagulants, they have been made capable of dealing successfully with municipal water purification.

The first important experiments were made by E. B. Weston in 1893 on the river water supply of Providence, Rhode Island. After adding 0·7 grain per gallon of aluminium sulphate the water was forced through a cylinder 30 inches in diameter containing a sand-bed 34 inches deep, the filtration rate averaging 128 million gallons daily. Seventy to 90 per cent. of the colour was removed, and on the average 95 per cent. of the bacteria.

Subsequent trials at Louisville, Kentucky, between 1895 and 1897, under G. W. Fuller, were directed towards clarification of a muddy water as well as bacterial purification. At least 0·75 grain per gallon, and sometimes more, of aluminium sulphate were here necessary for clarifying, and at the same time "*fair* bacterial purification was *nearly always* obtained." Whatever may be meant by "fair," the figures given for "bacterial efficiency," that is, percentage removal of total bacteria, are low, furnishing an average of 96 per cent. for the Jewell filter used, and 96·7 per cent. for the Warren.

A case where the principal object was, on the other hand, removal of bacteria from an apparently clear water (Lake Erie), was the subject of trials by Allen Hazen at Lorain, Ohio, and the State Board of Health Report for 1897 gives the following summary of results :—

Week ending	Average rate of filtration gallons per sq. ft. per minute.	Aluminium sulphate grains per gallon.	Bacteria per cub. centimetre.		Percentage reduction.
			Raw water.	Filtrate.	
June 19	1·06	2·58	1441	16	98·9
,, 26	1·10	2·50	385	6	98·4
July 3	1·11	2·27	367	9	97·5
,, 10	1·28	1·07	154	14	90·9
,, 17	1·14	0·94	189	26	86·3
Averages	1·14	1·83	507	14	96·4

There were 6 filters like those at Louisville, each 17 feet diameter, giving a total filtering area of 1356 square feet. These results show that it requires a larger quantity of coagulant for removing bacteria than for clarifying or decolorising, and that one grain per gallon is here insufficient. The figure 96·4 exemplifies the caution we have already given, that an average without details often misleads.

The elaborate experiments at Pittsburg are described in Hazen's work on "Water Filtration," and Mason's "Water Supply" gives the annexed table :—

	Source of water.	Alum. sulphate grns. per gal.	Bacteria removed per cent.
Pittsburg experimental filter .	Alleghany river	0·70	95
,, ,, ,, .	,, ,,	0·72	96
,, ,, ,, .	,, ,,	0·78	97
,, ,, ,, .	,, ,,	0·98	98
,, ,, ,, .	,, ,,	1·22	98½
,, ,, ,, .	,, ,,	1·66	99
Elmira, N.Y., May, 1901 .	Chemung river	1·38	98·43
East Providence, R.I., 1901 .	—	1·0	99·24

Recent reports from eighteen large cities and towns in the United States using mechanical filters and sulphate of alumina give the average reduction in total numbers of bacteria as 98·57 per cent.

In Dr. Schreiber's report of investigations and experiments with the same process at the Berlin Waterworks, the official tests showed that in the general city supply it effected a reduction of bacteria equal to 99·6 per cent., but with raw Lake Muggel water, containing an average of 368 colonies per c.c., the percentage reduction was only 93·5. He is of opinion, from his results, that the method is bacterially as efficient as slow sand filtration, provided that the operations are correctly adapted to existing conditions. For the removal of turbidity and colour, he finds it distinctly superior to the old system.

Ordinarily, the first cost of a mechanical filter installation is considerably less than that of slow sand, and occupies but a fraction of the area required by the latter, while the operating costs are considerably higher than those of the slow sand method, due largely to the necessity for using a coagulant in the mechanical process.

At the commencement of the last chapter we quoted from the published health records of New York State the lowering of typhoid death rates which had attended improvements of the water supply, specially adducing the effect of the introduction of slow sand filters at Albany, N.Y. The same report gives further details, referring particularly to mechanical filters. We have included Albany for comparison.

Column A is the average typhoid mortality per 100,000 before the improvement.

Column B ditto after the improvement.

Column C percentage reduction in the death rate.

Place.	Nature of improvement.	A.	B.	C.
Albany	Slow sand filters	88·8	23·7	73·0
Binghamtown	Gravity mechanical filters	39·3	11·7	72·2
Elmira	Ditto	54·9	41·5	24·4
Hornell	Horizontal pressure mechanical filters	42·2	24·7	41·4
Hudson	"Purer source and modernised filter plant"	64·3	31·9	50·5
Ithaca	Part wells and springs, part gravity mechanical filters	67·2	14·6	78·3
Rensselaer	Gravity mechanical filters	95·5	54·4	43·0
Schenectady	Wells or infiltration galleries	25·0	14·4	42·6
Troy	Surface gravity instead of Hudson river	58·2	31·0	42·6
Watertown	Gravity mechanical filters	94·7	36·9	61·8

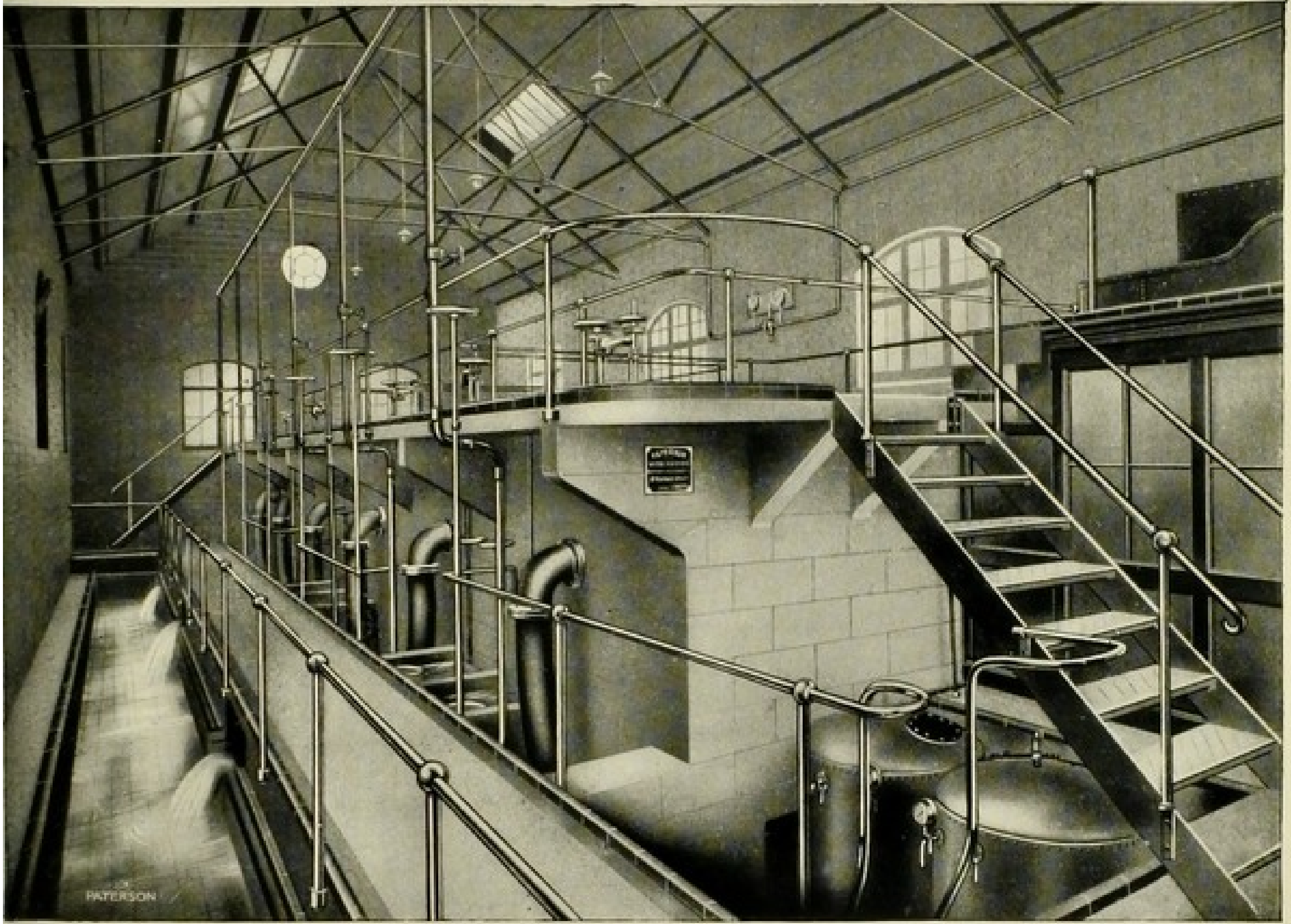
The average reduction for the whole is 53·4 per cent. The other statistics show that improvement in general sanitary conditions had nearly always caused a lowering of typhoid rates, but this had been very slight where there had been no change in the system of water provision.

With regard to chemical coagulants and precipitants see *ante*, Chapter VI, p. 80. Their composition should be analytically known. The catastrophes from haphazard working need not be recalled if they were not sometimes recurrent.

Aluminium sulphate solution is naturally acid, but in the commercial article, besides a variable amount of water of hydration, there is sometimes an objectionable excess of sulphuric acid, and also other impurities; therefore the substance should always be bought by analysis. (This is the more necessary as it is liable to contain arsenic. Large quantities have been recorded.)

It works by reacting with the carbonates of lime and magnesia in waters, when, as aluminium forms no carbonate, hydrated alumina (aluminium hydroxide) is separated in the gelatinous form that entangles impurities, and sulphate

PLATE XVII.



INSTALLATION OF RAPID FILTERS AT TEWKESBURY, PATERSON SYSTEM.

[*To face p.* 124.

of lime or magnesia is left in solution, according to the typical equation :—

$$Al_2(SO_4)_3 + 3CaCO_3 + 3H_2O = Al_2(OH)_6 + 3CO_2 + 3CaSO_4.$$

Temporary hardness is thus changed into *permanent* (see Chapter IX), a point that here only affects, and that not as a rule seriously, water subsequently employed for boiler purposes.

With very soft waters there may not be sufficient earthy carbonate to precipitate the reagent, therefore more lime or chalk must be added. Another plan has been to use a basic aluminium sulphate. When the use of the alumina film was first carried out on a large scale by the Morison-Jewell Filter Company of New York in 1887, they employed a "basic sulphate" made by adding soda to aluminium sulphate, giving a precipitate of gelatinous aluminium hydroxide and sodium sulphate in solution. This is quite different from a basic solution of the metal.

We will here define the terms, as the polyvalency at first introduces a little complexity. Aluminium being a triad, and sulphuric acid dibasic, 2 of the metal will unite with 3 of the acid to form the *normal* salt, $Al_2(SO_4)_3$:—

$$2Al + 3H_2SO_4 = Al_2(SO_4)_3 + 3H_2.$$

Commercially it is made from the oxide, alumina, Al_2O_3 :—

$Al_2O_3 + 3H_2SO_4 = 3H_2O + Al_2(SO_4)_3$, corresponding to Al_2O_3, $3SO_3$ for the relations in the normal salt. But, as with many other metals, salts can be prepared containing less of the acid, and therefore a larger proportion of the metallic oxide. These are called *basic* salts, and some of them are soluble in water. There are several such basic sulphates of alumina, and they will evidently require less lime, or carbonate of lime, for saturation, than the normal salt, and will produce less calcium sulphate.

For example, omitting water from the equations :—

$$\overset{\text{Normal sulphate}}{Al_2O_33SO_3} + 3CaO = 3CaSO_4 + Al_2O_3$$

basic sulphate

$$Al_2O_32SO_3 + 2CaO = 2CaSO_4 + Al_2O_3.$$

Schmatolla * obtained the compound $(Al_2O_3)(SO_3)$, containing only $\frac{1}{3}$ of the normal amount of acid, by the action of calcium carbonate in the cold. A basic sulphate is made, according to H. Spence's French patent † 331836 of 1903, by mixing a concentrated solution of the normal sulphate of about 1·4 sp. gr. with a proper quantity of chalk, filtering off the precipitated sulphate of lime, and gently evaporating further, when "pure crystals of a definite basic aluminium sulphate are obtained," which are separated from the mother liquor by a centrifugal apparatus and dried ; they are said to be fairly permanent and freely soluble.

In general, however, these special preparations have the disadvantages of expense, doubtful stability, and difficulties in solution, so that the normal salt, $Al_2(SO_4)_3$, is commonly used as sold in blocks or granules, and is weighed and stirred with water to make a stock solution of known strength. The quantity of lime or chalk required to completely precipitate it, should always be ascertained by experiment with carefully averaged samples of each material, and the hardness of the water supply must also be periodically determined. It is clear that as so many variations in the constitution of the reagents and of the water under treatment occur, successful working will need to be always strictly quantitative. One grain of sulphate of alumina per gallon is often found sufficient, but more or less suits different conditions.

To treat drinking supplies chemically involves a natural fear that some of the chemicals may be left behind, and be injurious to the community. It has been said that alumina can be kept in solution by soluble organic matter, and this is the case with concentrated solutions, but is not observed with the very dilute conditions in water treatment. When the alumina-coagulation process is properly conducted, the whole of the base is retained, and the filtrate is free from alumina. This is verified by testing it with a solution of logwood, which gives with ordinary water a pink colour, but in presence of traces of alumina a purple. The logwood test

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* *Z. Angew. Chem.*, 1903, 202.

† U.S. Patent 754824 of 1904.

must be continually used, and will show at once when too much coagulant has been applied. Alumina salts have no physiological action beyond astringency, therefore an accidental excess would be generally harmless, but must be avoided.

Whipple * remarks that "sand filters are specially applicable to relatively clear waters and mechanical filters to waters that are turbid for a considerable portion of the time. In general, practice has followed this classification."

Many towns outside the United States now employ the so-called rapid or American filtration system using coagulants, generally on the muddy water of rivers. The mechanical filter is an enlargement of the principle of forming a filtering skin on our ordinary sand beds, but it makes the film entirely inorganic and very strong and tenacious, therefore a large head of water can be allowed, and a more rapid passage per square foot. Sand beds pass about two and a half million gallons per acre per 24 hours, while a mechanical filter passes about 100 million gallons per acre in the same time. With the latter there is obviously no time for organic solids to be broken down by bacterial action as with slow sand filters, and frequent cleaning is necessary. After clearing away the old film and washing out its supporting medium, a fresh supply of the coagulant is added, and at this rapid rate, in about ten minutes the filter is again ready.

The following curve illustrates the working of a mechanical filter as regards time-reduction in number of bacteria. It will be noticed that this proceeds rapidly during the first minute, then more slowly, until after ten minutes it reaches 90 per cent., with a gradual increase of efficiency afterwards.

The quantity of water that has to be wasted in washing out the old film and in forming the new one has varied between 2·5 per cent. and 5 per cent. of the total amount of water passed. The washing is usually done by reversing the flow and sometimes injecting steam, and occasionally soda, and in very muddy waters may be even required two or three

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* *Amer. Soc. Mech. Engineers*, Nov., 1912.

times a day. In some types, during the cleaning the sand or quartz is stirred round by vertical rods hanging from radial revolving arms. The gelatinous precipitate of hydrated alumina draws down with it the colloidal albuminoid putrescible matter, as well as up to 98 per cent. or even more of the bacteria, in addition to practically all the suspended matter whether organic or inorganic. Since settling down takes time and space, the rapid method strains the liquid almost at once through some finely divided medium, sand, crushed quartz, or coke which has passed through a 0·38 millimetre (0·015 inch) screen.

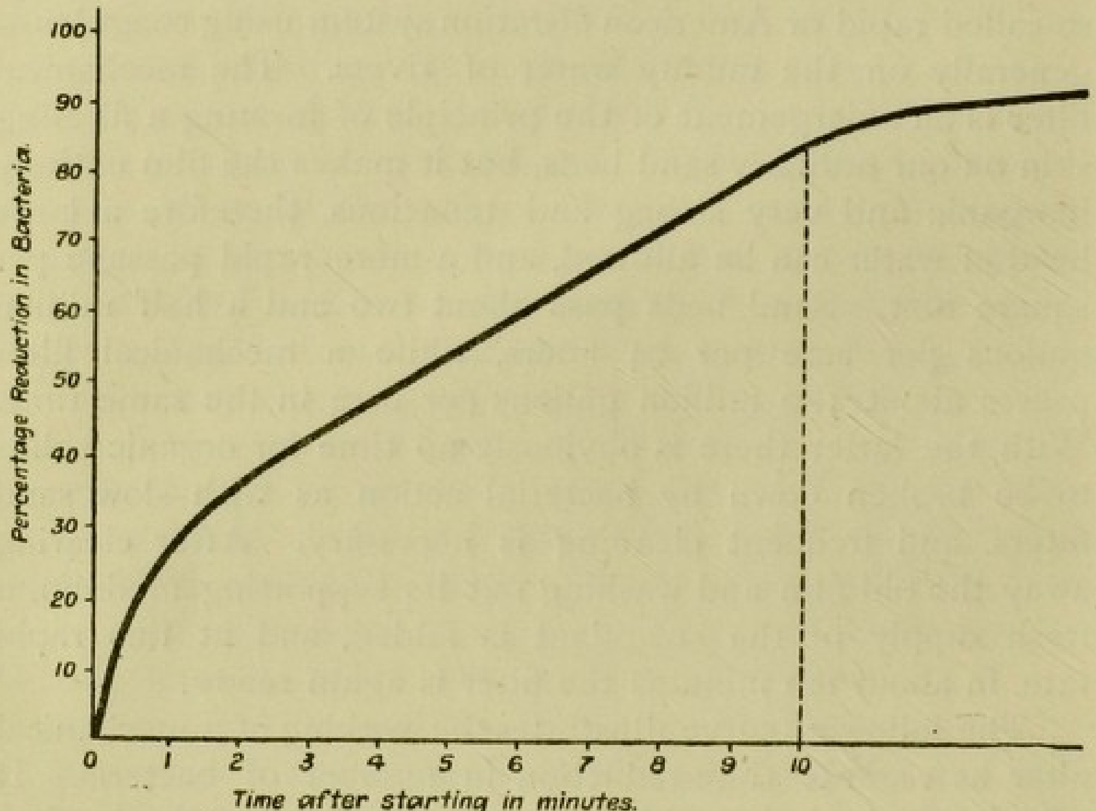
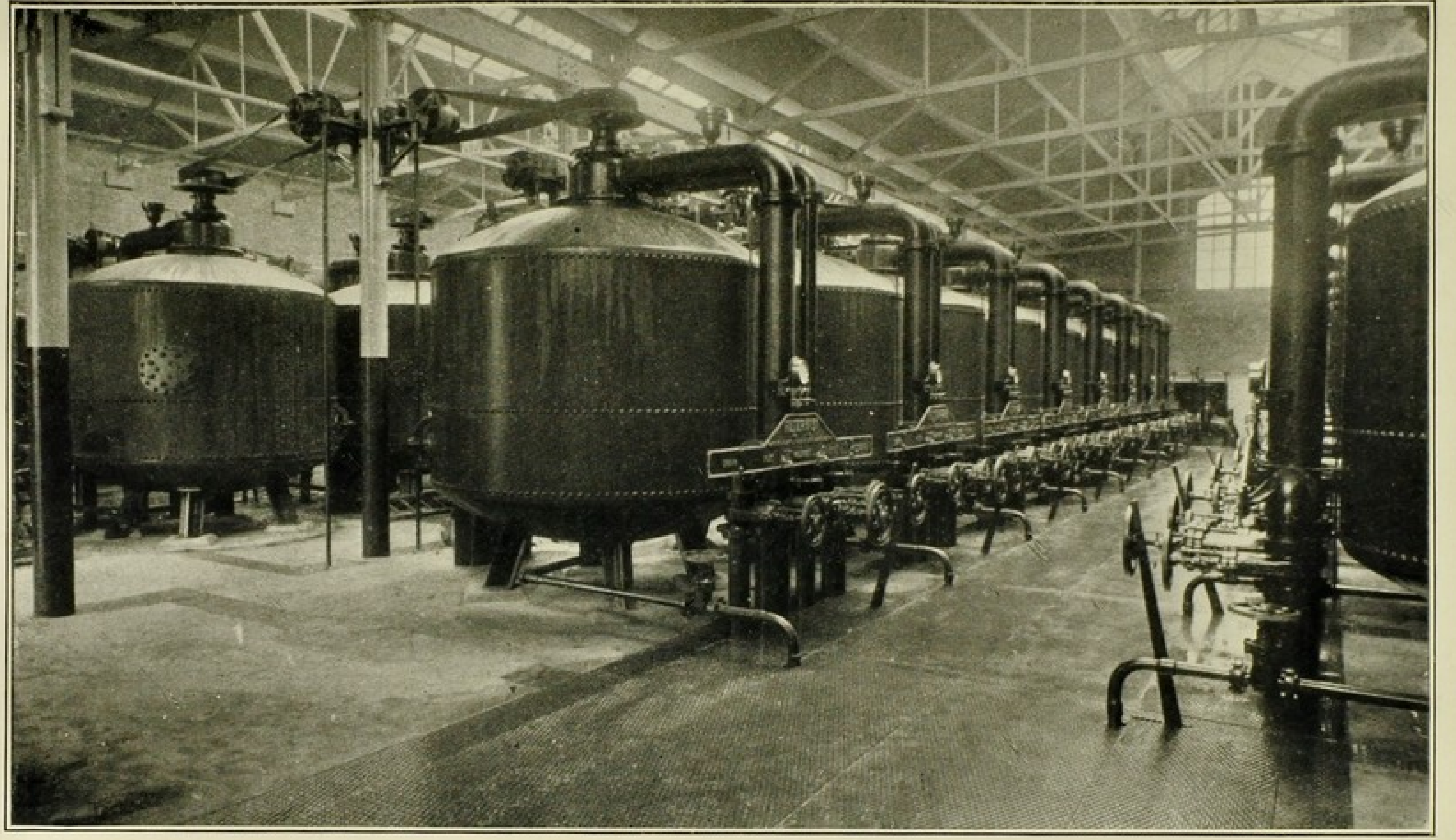


FIG. 5.—A curve showing the relationship between bacterial reduction and time of filming.

It is a disadvantage of the process, as we have noticed (p. 125), that it cannot be used for soft waters without auxiliary treatment.

Mechanical filters also lower the soluble organic matter: the reduction of the oxygen-consumed figure (Chapter XII) varying from 40 to 80 per cent., and there is often a marked decrease in the free and albuminoid ammonias.

PLATE XVIII.



INSTALLATION OF RAPID FILTERS FOR SHEFFIELD, MATHER AND PLATT SYSTEM.

[*To face p.* 128.

There are two main types of these filters :—

1. The "Gravity" form, open at the top, and allowing easy inspection and control, but at the same time involving a loss of head ;

2. The "Pressure" form, in a closed cylinder, which delivers the effluent at the entering pressure, except for friction, but is difficult to inspect and renovate. It is often used for private supplies, where it can be interposed on the mains.

The first form gives a better standard of purification and is the one in general public use. The filters are placed in a roofed building to protect from frost, and it is a benefit of the process that they can be better guarded from aerial and accidental contamination than can exposed sand beds.

Pre-Sedimentation,

as carried out in a number of the plants, sacrifices some of the rapidity, but has distinct advantages, one being that the mixing can be better arranged and controlled, another that time is allowed for the reaction with the coagulant, which is not instantaneous, and a third that the filter has not to be washed out so often. Instead of running the treated water directly on to the filter, it is allowed to subside in the settling tank for one to six hours, according to its character. If the period of rest is too long there will be an insufficient amount of colloid matter in suspension to form a surface film on the filter ; if too short the beds are liable to be unduly clogged. The tank is placed above the filter to preserve a head of water on the latter.

According to the investigations of Bitter and Gotschlich,* in the settling chamber 15 to 75 per cent. of the bacteria are eliminated. Schreiber † in his work with the Jewell filter found by this method a total bacterial reduction varying between 91·3 and 99·6 per cent. These papers state that the velocity of filtration may be as high as five metres per hour,

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* *Zeit. f. Hyg.*, 1908, lix, 397.

† *Mitteil K. Prufungs f. Wasservers.*, 1906, vi, 88.

i.e. about fifty times as fast as through an ordinary sand bed, and the pressure may be raised to 3 metres without any likelihood of film rupture. The quantity of coagulant varies with the water and is ascertained by experiment. In America 17 grammes per cubic metre (1·19 grains per gallon) is usual, Bitter and Gotschlich found 20 grammes a minimum, while 25 to 35 grammes were often required. Schrieber recommends an average of 33 grammes (2·3 grains per gallon).

In Great Britain 0·5 to 0·75 grain per gallon has been commonly found to be sufficient, increasing the amount now and then when the river from floods is made more turbid.

Pure anhydrous normal sulphate of aluminium, $Al_2(SO_4)_3$, contains 30 per cent. of Al_2O_3 and 70 per cent. of SO_3; the crystallised form $Al_2(SO_4)_3$, $18H_2O$ contains 15·4 per cent. Al_2O_3, 36 per cent. SO_3 and 48·6 per cent. H_2O; the commercial article usually contains about 17 per cent. of Al_2O_3.

As to aluminoferric, and iron oxides, see Chapter VI. The following are analyses of some coagulants:—

	Pure potash alum.	Alumina sulphate, commercial.	Alumino-ferric.	Sulphate of iron.
Matter insoluble in water .	—	0·30	0·06	0·50
Al_2O_3	10·77	17·00	14·26	—
Ferric and ferrous oxides .	—	0·25	0·60	57·50
Potash, K_2O	9·93	—	—	—
SO_3	33·76	38·70	35·81	28·80
H_2O	45·54	43·75	49·27	13·20
	100·00	100·00	100·00	100·00

Oxidising Filters.

Besides the simple straining off of suspended solids we have seen that other actions occur in filters, connected with absorption and with oxidation. It has been an object to assist each of these in two chief ways (1) by replacing the ordinary inert filtering medium, sand or crushed quartz, by one that has a higher absorptive power and also contains oxygen which can communicate itself to the percolating fluid ; (2) by forcing air through during transit. In the second process most of the energy is wasted, since unaided atmospheric oxidation is naturally slow, therefore the greater part of the oxygen escapes unabsorbed. By good ordinary ventilation it can usually be supplied as fast as it is consumed. At the same time the oxidation is decidedly more rapid when air and water are passed through a closed filter under pressure, because the solubility of the oxygen is increased and it comes in quicker contact with the organic matters. But the increase of effect has not repaid the expense.

In the first method certain porous compounds of metals such as iron or manganese, which have two or more oxides, are of great service through a carrier action, parallel with the well-known function of nitric oxide in vitriol chambers. They can give up to organic matter a part of their combined oxygen, becoming themselves reduced to a lower oxide ; which is then reoxidised by the air. These filters therefore must be worked intermittently, and allowed to stand empty at intervals for aeration. The processes can occur indefinitely as long as the material remains porous. At the same time such materials have a high absorptive power, so that their rate of purifying much exceeds that of silicious media.

It is to porosity and absorptive power that charcoal and coke owe what purifying activity they possess. The former great popularity of domestic charcoal filters will be remembered, and Wedekind * described good results on the large scale with coke-beds in waterworks. Chemical oxidation by the medium is, however, an additional factor.

For filtering materials the dense crystalline oxides found as natural minerals, *e.g.* hematite and pyrolusite, are quite as inert as silica, but it was many years ago discovered that they could be rendered active by heating under certain conditions with carbon in a furnace, when the cooled material contained lower oxides of the metal which could act in the above way as oxygen carriers, and diffused through a body of silica or carbon make it strongly oxidising. This was the principle of

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* Wedekind, *Proc. Mech. Engineers*, Lond., Jan., 1909.

the Bernays "manganous carbon" filter of 1870—manganese is about three times as active as iron, but too expensive for use on a large scale.

Another oxidising type is the Candy filter, which uses oxides of iron in preparations called "Oxidium" and "Polarite," said to contain respectively 11 and 54 per cent. of magnetic oxide of iron, with silicates of alumina, magnesia and lime. These filters, on the pressure system, with ingenious arrangements for washing, cleaning and aerating have been worked successfully in a number of towns, with good chemical and bacterial results. The average volume of water required for washing is said to be $\frac{1}{200}$ of the total amount treated.

There are many special forms of mechanical filters, differing in structural details and modes of working, particularly of washing the sand. Most of the firms now make both the open gravity and the closed pressure types. Tables comparing the different makes are of little use, as they refer to individual installations. We may mention the Jewell, Bell, Paterson, Turn-Over, Reisert, and Mather and Platt. The Ransome filter embodies the use of continuously moving sand.

Mechanical Filtration is the prevalent system in the United States, where it is said that 70 per cent. of the water supply is thus purified. In Canada it is largely used, and in Europe there are many installations. The city of Alexandria, Egypt, is supplied daily with upwards of 10 million gallons of Nile water purified by mechanical filtration at the works completed in 1910. In India a number of the military stations are using it, and the works at Mysore purify in this way 2 million gallons daily. In England one of the first installations was that which still supplies the city of York with nearly 6 million gallons per day: a detailed description is given by Mr. W. H. Humphreys, who superintended the construction, in his presidential address to the Association of Water Engineers. (See *Water*, Oct. 15th, 1910.)

Domestic Filtration.—It is well known that the earlier types of household filters, although they improved waters physically, could not be trusted to eliminate all the minute organisms which were capable of causing chronic ill-health or even acute disease, and that the only filter giving complete security is the Pasteur-Chamberland porcelain "candle" kept scrupulously clean. This has the fault of a slow delivery except with extra pressure, and several more rapid forms, of nearly equal efficiency, have been introduced. All of them obviously require cleaning at intervals. Some are attached directly to the tap, thereby receiving pressure from the main, but the method is unsafe, as the rate is apt to be often too rapid for the filter to have any chance of purifying. At the same time, when carefully controlled, good results have been obtained.

Experience with filters, generally, has shown that the filtering medium need not be a micro-membrane or a partition with interstices of microbic or sub-microbic dimensions, provided that the material used in construction has the power of absorbing the organisms, and that the rate of filtration is controlled. This point has been demonstrated by Hofstaedter in Germany, also by Bullock, Craw and Anderson, and is technically of great importance, since fineness of membrane diminishes rate of filtration, and it is very difficult in the manufacture to make the material perfectly homogeneous.

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CHAPTER IX.

SOFTENING OF WATER.

THE term "hard" as applied to water had primarily reference to the harsh or hard feeling in washing the hands with soap, when instead of forming a smooth elutriant coating which removes grease and dirt, the lather disappears and there is a curdy appearance in the wash-water. This consists of insoluble compounds of the earthy metals in the water (mainly calcium and magnesium) with the fatty acids in the soap. The subject involves a knowledge of the following reactions.

Saponification.

Most natural fats and fatty oils consist almost wholly of the glyceryl esters of the higher fatty acids, palmitic $HC_{16}H_{31}O_2$, stearic $HC_{18}H_{35}O_2$, and oleic $HC_{18}H_{33}O_2$, which are, as fats, insoluble in water. To make ordinary soap, the fats or oils are heated with caustic soda, NaOH, and water, when the esters are broken up into glycerol ("glycerine"), $C_3H_5(OH)_3$, and sodium salts of the fatty acids. Taking stearin (glyceryl stearate) as a type, the reaction, called saponification, is :—

$$\overset{\text{stearin}}{C_3H_5(C_{18}H_{35}O_2)_3} + \overset{\text{soda}}{3NaOH} = \overset{\text{(stearic) soap}}{3NaC_{18}H_{35}O_2} + \overset{\text{glycerine}}{C_3H_5(OH)_3}.$$

On adding hot water the whole dissolves. A separation is made by "salting out," that is, adding common salt, NaCl, until the soaps are precipitated, when the glycerine remains in solution and is removed in the brine. The soaps are lightly washed, pressed, redissolved in hot water, evaporated, melted and cast into the usual forms. These are "hard soaps"; in "soft soap" the basis is potash. With a large quantity even of pure water, soaps dissociate more or less completely into free alkali and fatty acid, forming an emulsion, and to this the detergent properties are due. But, as stated above, when the water contains compounds of calcium, magnesium, or the heavy metals in solution, these form insoluble salts with the fatty acids, and produce the curdy precipitate, which has little or no detergent power.

Examples of the reactions for temporary and permanent hardness are, taking different soaps and bases :—

$$\overset{\text{(stearic) soap}}{2NaC_{18}H_{35}O_2} + CaCO_3 = \overset{\text{insoluble calcium stearate}}{Ca(C_{18}H_{35}O_2)_2} + Na_2CO_3$$

$$\overset{\text{(palmitic) soap}}{2NaC_{16}H_{31}O_2} + MgSO_4 = \overset{\text{insoluble magnesium palmitate}}{Mg(C_{16}H_{31}O_2)_2} + Na_2SO_4.$$

Therefore with hard waters the soap has to be supplemented by the use of "washing soda" (carbonate) or other soluble alkaline substance: borax may be mentioned as about the mildest. None of them have as good an emulsifying or cleansing power as soap itself. An alternative is to use more soap: in any case there is corresponding waste, since soap has to be added until all the calcium and magnesium salts are used up. Hardness is usually recorded in degrees Clark, that is, the equivalent of carbonate of lime in grains per gallon. The above equations show that for every degree of hardness between eight and nine pounds of soap are wasted per 10,000 gallons of water.

The greasy insoluble deposits cause fouling of sinks and blocking of drain pipes. They are a difficulty in sewage works. It has been suggested that a soap could be made with acids forming soluble salts with calcium and magnesium, but such has not yet been found. The common remedy at present is to "soften" the water by removing lime and magnesia.

A large number of analyses of British waters are contained in the reports of the Rivers Pollution Commissioners between 1865 and 1874. They broadly distinguished three classes as affected by the source :—

(*a*) *Soft*, from igneous rocks: dissolved solids up to 3 parts per 100,000.

(*b*) *Moderately hard,* from sandstones and shales: ditto about 15.

(*c*) *Hard,* from chalk and limestone: ditto up to 77·5.

The hardness is of course below these figures, but follows in about the same proportions.

The Table in Appendix shows how these values run. If the hardness is much below the solids, it points to the presence of alkaline salts.

Varieties of Hardness.

Total hardness is divided into *temporary* and *permanent.*

Calcium and magnesium carbonates are almost insoluble in water, but in the presence of carbonic acid derived from the carbon dioxide in the atmosphere (which contains about 4 parts per 10,000 of CO_2) and also from oxidation of organic matter, they dissolve in the form of unstable, yet quite definitely-constituted bicarbonates, which change can be represented by the following equations:—

$$\overset{\text{carbonic anhydride}}{CO_2} + H_2O = \overset{\text{carbonic acid}}{H_2CO_3}$$

$$\overset{\text{calcium carbonate}}{CaCO_3} + H_2CO_3 = \overset{\text{calcium bicarbonate}}{CaH_2(CO_3)_2}$$

$$\overset{\text{magnesium carbonate}}{MgCO_3} + H_2CO_3 = \overset{\text{magnesium bicarbonate}}{MgH_2(CO_3)_2}$$

Very nearly all natural waters contain these earthy bicarbonates. When the liquid is boiled, an escape of gas will be noticed; the bicarbonate is gradually decomposed, CO_2 is evolved, and the carbonate again become insoluble and is thrown down as a white precipitate, with a corresponding loss of hardness. The quantity of calcium and magnesium salt deposited on boiling constitutes what is termed the "temporary hardness" of the water.

The rate of decomposition and precipitation varies in different waters. The following are two examples of the progress of this reaction:—

London tap water.		Letchworth water.	
Minutes boiled.	Hardness left.	Minutes boiled.	Hardness left.
	(Degrees, Clark.)		(Degrees, Clark.)
0	15·4	0	18
3	10·6	—	—
6	8·5	—	—
10	6·5	10	8
15	6·0	15	7
20	5·5	20	2·6
25	5·4	25	2·1

On the other hand, the sulphates, chlorides, and nitrates of calcium and magnesium are soluble in water and therefore not precipitated on driving off CO_2. They remain in solution and form the "permanent hardness," or hardness after boiling. The distinction is a practical one and details of the test will be given in Chapter XII.

For purposes of comparison, both forms of hardness are recorded in terms of the amount of dissolved carbonate of lime that would decompose and precipitate the same amount of soap. Hardness as already mentioned is customarily* recorded in "degrees Clark," *i.e.* grains of carbonate of lime per gallon equivalent to the soap-destroying power of the water under examination. From this number the parts per 100,000 can be obtained by multiplying by 10 and dividing by 7.

In Germany the degree of hardness is defined as equivalent to ten milligrammes of anhydrous lime, CaO, per litre. So that 1 degree Clark = 1·43 parts of $CaCO_3$ per 100,000 = 0·80 degree German.

The natural presumption that the hardness of rivers is less when the water is high, because there is more rain water, is not always justified, since the washings of land are often very hard.

The influence of hard waters will be discussed in two sections.

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* Officially, in British water reports, according to a decision of the Local Government Board, in Aug., 1911.

I. Physiological.

There are more than enough mineral constituents in food to supply the amount necessary for bodily growth. But it has been recently contended that "oligodipses"—a new word meaning those who drink little—starve their bodies of mineral ingredients, since the necessary mineral constituents are more easily assimilated from water than from food, because in the former they are directly diffusible and ready for immediate absorption. Statistics as hitherto collected show that the hardness of the water supply does not produce any perceptible effect upon the mortality. Gaertner states [*] that the village of Bürgel, in the Thuringerwald, has always drunk with impunity from time immemorial a water with the extraordinary hardness of 129 degrees Clark, of which 110° is calcareous and 19° magnesian. He also cites Göttingen with 56° and Würtzburg with 37·5°.

There is, however, a balance of evidence that very hard waters produce a prevalence of gouty and calculous disorders and goitre. In new comers they cause gastric and intestinal disturbances. Every one knows how the human body can become habituated to surroundings. In transference of habitat a change of water has frequently as much influence as a change of air.

On the other hand, very soft waters, besides being less palatable, are not wholesome. Rose said, about 1680, "it is important that the drinking supply should have chalk in it, because a very soft water helps to decay the teeth and has an injurious effect on bodily growth, and also on the military resistance of men and the suckling power of women."

Recent investigations by surgeons in the French Navy have led them to the opinion that the continued use of distilled water for drinking is prejudicial on account of the absence of the mineral salts necessary for bodily nutrition. They attribute numerous cases of tubercular conditions among the sailors to demineralisation of the water. Experiments

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[*] *Klin. Jahrsb.*, ix, 1902.

on animals are in progress to definitely prove the point, and to see how far it can be remedied by restoring the mineral salts.

Dr. John C. Thresh, Medical Officer of Health for Essex, in a *Lancet* article, October 11, 1913, on "Hard *v.* Soft Water," gives a series of tables from the county records, which he has summarised as follows :—

Character of water supply.	Districts.	Death-rate per 1000	
		1907 to 1911.	1912.
Soft (under 7° Clark . . .	Leigh, Maldon, Southend, etc. .	11·0	10·0
Hard (14 to 21° Clark) . .	Metropolitan . .	11·1	10·6
Ditto	Country towns .	11·2	9·9
Moderately hard (7 to 14°) .	South Essex . .	11·2	9·9
Ditto	Country towns .	11·5	10·9

This indicates no co-relation between hardness and death rates, and he adds, "In my 1910 report I also showed that the tabulated results gave no indication of the hardness or softness having any bearing on the prevalence or mortality from cancer, phthisis, or enteric fever." But he notes, as important, that the soft waters of Essex differ materially from soft Moorland and Upland waters, which contain very little saline matter and are often acid, whereas, those of Essex contain sodium bicarbonate, and, therefore, are alkaline in character. "The inquiry shows that such waters are perfectly wholesome." The same view is upheld in a paper by Percy Lewis, read at the Folkestone meeting of the Royal Society of Medicine, 1911. See an abstract in the *San. Record*, June 15th, 1911, p. 556.

On the whole, a moderately soft water is most hygienic. Very soft ones, as a class, have the very serious fault we have already described—that they are plumbo-solvent,—and very hard ones are certainly conducive to the disorders we have mentioned.

Effect on Plants.—It is well known that soft water is best as most assimilable, and gardeners use preferably rain water unless it is sooty, as in towns. Hard water forms a crust on the leaves which blocks the pores and hinders transpiration and respiration.

Speaking generally, it is difficult to set a maximum limit for the amount of hardness a water may contain and yet be considered satisfactory. In the American lake cities 10 parts per 100,000 (7° Clark) is approved, yet in Eastern Atlantic cities, according to Geo. A. Johnson, this is thought too high. It would be pronounced quite moderate hardness in Europe. Municipal softening of the public supply is carried out in a number of American cities, notably Columbus, Ohio, where it was adopted in 1908, on their finding that it rendered the water good both commercially and bacterially. The total hardness of the Scioto river there varies from 4 to 37 parts at different seasons, averaging 22. It is softened to a limit expected to be not over 10 parts: in 1912 it averaged 7·9.

About 1900 Sir W. Crookes and Sir Jas. Dewar recommended the London Water Companies to adopt a similar plan, but it was alleged that the cost of getting rid of the precipitated lime was absolutely prohibitive.

As examples of English towns, the water at Nottingham and Wolverhampton is between 8° and 10° hardness, whilst at St. Helens it is 23° before the softening treatment and 10° after. The Bristol supply from springs in limestone and wells in sandstone averages 18°. Kent waters from the chalk have 16° or 18°, while Mid-Kent from the greensand has about 10°. At Liverpool well-supplies had hardnesses as high as 21° (Green Lanes); in the present supply from Lake Vyrnwy it is only about 1·7°. The London Metropolitan Water Board supply has a general range between 16° and 17°.

II. Industrial.

Here the disadvantage of hard waters is much more evident. Even when only used for cooling, they lessen the effect by producing gradually a non-conducting coat on the tubes, as the interior heat causes liberation of CO_2 and deposition of earthy carbonates. In textile industries more soap, or supplementary alkali, has to be employed ; the fabric is injured and insoluble earthy soaps are left on the fibres. Nearly all great manufacturing centres except London have soft supplies. One grain of calcium carbonate (chalk) wastes 8 grains of soap. Glasgow is estimated to save £30,000 annually in the matter of soap since using Loch Katrine water, the hardness of which is under a grain per gallon.

In cooking, a hard water is objectionable, as a deposit of lime salts is formed upon the surfaces of tea leaves, meat, vegetables, etc., which hinders their extraction or hardens their tissues. It has been asserted that "ten ounces of tea made with soft water is as strong as 18 ounces brewed with hard water" ; and M. Soyer, in his evidence before a Royal Commission, proved that in the making of soup more meat is required with a hard water, and the operation takes a longer time. Vegetables have their colour darkened by the action of the carbonate of lime. For these reasons it is a common practice to add a little bicarbonate of soda in culinary operations, but in this way more colouring matter and other constituents are dissolved out, a good thing for a soup, but bad for ordinary boiled vegetables.

In baking, the dough rises better, and bread is lighter in colour, when soft water is used.

Brewers and distillers find a soft water very desirable for many of their purposes. When the water has a high temporary hardness, the refrigerators become coated, as above explained, with a non-conducting scale of carbonate of lime mixed with organic matter, which is often very thick and difficult to remove. Another point is that the presence of a large quantity of carbonate of lime makes the water alkaline, and so hinders the fermentation and favours the growth of unhealthy organisms. *Permanent* hardness, on the other hand, seems a condition for the brewing of light-coloured ales, and Burton has gained its reputation from the sulphate of lime which is present in the waters of the Trent and wells in the neighbourhood. So much is this the case that, in other localities, sulphate of lime, as gypsum, is added by the brewer when the water supply is deficient in this ingredient.

Incrustations in Steam Boilers

are obviously promoted by water hardness. In lowering conductivity they hinder the raising of steam, besides causing the metal of the boiler to be overheated. Rankine's figures are that calcium carbonate conducts heat eighteen times as badly, and calcium sulphate fifteen times as badly, as iron, and it is estimated that one-sixth of an inch of scale necessitates the use of 16 per cent. more fuel; $\frac{1}{4}$ inch 50 per cent., and $\frac{1}{2}$ inch 150 per cent. additional coal. If under these circumstances of overheating a crack occurs in the boiler crust, the water suddenly penetrates to the superheated metallic surface, and explosions have often followed. There is also the trouble and expense of periodically removing the crust with risk of injury to the boiler.

When heated under pressure the reactions are somewhat different from those that occur in ordinary boiling. The carbonic acid is less easily liberated, therefore the carbonate of lime is deposited more slowly, and is denser. From waters whose hardness is mainly temporary, the deposit forms warty detached and fairly friable masses, besides a crust which is not strongly adherent to the metal. But the "selenitic" class, or those heavily charged with calcium sulphate, and also those in which magnesium chloride, sulphate, and nitrate are predominant, give rise to a hard and crystalline incrustation, much more dangerous and difficult to remove. Chloride of magnesium is dissociated by the heat according to the equation:—

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl.$$

The magnesium hydrate is deposited in the crust, while the hydrochloric acid evaporates with the steam, and is very corrosive to metallic surfaces. This decomposition is retarded by the presence of alkaline chlorides, which form stable double chlorides with the magnesium salt, such as the sodium chloride compound, $MgCl_2$, NaCl, H_2O (*Comptes Rend.*, xx, 1130), remaining even on evaporation to dryness. Therefore it has been proposed to hinder the hydrolysis by adding common salt, but it is far preferable to soften the water before entering the boiler. The ordinary Clark's process of softening with lime is not so effective with magnesian waters, because carbonate of magnesia is more soluble than carbonate of lime, consequently more magnesia remains unremoved. But a great improvement is often effected.

A very large number of patents have been taken out for the prevention of boiler incrustations; some of them are mechanical, introducing wires, chains, or brushes to entangle the deposit. The electrical generation of hydrogen on the boiler plates, by means of the electric current has also been attempted but without coming up to expectations as a scale remover. Tanninoid and mucilaginous organic materials act mechanically in rendering the crust looser, but they clog the boiler, promote priming and foaming, and furnish so much more solid matter to remove. Tallow and fat oils are to be condemned, not only because they form greasy lime—and magnesia soaps which agglomerate into hard concretions, but because by the heat and pressure they are hydrolysed, the resulting fatty acid acting on the boiler plates. The scale where tallow is used has been found to contain 12 to 26 per cent. of iron from the plates. Paraffin oil causes the deposit to be thrown down in a pulverised form by incrusting the particles with a very thin oily coating. Such a deposit is easily blown, and its use is unattended by priming or frothing. Its action is, however, only temporary, as it passes off with the steam and requires constant renewal. Soda-tar, from paraffin-refining, containing sodium carbonate and sodium hydroxide, is a well-known anti-incrustator. In excess it is liable to cause foaming and wet steam, especially in locomotives, and is apt to corrode the fittings, particularly asbestos packing. Grease of any kind in boilers should, as far possible, be avoided, for the film of oil is an exceptionally bad conductor. If derived from the condenser it is best excluded by passing the feed water through a feed filter, kept clean by "blowing through" occasionally.

Tri-Sodium phosphate, Na_3PO_4, called "Tripsa" (Davis's English patent 5655, 1887), gives good results, especially for softening magnesian waters, in the proportion of 2½ grains per degree of hardness, and it has been proposed to sell the resulting earthy phosphate as manure. In Germany barium chloride has been added to the feed-water in order to turn the calcium sulphate into soluble calcium chloride, leaving a pulverulent precipitate of barium sulphate. A. Nieske * employed chromates as incrustation preventers, the calcium carbonate and sulphate being decomposed under pressure, yielding a light non-adherent sludge of calcium chromate, easily removable by blowing, and recoverable as a chromic pigment. Spent waste from chrome dyeing has been used for this purpose.†

Removal by Fluorides.—Doremus gives the following prescription for preventing scale: "Determine the lime and magnesia in the water; multiply the CaO by 1½ and the MgO by 2. The sum gives the amount of sodium fluoride required to throw down the lime and magnesia. One-fourth of this quantity suffices, as the earthy fluorides do not adhere, but form nuclei for the other hardening salts to deposit. Two ounces per 1000 gallons is the average quantity added to the feed."

Any chemical reagent is better added outside the boiler before the water enters. Even if used in the feeder-heater it is liable to choke up the tubes, and require continual removal of deposit. In any case the compound and the water it is intended for should always be analysed at intervals, as variations in the water and in the commercial article make stereotyped prescriptions delusive. Much money is spent on "incrustation preventers" which would better go to preliminary softening.

Removal of Temporary Hardness.

We have already explained how this is attained by boiling, but, as ordinarily carried out, the process is expensive, causes a loss of water, and the product is of flat taste because the

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* *Wochenschr. f. Brauerei*, 1895, 215.

† Tatton, *Proc. Inst. Civ. Eng.*, 1900, 409.

dissolved gases are driven out. Boiling is said to cost not less than a shilling per 1000 gallons.

Clark's Method, patented by Dr. Clark, of Aberdeen, in 1841, adds lime water to neutralise the excess carbonic acid which keeps the earthy carbonates in solution as bicarbonates. The results may be expressed as follows :—

$$\underset{\text{calcium bicarbonate}}{H_2CO_3 . CaCO_3} + \underset{\text{slaked lime}}{Ca\,(OH)_2} = 2CaCO_3 + 2H_2O.$$

$$\underset{\text{magnesium bicarbonate}}{H_2CO_3 . MgCO_3} + Ca\,(OH)_2 = MgCO_3 + CaCO_3 + 2H_2O.$$

By the first reaction all the lime present in solution as bicarbonate is thrown down as carbonate, with the exception of about 2 grains per gallon which remains dissolved.

The second reaction seldom throws down any magnesia (except a small quantity adherent to the carbonate of lime) because magnesium carbonate is soluble in cold water to the extent of about 28 grains per gallon. With excess of lime, magnesium hydrate, which is less soluble, may be precipitated.

Therefore the treated liquid retains the permanent hardness *plus* about 2 grains per gallon of $CaCO_3$, and a great part of the magnesia. The precipitate carries down heavy metals such as iron and manganese, and also entangles much of the organic matter, organisms and mud, so that a great improvement is almost always gained.

Sedimentation afterwards in reservoirs or tanks is attended with the disadvantages that the precipitate is rather slow in subsidence and apt to rise, and some of it is redissolved by CO_2 absorbed from the air, hence it is better dealt with by a battery of pressure cloth filters, which are very easily cleaned. The carbonate may be air-dried and re-burnt for lime.

Inasmuch as stones, rubbish, and impurities embarrass the process and add uselessly to the quantity of sludge that has subsequently to be dealt with, the quicklime purchased should be of good quality, containing at least 90 per cent. of free CaO. It is slaked in the usual way with water, when it passes into calcium hydrate, $Ca(OH)_2$, which is soluble in about 900 parts of water (78 grains per gallon), so that if the quicklime is of the above good strength, 1 lb. of the slaked lime will make 80 gallons of saturated lime water. On exposure to air a skin of calcium carbonate forms on the surface through absorption of CO_2 from the atmosphere ; this film for a time protects the liquid, but gradually all the lime becomes carbonated and deposited. Therefore lime-water tanks must be as far as possible air-tight, and measurement and delivery must be quickly managed with minimum exposure. Wooden vats are not suitable for storage, since the wood becomes more or less softened, and brown matters pass into solution. Zinc is apt to be dissolved from galvanised iron, and most oil-paints are attacked and contaminate the liquid with lead. Cement tanks alter the composition of the liquid, and the only ones generally proof against it are those made of slate. It will be seen that lime water is rather difficult to store, and very liable to deteriorate, hence there is a great advantage in making it fresh as wanted.

In general the lime has three distinct reactions to complete :—

1. It must absorb the free CO_2, and as water can dissolve its own volume of this gas, a considerable quantity of lime may be used up for this purpose alone.

2. It has to combine with the half-bound CO_2 of the bicarbonates, as shown in the above equations.

3. It may be required to transform magnesium carbonate, chloride or sulphate into magnesium hydrate.

It follows that the proper dose of lime water is often rather higher than the amount calculated from the temporary hardness as found by the soap test, and must be directly ascertained by trial on a measured sample of the water. One or two drops of phenolphthalein tincture are added, and the lime water is run in from a burette until the agitated liquid becomes faintly pink, indicating a slight excess of lime. A little below this proportion will be sufficient for the water, since it must not contain an excess of lime after treatment. Another test is a solution of nitrate of silver, which gives with free lime a brown colour (silver hydroxide) easily distinguished from the white precipitate of silver chloride produced by ordinary waters.

The Porter-Clark modification mixes the lime with the water by paddles, and then passes the mixture through cloth filters. By allowing the lime-water to flow in at a constant rate checked by occasional testing the softening process can be made continuous. An intermittent system consists of two lime-water tanks in which the lime-water is prepared one day and used the next, and three softening tanks, of which two are for use on alternate days, and the third is for reserve while cleaning out. The lime-water is run into one of the tanks, and the hard water pumped in ; next day the carbonate of lime has been deposited, and the clear water is run off for use.

Geo. A. Johnson's report (see Bibliography, last Chapter), tabulates the total hardnesses in sixteen U.S. cities, from 58 parts per 100,000 (41° Clark) at Warren, Ohio, to 9·5 parts (6·6°) at New Orleans. The figure generally increases during the months of low stream flow, and lessens during high-water periods. For softening, lime water must be used, and not milk of lime, because with the latter the suspended particles of calcium hydrate becomes coated over and are rendered inactive. He describes the "lime saturators." Water softening is not widely practised in America except by private industries. A list is given of cities where the public supply is softened, commencing with the largest and most complete installation at Columbus, Ohio, in 1908, described chemically in *J. Infect. Diseases*, May, 1909. The general prescribed aim is to reduce the hardness to about 2·5° Clark.

The purpose of the "Excess Lime" method of treating water is primarily germicidal, and only secondarily and incidentally for softening, hence it will be dealt with in the next chapter. As a preface to his description of this method, Dr. Houston, in the Eighth Research Report of the Metropolitan Water Board, February, 1912, discusses the economics of the Clark process, and maintains that the saving in soap by removal of earthy salts from the water is generally less than has been calculated, because the calculations assume that in washing a permanent lather must be produced, whereas he finds that in practice this is only needed on the actual spot required to be cleaned, the rest of the water being used for rinsing. In an experiment, ten people washing their hands only reduced the water-hardness from 20·6 to an average of 18·28, equal to 11·26 per cent. "It is admittedly different in the case of washing clothes and various scouring operations, but even here there is always a tendency to bring a minor volume of water into relation with the soap, and to employ the major portion for rinsing purposes."

Removal of Permanent Hardness

is required by many waters used for boilers and in manufactures, and is of service in some drinking supplies. Sodium hydrate (caustic soda) or carbonate of soda, and sometimes other alkaline mixtures are added in composition and amount depending on the chemical characters, with or without the accompanying addition of lime. Working must always be judged by trials on samples, but the following approximate rules will assist :—

RULE I.—For a water in which the temporary hardness exceeds the permanent, caustic soda must be added equivalent to the permanent hardness, and lime equivalent to the temporary hardness minus the permanent hardness.

RULE II.—For a water in which the permanent hardness, due to compounds of lime, exceeds the temporary hardness, carbonate of soda must first be added in proportion to the permanent hardness, and then, if necessary, lime equivalent to the temporary hardness.

As with lime, the quality of each batch of the reagents must be tested, and allowance made for impurities. Each degree of hardness is equivalent to 0·56 of CaO, 0·74 of $Ca(OH)_2$, 1·06 of anhydrous Na_2CO_3, or 2·86 of the crystallised carbonate, Na_2CO_3, $10H_2O$.

Waters containing exceptional amounts of magnesium salts possess special difficulties. With soda or carbonate of soda the separation of magnesium hydrate is never complete, and addition of lime generally increases the proportion of calcium sulphate, which is very objectionable in steam boilers.

The magnesium can be almost entirely got rid of by precipitation as phosphate or fluoride, and two preparations for the purpose are "Tripsa," Na_3PO_4, already mentioned, and Doremus's double phosphate and fluoride, Na_3PO_4, NaF, $12H_2O$. The precipitate is of some value as manure.

For cheapness, caustic soda is often added indirectly by running in lime mixed with a solution of commercial soda-ash (crude sodium carbonate), when the reaction occurs :—

$$Na_2CO_3 + Ca(OH)_2 = CaCO_3 + 2NaOH.$$

But the additional calcium carbonate so precipitated evidently increases the amount of insoluble matter that has subsequently to be removed. For this reason it is generally better to use a definite quantity of caustic soda itself.

Heating greatly facilitates the process by rendering the precipitate granular and dense. The following are examples of results with some difficult waters of treatment with soda :—

	I.	II.	III.	IV.
Original water :—				
Total hardness	43·6	28·7	65·1	18·6
Temporary do.	23·2	14·4	46·4	9·9
Permanent do.	20·4	14·3	18·7	8·7
Total hardness—after treating :—				
Cold treatment	12·0	12·8	—	8·1
Hot treatment	7·5	—	8·8	7·2

The reagents, as in other cases, should always be added quantitatively. An excess of alkali gives a tendency to "priming" or foaming.

Priming is the technical term for the difficulty that occurs from the liquid boiling irregularly and violently, so that globules of water are carried along with the steam into the cylinder, which is a great trouble.

In a paper of Sept. 1909,* Mr. G. Hughes, chief mechanical engineer to the Lancashire and Yorkshire Railway, describes

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* *Proc. Inst. Mechan. Eng.*, 1999, p. 609.

some investigations as to the cause of priming. He found that the design of the boiler had little effect, and that priming depended on the quantity of soluble salts in the water evaporated. Two waters experimented upon contained :—

	No. 1. Grains per gallon.	No. 2. Grains per gallon.
Calcium carbonate	4·9	3·8
Magnesium carbonate	0·5	0·5
Calcium sulphate	3·7	3·2
Magnesium sulphate	2·5	2·0
Oxide of iron and aluminium	0·1	*nil*
Total scale-forming matter . . .	11·7	9·5
Sodium chloride	5·7	2·8
Total dissolved solids	28·0	16·0

Although the total dissolved matter in No. 1 is much greater than in No. 2, as far as scale-forming constituents are concerned, there is no great difference. But at the same rate of boiling No. 1 caused priming much sooner than No. 2, and it is concluded that scale-forming constituents are not the cause of the fault. The question of the soluble salts was then considered, very accurate measurements being made of the water collected and evaporated and of the amount of solids carried into the boiler. It was found that there was a gradual concentration of soluble salts (chiefly sodium sulphate) up to the point of priming, as is shown by the following table. The figures are the soluble salts in grains per gallon.

	1st day.	2nd day.	3rd day.	4th day.
A. . .	46 No priming	117 No priming	164 No priming	210*
B. . .	127 ,,	194 ,,	269 Bad	—
C. . .	184 ,,	266 Bad	—	—
D. . .	132 ,,	230 ,,	—	—

These results, from boilers of different types, point to the conclusion that priming does not occur as long as the

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* Signs of priming, so boiler washed out.

dissolved matter in the water in the boiler does not exceed about 200 grains per gallon. Excess of saline matter causes pitting through electrolysis. "If soda softening be carried below 4°, there is corrosion" (Dolby, in discussion on above paper). On the other hand, free alkali, *per se*, rather protects the iron, as the metal becomes passive in alkaline solutions.*

Permanent hardness costs about nine times as much to remove as temporary. Maignen † used a mixture of lime, sodium carbonate or sodium hydroxide, and alum; the latter on dissolving gives sodium aluminate, which aids in the precipitating and clarifying.

The Permutit Process

was introduced by Dr. Gans, of Berlin, as an application of his geological researches on the class of rock-minerals called *zeolites*, consisting of hydrated silicates of aluminium and alkalies. He succeeded in producing zeolites artificially by his patent of 1906, and named his product "permutit," from "permutare," to "exchange," on account of its power of exchanging the base for other bases. Sodium-permutit can be converted into calcium-permutit, magnesium-permutit, potassium-permutit, etc., by passing through it solutions of calcium, magnesium or potassium salts. An important corollary is that a reversion can occur; for instance, if through the calcium-permutit so formed a solution of a sodium salt is passed, sodium-permutit is regenerated and soluble calcium salt is liberated in the liquid, so that the medium can be revived, and the earthy salts washed out. The application to water softening is well described by Dr. J. F. Meyer.‡ If a hard water is passed through a bed of sodium-permutit, the sodium in the latter is replaced by the calcium and magnesium taken from the water, and a calcium-magnesium permutit is retained in the bed, while the acid radicles originally united

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* See an investigation by Traube, *Berichte*, xviii, p. 1877.

† *J. Soc. Chem. Ind.*, 519, 1891.

‡ *Inst. Munic. Engineers*, May, 1912.

to calcium and magnesium in the water unite with the sodium which is turned out of the permutit, so that the hardness is correspondingly reduced, it may be to nearly zero.

Gans's artificial zeolite, "sodium-permutit," is made by Riedel of Berlin, by fusing a finely-powdered mixture of silica (quartz), alumina (or kaolin, aluminium silicate), and sodium carbonate, and afterwards treating with water. It is a crystalline body of the formula $Na'Al'''(SiO_3)''_2, 2H_2O$, a hydrous meta-silicate of sodium and aluminium, allied to the natural zeolites analcime, gmelinite and sodalite, and having the percentage composition, silica 46, alumina 22, sodium oxide 13·6, combined water 18·4. Commercially the material is now made by fusing together felspar (which introduces some K), kaolin, clay, and soda. The action of the medium gradually lessens as it absorbs the earthy bases and would finally cease when they had replaced all the sodium. Hence the bed is regularly "regenerated" by the reverse reaction indicated above, proceeding as follows: "the cylinder through which the water is made to flow with a velocity of from three to four metres per hour, according to its hardness, is emptied every night, and filled with a 10 per cent. brine. In the morning the brine containing the chlorides of magnesium and calcium is run off, the permutit washed with fresh water to remove the salt adhering to the crystals and the apparatus is again ready for work." *

The quantity of salt required for regeneration is from six to eight times the quantity of hardness removed, and the permutit itself is washed away at the rate of at least 5 per cent. per annum.

Sodium permutit is slowly decomposed by free carbonic acid, and more rapidly by waters containing small quantities of stronger acids such as those from mines. To hinder this

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* Another preparation termed "alligit" has also been prepared for water softening. It is claimed to be acid-resistant and unaffected by free carbonic acid in water, which is not the case with "permutit." It appears to be somewhat similar to permutit in composition, but in physical characters more akin to trachyte tufa or lava than to the semi-crystalline zeolites.

effect the bed is covered with a layer of granular marble or limestone.

The principle is carried out successfully in a Gans apparatus for industrial or domestic softening.

We have found it necessary that before being passed on to permutit, a water should be freed from suspended matter by straining, otherwise the efficiency of the zeolite becomes much reduced through clogging of its surfaces by fine particles of iron oxide or dust. A calico screen is quite sufficient.

Permutit Method for Removal of Iron and Manganese.—The special preparation contains higher oxides of manganese. It oxidises and absorbs the whole of the iron and manganese in waters, and, as soon as its activity declines, it is regenerated by passing through it a solution of a permanganate. See an article by L. H. Harrison, *Chemical World*, July, 1912.

The permutit method is really an application and artificial acceleration of natural processes that have always been going on in many parts of the world. The hard fused silicates of igneous rocks like granite, gneiss, and others, are about as resistant to water as glass or porcelain ; streams passing over them are known to take up very little mineral matter. But they may become geologically "metamorphic" by the action of heated steam, may be "weathered" or broken down in soils ; leading in each case to the formation of hydrated silicates or "zeolites" which have chemically active properties.

Dr. Thresh has shown that many samples of Thanet sands possess softening properties to a marked degree. Thus the chalk water in Hertfordshire, which is very hard, after filtering through Thanet sand becomes very soft and contains carbonate of soda instead of carbonate of lime. He made a large number of experiments with samples of these sands from different localities, and found that their softening power varied very much and was rather rapidly lost, but in some of them it could be revived by washing with acid or much better by treating with brine. He noted that there was a frequent occurrence of clogging, and of turbidity in the filtrate due to the formation of a "sol" or colloid solution.

An analogous interchange of bases has been observed near Great Salt Lake, Utah. A hydrated double carbonate of lime and soda called Gaylussite, which is sometimes deposited by saline waters, has here formed raised terraces, but the crystals have been gradually changed, by the passage over them of a hard limestone water, into carbonate of lime alone, the soda dissolving in the liquid.

In 1911 we had to investigate a similar action at Baku near the Caspian Sea. Some of the sand contained a considerable amount of a hydrous silicate or zeolite gelatinising with hydrochloric acid. In the water that had passed through it there was much sodium salt and little lime or magnesia, whereas neighbouring waters contained a large amount of lime and magnesia and little alkali.

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CHAPTER X.

STERILISATION.

In sedimentation with or without coagulants we have seen that a remarkable purification of the water is often effected in regard not only to ordinary suspended matter but also to organisms. Sedimentation followed by sand or mechanical filtration can under the best conditions maintain a constant reduction in the number of bacteria up to 98 per cent. of the total number present. In none of these cases is the water at the end of the treatment sterile. Although the likelihood of any pathogenic germs surviving the treatment has been shown to be remote, yet it has to be remembered, that firstly the filters must always be working at maximum efficiency to produce this result (failures of a filter due to frost, worms, rupture of the film, or want of care are not immediately detected), and secondly the two per cent. or more of organisms not removed may after all include pathogenic forms, as has been evidenced by recent outbreaks of typhoid, etc., at St. Petersburg and other places. The products of bacterial growth are certainly injurious to health and are not destroyed by the comparatively mild oxidising agency of the mechanical filter, or even by the sand filter in the winter time when the algic growth is at its lowest point. In the case of upland waters it has been shown that any slight bacterial contamination is fatal to the sanitary safety of the water, and yet there are numerous great cities that daily run this risk, which continually becomes greater with increase of population and consequent encroachment on gathering grounds.

The question arises—" Why is our present-day standard so low? is it not possible to raise it and secure a sterile water supply? "

The ideal has been limited by questions of cost. But by research on the processes and their practical application on the large scale they have been rendered so cheap and easy, that, according to a forcible American dictum: "The time for raising the arbitrary conventional standards has now come, since a sterile water can now be produced from whatever the source, by an installation that does not require the constant presence of skilled attention, and which is practically fool-proof. Such modern installations as have been already installed are so arranged that, with unskilled attention no risk of delivering a poisonous or unsterile water is run. The common plan *now* only *chances* whether your raw water has disease germs in it. Why not make it always safe?"

Since methods of producing sterility are usually dearer than simple sedimentation or filtration systems per unit of organic matter dealt with, it comes cheaper to remove as much as possible by prefiltration or pre-sedimentation, reserving the sterilisation for the odd 2 per cent. of dangerous matter.

In localities where the water supply has been sterilised, many diseases which are not usually attributed to water contamination have materially decreased, showing that the liquid may contain a number of harmful organisms besides those commonly recognised as disease germs.

As an axiom, *there is no safe method of preventing water-borne diseases except sterilisation of the liquid.* Its adoption has frequently been postponed by questions of expense, and by the statement that the population "gradually became accustomed to these organisms," but it must be remembered that the human resistance is always liable to break down, and that large epidemics have been enormously expensive in the past, and smaller ones still continue to be costly.

Even if individuals can become acclimatised to sewage, such immunity is only because the human body includes (1) resistance to penetration; (2) secretions which can disable, kill and even digest organisms; (3) destruction by phagocytes if they enter the blood. But the defensive powers experience an unfair strain if we are always calling them into action:

ill-health becomes constant, and disease ensues. Fuertes and others have shown us the enormous cost of disease to the community, and Dr. Eustace * has demonstrated the effect of hygiene upon wage-earning capacity—that money spent on health is sound capital outlay—and hardly a point is more important than that our health should not be deteriorated or imperilled by impure water. It is a truism that the price of peace is incessant vigilance, and should not this be devoted to making our drinking waters always healthy—not "comparatively wholesome," and systematically barring *all diseases* from entering our systems by this conduit?

Hazen first noticed that where one death from typhoid has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes had been avoided, and what is called the Mills-Reincke phenomenon is that where purer water is supplied the general death-rate declines more rapidly than the typhoid death-rate. Sedgwick and McNutt, after an examination of the subject in great detail in the Massachusetts Institute of Technology Reports, 1910, fully established the fact.

The idea of *excluding* danger by drawing from an uninhabited and presumably unpolluted source, has led to many municipal undertakings parallel to the aqueducts in ancient Rome. New York impounds from uninhabited land, Frankfort draws mainly from the subsoil waters of an extensive wood, which is carefully kept free from dwellings and other causes of contamination—it must be noted that in the neighbourhood of large cities such care could seldom be exercised. Mountain and upland sources have often been strenuously advocated on account of their softness and purity, but apart from the fact that from limestone ranges the water is often hard, it has been proved that nearly as much care is necessary in the protection of the gathering ground as in a lowland origin. Many towns in America, for example, have rightly adopted a sanitary supervision of watersheds, but with corresponding expense, and water departments must arrange for the notification of infectious diseases within the area.

* *J. R. San. Inst.*, Nov., 1910.

Animal pollution of upland ground is contributed by sporadic occupation, by farm buildings, cattle and sheep, and the various wild animals that are often abundant. The Local Government Board Reports give several instances of epidemics occasioned by upland water, generally traced to manure that was sometimes human, as on the Tees and in South Yorkshire in 1891. See especially the issue of 1905. In this and other countries the plan of clearing the water-shed from farming and other occupation has at times been carried out at very great cost, but it is evident that such a policy does not make the water safe, although it requires a heavy outlay, on fencing and guarding, besides that on dams, masonry and conduits. The aqueduct in the new Aberdeen scheme is 47 miles long; existing aqueducts for these distant supplies are in miles: Thirlmere (Manchester) 99, Vyrnwy (Liverpool) 77, Elan (Birmingham) 81, Derwent (Leicester) 64, Alwen (Birkenhead) 43.

There are serious objections to the entire annexation of large upland areas for providing urban water supplies, since rivers are thereby considerably depleted, fisheries and mills affected, without mentioning effect on scenery. As an instance of the absorption of streams, Mr. Parry in his report on the Liverpool works for 1910 describes how the upper part was completed in that year by the diversion into the artificial reservoir, named Lake Vyrnwy, of the Rivers Cownwy and Marchnant, the River Vyrnwy having already been impounded: the total area of gathering ground was thirty-five and a half square miles. Compensation works to feed rivers are generally demanded, and add considerably to the cost of a distant mountain supply, which is also made more expensive by the factor noticed in all countries, that it is necessary to remove old decaying matter including peat, from the sites of reservoirs. On the whole it must be concluded that initially pure water in a hygienic sense is impossible to procure with certainty, however far we go for the source.

It is now understood that water from shallow wells is wholly unfit to drink, and should never be used for that purpose without being sterilised. Deep-water sources have usually been considered safe, owing to their having undergone a natural filtration, but it is well known that the earth, like an ill-managed artificial filter, may often have fissures or channels through which water can pass freely and be little better than unpurified surface water. On this subject the report of the Local Government Board for 1909 contains an inquiry into the water supply of Cambridge from the lower chalk, and recommends its abandonment (see *J. R. San. Inst.*, March, 1910). However, it was later established at Cambridge that treatment with a very small quantity of hypochlorite, equal to one part per million of available chlorine, or even less, was a practical means of rendering the water safe.

As to storage, the construction of reservoirs capable of holding fourteen to thirty days' consumption—the length of time now advised for bacterial safety—involves a very serious addition to capital outlay. In slow-sand filtration we have learnt that the surface skin is not, fortunately, the sole dependence, and that the lower layers of the material develop an adhesive coating which entangles organisms. But, in spite of all engineering improvements, these methods give only a more or less efficient mechanical straining, which has on many occasions broken down and let in epidemics. With the rapidly increasing urban population of most countries it is certain that filtration alone is seldom an assurance of safety. Under practical conditions, a filtration system of any type can but reduce, it cannot entirely remove, the dangers of a water supply which is continually subjected to excessive sewage pollution. The ordinary bacteriological tests require at least two days, and, unless there was storage for several days, it might happen that a contagion had infected the whole supply and that the danger signal was too late. In spite of systematic investigations in municipal laboratories, it has been admitted in reports of many countries, even in those of our own Metropolitan Water Board, that water frequently passes into public consumption, the quality of which has not been bacterially determined. Averages of analyses published in official reports tend to smooth over individual results, which sometimes are the reverse of satisfactory.

Dr. Houston * says, "Too much reliance must not be placed on the work of water examination. For technical and other reasons the most perfect and costly system of water examination that could be devised might fail altogether to detect an accidental contamination."

Whipple has pointed out that in some cities the adoption of filters has not been followed by a lowering of the typhoid fever rate, and gives marked instances of this at Youngstown, Ohio, and at Washington, D.C. Bulletin 115 of the U.S. Department of Agriculture says, "that where sewage is rendering a water supply dangerous, either the water must be disinfected before being distributed to the consumers, or the polluting sewage must be purified, or at least partially disinfected before it is discharged into the stream or lake." This is followed by a description of sterilising agents and costs of treatment.

In the Seventh Annual Report of the London Water Board for 1913, Dr. Houston reiterates the same doubt of safety which he has so often expressed, and thereby agrees with universal scientific experience. Thus, he says (p. 33), "The only way, *apart from sterilisation*, of rendering the prefiltration water always *comparatively*, *if not absolutely*, innocuous, is by storage." "The Water Board are securing the *reasonable*, *if not absolute*, 'safety' of the supply." "The evil effects of an impure source can be *largely*, if *not entirely* annulled by *adequate* storage and *efficient* filtration," which, according to p. 34, "renders the water *reasonably*, *if not absolutely*, 'safe' for drinking purposes." He also repeatedly recommends the adoption of "those supplementary processes of purification alluded to in previous reports." These were methods of chemical sterilisation. His only hesitation is on the score of expense. Yet it is done elsewhere, and an important point is that a great saving of water could undoubtedly be made by reducing the enormous waste that occurs in towns. Moreover, it should be possible to supply a smaller quantity sterilised for drinking, and a

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* Metropolitan Water Board Report of 1913.

larger volume of ordinary quality for washing, trade and sanitary objects.

We might notice that historically a dual supply was a natural instinct—from springs or wells for drinking, and from rivers or fresh-water pools for ablution. The extravagant but well-meant idea of artificially purifying the whole supply began in the nineteenth century and was in some respects an advance on fortuitous practice in Ancient Rome and other countries, and on that of the sixteenth to eighteenth centuries when there was no scientific knowledge of real purity or the means of purifying. When speaking historically, we may mention incidentally that ancient Japanese records describe methods of water purification that would practically sterilise, such as by sulphur or other drugs. It is at any rate great waste of money to expensively purify by present methods, the tons of water that are occasionally used for fire extinction, and constantly for sanitary purposes.

Objections to the dual supply have been :—

1. That extra plant would have to be provided throughout for the pure water (by the savings we have indicated this would be made smaller and little if at all dearer).

2. That a coarse and bad liquid would be laid on for the unsterilised supply, leading people to use the pure water for washing, etc. (This is unlikely and could be prevented.)

3. That, on the other hand, the common water might be drunk by mistake. (But the taps could be made unmistakable, and put in distinct places. Also, storage reservoirs are in existence, do not cost much for maintenance as compared with filters, and storage for about two or three weeks renders water *fairly* safe and the above accident negligible. In any case it is absolutely necessary to have water stored against emergencies.)

In our opinion, the most suitable water scheme for a town consists of a modified dual-supply system to which the above objections cannot be raised. One delivery for private houses, drinking fountains, and the like, would provide a pure and sterile water for all household purposes.

The other delivery would be laid on for municipal purposes such as fire hydrants, street watering, public lavatories, fountains in public parks; from this also manufactures and industries would draw their necessary demands. This water should be stored for a suitable period to remove turbidity, etc., and should be soft and not liable to attack boilers; further treatment would be unnecessary.

Physical Methods of Sterilisation.

Boiling is the only one that has been thoroughly investigated from a practical point of view, and the general conclusion is that the process is limited to small installations where the working costs can be tolerated. Theoretically we could recover nearly all the energy put into the water as heat, but in practice the losses by radiation and otherwise make the method prohibitive on the large scale.

On the small scale, such as in cases with a doubtful water supply, apart from exclusion of germs by a Pasteur-Chamberland filter (Chapter VIII, p. 133), which is rather slow, heating must be depended upon. Wide hygienic danger has repeatedly been combated successfully by a local notice that "all drinking water must be boiled." As a type the County Medical Officer of Health for Huntingdonshire issued a warning to his district in September, 1912, that, "owing to the recent floods and the consequent pollution of wells, it is advisable that all drinking water be boiled before use."

After epidemics of typhoid at Lincoln, Maidstone and Worthing the common features were (1) a polluted water supply; (2) defects and overtaxing in the company's sand filters; (3) spread of the disease among the water consumers, except those who had practised boiling or filtration: (4) no implication of milk, sewers, or other occasional causes; (5) rapid decline and almost entire extinction as the citizens began generally to boil their water or obtain it from other sources. The lesson drawn was that although the water had been really dangerous for years and had originated isolated cases, and been generally injurious to health, and warnings had been conveyed by Medical Officers of Health and by analysts, the community had used the supply for a long time with an effect that was not conspicuous, until the disease germs suddenly increased in number and virulence from a combination of causes.

At the time there was a great general alarm on the subject. It was pointed out that the majority of adults escaped consequences because they rarely drank water except in a more or less sterilised form in tea, coffee, or artificial beverages, while the danger was more incident to children, and would be a large feature in infant mortality. Boiling the water remained the best common resource.

Adding chemicals to the water is not advisable in private houses, since in the use of chemicals on small quantities of water a slight excess may yield a solution that is strong enough to have toxic properties, unless it be possible to issue the chemicals, as has been suggested, in tabloids. In houses where electric light is laid on, small automatic installations for sterilising water by means of ozone, ultra-violet light, or electrolytic sodium hypochlorite may be easily worked. Once adjusted for the water supply of the house, they require scarcely any further attention, since the whole system is automatic, the operation of opening the tap to draw off the water starts the apparatus, with the result that sterile water is obtained after rejecting the first runnings.

Boiled water is flat and insipid, unless heated under pressure. This gives a higher temperature with quicker sterilisation, and in addition the dissolved gases are not driven off, and thus the fluid preserves its naturally bright appearance and fresh taste. For the steriliser to be economical, some arrangement must be provided by which the water that has already been heated up may transfer its heat to the entering supply so that the water is discharged at practically the same temperature at which it enters. Thus the heat required to be added, after the first, should be only that which may be lost by conduction and radiation. Water to be sterile needs heating to a temperature of not less than 100° C. for ten minutes, since the spores of certain organisms are comparatively resistant to heat.

The above principles have been patented in several machines. The earliest large apparatus was invented by Charles Herscher in 1888, and along with the Rouart of 1890 was officially tested at Brest in 1892. The former was introduced in England as the Geneste-Herscher or "Equifex," and was subsequently abandoned. These apparatus and the later Vaillard-Desmaroux were founded on the above principle that by exposing water for a short time under pressure to a temperature above boiling (113° to 116° C.) it was sterilised rapidly and effectually, the gases were not removed and therefore little deposit occurred, while the flat taste, and sometimes burnt flavour of ordinary boiling, was avoided. They also included a *heat-exchange*, in which the issuing sterilised water parted with its heat to the entering feed, and was thereby cooled while the feed was heated, so that a great economy of fuel was attained. But the long and costly spiral tubes of these machines were found rather soon to become encrusted, and were difficult to clean and not very durable, so that subsequent apparatus had to be simplified. The Forbes Steriliser, successfully used in the United States army, and since introduced into Europe, is supplied by the London Gas Light & Coke Co. The water is not heated under pressure, but is brought to the boil, and passes over a weir to a temperature-exchanger of a simple pattern. As the boiling only lasts a few seconds, the original gas and taste are here again retained, and there are arrangements for maintaining a constant level and preventing any water that has not been boiled from passing out.

An English invention, the Lawrence, accomplished sterilisation and softening together. The boiling vessel is a vertical cylinder with depositing trays of iron and a series of plates called "locators." The entering water passes down this column and is met by steam produced below, so that it is brought into violent ebullition and the earthy carbonates are deposited on the trays and locators, which are at intervals removed. The water thus treated passes up the cylinder to a heat interchanger of the ordinary construction. In common with the Forbes the rate of flow depends upon the heat applied rather than on the amount of incoming water.

Another steriliser called the "Salvator" was tried in France, and used in the Japanese campaign. The military pattern has a yield of two quarts a minute, and packs in a deal case 4 ft. 4 in. × 2 ft. × 1 ft. 2 in. outside, the apparatus and case weighing 168 lbs. On leaving the heat-exchanger the water passes through a float-valve connected with an automatic device which closes the valve instantly if the temperature on the sterilising chamber falls from any cause below 100° C.

The results we have obtained with different sterilisers of the types mentioned show that, even with varying rates of flow, sterile water can with care be usually ensured. Non-pressure sterilisers do not affect the destruction of all spores, but they are of use as a protection against cholera and typhoid. The portable forms require abundant and cheap fuel, and this factor militates against their use for armies in the field.

Improvements such as internal electric heating, or the adoption of surface combustion such as the Bonecourt boiler worked by compressed gas, petrol vapour, or acetyline, might solve this difficulty.

Attempted Sterilisation by Cold.

This idea has been the subject of a number of patents inspired by the use of refrigeration in keeping food. But it has been proved that cold or freezing does not render a liquid safe for drinking purposes.

About 1900 there were epidemics of disease traced to the consumption of ice creams made with contaminated water. They were found to contain large numbers of bacteria, and pathogenic organisms survived in them. At King's Lynn, in 1892, during a frost, discharges from typhoid patients collected on a river bank and were considered safe owing to being covered for some time with snow. On the snow melting, thirty-nine houses drawing their water from the river lower down were infected with typhoid fever.

Sedgwick and Winslow * in 1902 found that, when frozen,

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* *Effects of Freezing—Memoirs Amer. Academy Arts and Sciences*, xii, 467.

40 per cent. of the bacteria perish in 3 hours and 98 per cent. in 2 weeks. This of course ordinarily leaves a large number alive.

Houston * proved that typhoid bacilli when added to water actually survive longer at low temperatures :—

Temperature Centigrade.	Percentage of typhoid bacilli surviving after one week.	Period of final disappearance of bacilli.
0°	46	9 weeks.
5°	14	7 ,,
10°	0·07	5 ,,
18°	0·04	4 ,,

Prescott and Winslow † give other examples and remark (p. 22) that "almost without exception outbreaks of typhoid fever, due to polluted waters, occur in cold weather and this is, in part at least, due to the greater persistence of typhoid bacilli at low temperatures."

Therefore artificial methods of applying cold are of no service for sterilisation. Even under the far lower temperatures now attainable by liquid air, etc., bacteria can survive. Another deduction is that waters from melting snow or ice, like glacier streams, are not immune from danger.

Action of Light.

It was early noticed that the growth of green algæ can be prevented by excluding light from water during storage. With this object, as well as to protect from dust and smoke, reservoirs and wells are often covered over with brick arches. On the other hand, the beneficial effect of light in destroying the germs of disease is in this way hindered or lost. The algæ are infinitely less dangerous than the pathogenic bacteria; and as the former undoubtedly cause a disappearance of some of the organic matter present, when not superabundant or of objectionable species conferring odours or tastes, they are actually useful. We have referred in Chapter II to Dr. Strohmeyer's observations at Hamburg Waterworks.

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* *Seventh Report*, *Metropolitan Water Board*, 1911.

† *Elements of Water Bacteriology*, 1913.

Elementary considerations with regard to the effect of light on water organisms are :—

1. Green species containing chlorophyll do not grow in the dark, they develop in ordinary light, but are inhibited or even killed by strong sunlight, just as ordinary plants droop unless they are shaded.

2. The kinds not containing chlorophyll, including of course bacteria, grow almost continuously by night and day, and predominate in shady pools, but direct sunlight usually kills them. The latter action, called *insolation*, is of great importance in hot countries, when the sun's intensity keeps the open waters more wholesome than the heat-encouragement of such organisms would lead one to expect. The germicidal power of sunlight is strongest beyond the visible spectrum in the ultra-violet rays; we shall recur to them in the next chapter. A part of the visible spectrum, to which ordinary daylight mainly belongs and many forms of artificial illumination, so far from retarding these growths will often assist them. The subject was first systematically investigated by Downes and Blunt * in 1877, who showed how direct sunlight is speedily fatal to most bacteria and even in a little longer time to spores, while diffused light is harmful in a less degree. Dieudonné's † experiments worked out the difference in action between the rays of different wave-lengths in the spectrum; those of the longest wave-length and slowest vibration at the red end, the "heat rays," had no germicidal power; this began at the yellow "light rays" about the sodium line, where the vibration-velocity of the ray was greater, and its wave-length consequently shorter. The changes correspondingly progress through the green, blue and violet, the "chemical or actinic" rays, increasing in germicidal power. The invisible or obscure rays beyond the violet—"the ultra-violet"—were more germicidal still.

Westbrook at Marburg in 1900 (trying especially Vibrio choleræ) proved that the action was not simply a physical one, but depended greatly on the function of the chemical

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* *Proc. Royal Society*, xxvi, 488.

† *Arb. Kais. Gesund.*, 405, 1894.

rays in promoting oxidation, therefore free access of air is necessary. This of course accords with general experience. An important point to consider is that when water is in active circulation the action of light is continual on successive layers,* whereas in the quiescent liquid it diminishes with the depth. Observers have found that the inhibitive property of direct sunlight may penetrate in clear water to six or eight feet, but with any turbidity it is soon arrested. It follows that to get the benefit of this action reservoirs must be shallow and freely exposed to air. Buchner's † results with Vibrio choleræ, Bacillus typhi, and B. pyocyaneus, were that light is germicidal down to 1·6 metres (5 feet), but that its antagonistic effect on some bacteria in clear water did not become imperceptible till a depth of three metres (9·8 feet) was reached.

Sunlight undoubtedly exerts a powerful germicidal effect on bacteria near the surface, but even in a clear lake the rays quickly lose their energy in penetrating lower, so that, as Whipple ‡ remarks, disinfection by sunlight is not a factor at depths greater than a few feet. "Virtually without action in moderately turbid waters" (Jordan, *J. Exp. Med.*, v, 271 1900).

Geo. A. Johnson incidentally observes that under ordinary circumstances sun-bleaching is active for a depth of one foot below the surface, and in a month's exposure to the sun's rays the colour removal will amount to about 20 per cent. This, of course, is a chemical action, like that emphasised by Westbrook above.

Chemical Methods of Sterilisation.

The great advantage in several chemical processes is the possibility of determining systematically and within a few minutes, whether the liquid has been properly sterilised.

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* Rapp showed the effect of daylight in diminishing the number of bacteria in the river Isar at Pullach (*Arch. f. Hyg.*, xlviii, 179).

† *Arch. f. Hyg.*, xvii, 179, 1893.

‡ *Internat. Congr. Appl. Chem.*, N.Y., 1912, p. 291.

Bright, clear, and colourless waters are often dangerous, and slightly turbid ones inoffensive, so that the operations of water companies directed towards delivering a bright, clear, fluid may not always serve us with a wholesome one.

Sterilising mechanical and other filters at the time of washing reduces the cost of running by diminishing the amount of wash water required, and enables the filter to be sooner put back into use.

The opinion is gaining ground that measures for killing pathogenic organisms, and not merely sifting some of them out, are urgent for many places, and would be advantageous in all. We have seen ample evidence that the present system of simple storage and filtration is not sufficient to avoid altogether the peril of occasional epidemics, nor the constant depreciation of public health through the continual escape of noxious germs. At St. Petersburg during the fifteen years 1881 to 1895 the death-rate from enteric fever fell from 129 to below 50. During the next fifteen years it showed a considerable rise, attributable undoubtedly to pollution of the water supply, which culminated in the water-borne epidemics of cholera in 1908, 1909, and 1910. These had a monetary influence, and hastened improvements in the water supply, followed by a marked lowering of the enteric rate in 1911. At Montreal the polluted general water supply led to a formidable outbreak in 1910. There has been a rise at Birmingham and Glasgow, and a small rise at London and Edinburgh.*

Typhoid sometimes arises from polluted water used in washing milk utensils or for adulteration.

The Medical Officer of the Croydon Rural District in his annual report states that he has given much attention to watercress beds, "as the typhoid bacillus almost invariably gains access to the human body by the digestive track—

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* Dr. Stallybrass, Assist. M.O.H. Liverpool, *Public Health*, September, 1913. Incidentally Dr. Mitchell Bruce mentioned in his Harveian oration before the Royal College of Physicians, October 18th, 1913, that typhoid fever killed 78,000 persons in England and Wales in the ten years 1871–1880.

among other ways by the eating of watercress. The water supply to these beds has from time to time been examined for abnormal quantities of *B. coli*." Some cases of typhoid may obviously be brought in from outside by workers in the beds, as well as those derived from the sewage-polluted water, and infection may be washed in from roads and footpaths (*Water*, June 15th, 1912). An outbreak of typhoid from watercress occurred at Philadelphia in July, 1913. See Ohio B. of H. Bulletin, and *San. Record*, November 28th, 1913.

P. Vincy,* in an article on "Oysters and Typhoid Fever in Paris," shows graphically month by month the incidence of typhoid in the city, and the quantity of oysters brought in. The disease very much declines in the summer months, when no oysters are consumed. He describes experiments in the laboratory of the Minister of Marine, on the effect of cleansing polluted oysters in filtered salt water. *B. coli* disappeared after a few days' such treatment. He further describes the purifying installation at Concarneau for the daily treatment in this way of 6400 oysters, and calls for the construction of much larger plants at other places using artificial sea water.

It is evident that polluted water may cause danger in very many uncooked articles of diet. The risk is avoided by sterilising the water used for washing or dilution, but the agent has generally to be employed in the cold, with care not to injure wholesomeness or palatability. Several that we shall indicate are more active and suitable than the salt water mentioned above.

The chemical methods of sterilising water, especially the electro-chemical processes that we shall deal with in the next chapter have recently been developed to a remarkable extent. The problem is extensively an engineering one.

We will here summarise the points desired in a chemical agent for this purpose. They have been practically attained.

1. An effect on higher animals that is either *nil* or can easily be tolerated, and that is not *cumulative* by use from day to day, in proportions that are fatal to lower organisms.

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* *Bull. Soc. d'Encour.*, February, 1913, pp. 277–286.

2. The liquid must be left palatable.

3. The method should be economical and easy to use. This factor has often had undue weight, leading to many failures, and to the final recognition that in matters affecting vitality, efficiency should be thought of before economy or ease of application.

4. For economy the agent should be applied as a *finisher* to waters fairly clear naturally or previously purified mechanically.

5. If the reagent causes a precipitate, its removal adds to the cost.

Arranging the subject in groups:—

I. Acids and Acid Salts.

These are antagonistic to disease organisms and frequently kill them. It has long been known that nearly all bacteria thrive best in neutral or slightly alkaline solutions and decline in acid ones. This may have been an instinctive reason for the use of vinegar and lemon juice with foods. In 1892 Dr. Christmas showed that citric acid of strength 8 in 10,000 was fatal to cholera bacilli, but that 1 in 1000 was required for typhoid. This strength gives the water a decided acid taste and is moreover too expensive.

In 1901 Drs. Parkes and Rideal * introduced the use of tablets of acid sodium sulphate, $NaHSO_4$, for travellers and in campaigns: strength 15 grains per pint. They were successfully used in the South African war, and the very slight acidulous taste is not objected to.

It was observed in the Public Health Laboratory of Pennsylvania (Bull. No. 5, Harrisburg, Nov., 1909) that acid mine waters and waste tan liquors destroyed in several water supplies B. typhosus, B. coli, and B. anthracis.

Koch was the first to draw general attention about 1883 to the germicidal effect of acids, more particularly with reference to the cholera organism. Krönig and Paul † investigated the

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* *Epidem. Soc., London*, Jan., 1901.

† *Zeit. f. Hyg.*, xxv, 1897.

power in a number of acids and concluded that it was proportional to the "strength" or concentration of hydrogen ions. Burri * showed later that it was more dependent on the ease with which the particular acid can go through the cell-wall of the microbe. In his experiments with B. coli, aerogenes, putrificus, casei, and Güntheri, dilute hydrochloric, nitric, formic, acetic, propionic and lactic were equally active, sulphuric was weaker, phosphoric was very weak, citric was weaker still and tartaric had the least action.

Stutzer and Springfield † showed how water pipes can be disinfected and freed from growths by dilute sulphuric acid 2 in 1000 *left in contact for* 12 *hours*, which cleaned out rust and sediment without sensibly attacking the metal.

Carbonic acid under pressure has a slight sterilising action which is effective on storage ; a useful character in the mineral water trade.

II. Alkalies.

The one of most importance in this connection is lime. When Clark introduced his process (Chapter IX) in 1841 its object was only softening, and it was applied on a large scale at Canterbury about 1860, while at Southampton the water has been softened with lime since 1888. But it was soon found that there was a removal, and to a certain extent a killing or at least inhibiting of the organisms. Dr. P. Frankland ‡ published investigations on this subject, and stated that in the Colne Valley (Herts) Waterworks where lime was used the subsidence of the precipitated carbonate of lime was so rapid that the water after 3 hours was often ready for distribution, while he found that the average reduction of the organisms was 322 to 4 per c.c. or about 99 per cent. He remarked further (*Micro-organisms in Water*, 1894, p. 191) that "by excess of lime the most remarkable diminution in the bacterial contents of water may be effected, and such

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* *Landw. Jahrb. der Schweitz*, xxvi, 469, 1912.

† *Zeit. f. Hyg.*, xiv, 116, 1893. See also *Klin. Jahrb.*, x, 323, 1903.

‡ *Proc. Royal Soc.*, 1885 ; *Proc. Inst. Civ. Eng.*, 1886.

treatment, carefully carried out, must afford the most substantial obstacle to zymotic poisons reaching the consumer." Some of his experiments were made with London (Thames) water. Several observers noted that lime was particularly fatal to pathogenic bacteria before it could kill all the ordinary water organisms.

Liborius[*] observed that 0·25 grm. per litre of CaO destroyed cholera germs (time not given), and Pfuhl[†] states that they and typhoid were killed in a canal water in 1½ hours by 1·0 grm. per litre of slaked lime, $Ca(OH)_2$, = 0·75 grm. CaO, corresponding to three times the previous quantity. Kaiser[‡] in the case of a typhoid epidemic in South Austria used 0·5 grm. of CaO per litre which sterilised water containing an average of 310 organisms per c.c. See also P. Auer, *Z. f. Hyg.*, 1908, lxvii, 237.

On the other hand with many water organisms of the B. subtilis type, highly resistant though fortunately harmless, the result of lime addition is rather removal than killing, and the fatal effect will vary according to the species.

Grether[§] found that such were not sterilised by 1·0 grm. of CaO per litre. Kruger[‖] added to water of this kind 0·2 grm. per litre of CaO and incubated it for 3 weeks: it was then not sterile, the spores were not killed. Dunbar and Zirn[¶] record a similar result with as much as 2 grms. per litre.

In mere softening with a minimum dose of lime there is only a partial removal of the organisms and only some of them are killed. It has long been known that in this way after sedimenting for a time the mechanically carried down or inhibited bacteria rise again and develop in great numbers in even the upper layers. Kruger in the above paper confirms the after distribution and multiplication in a number of waters and also the effect of "excess lime" on bacteria. He added

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[*] *Z. f. Hyg.*, 1887, p. 15.

[†] *Ibid.*, 1889, p. 509.

[‡] *Centr. f. Allg. Ges. Pflege*, 1908, p. 286.

[§] *Arch. f. Hyg.*, 1886, 189.

[‖] *Z. f. Hyg.*, 1889, 86.

[¶] *Vierteljahr f. Off. Med.*, 1898, xvi, Supp. p. 138.

slaked lime equivalent to 14 grains per gallon of CaO (20 pts. per 100,000 or 0·2 per cent.), by which the liquids were rendered strongly alkaline. The average numbers of bacteria per cubic centimetre were :—

	1st day.	3rd day.	23rd day.
Original water	5142	21,344	15,714
Proportion of increase by time .	—	4·1	3
Limed water	662	824	1580
Proportion of increase by time .	—	1·24	2·4

Showing :—

1. In the first case the ordinary first multiplication then reduction of bacteria that occurs on storage.

2. The action of lime in reducing the number of organisms by 87·2 per cent. in 24 hours.

3. That the treatment does not hinder the remaining organisms from growing till the rate of increase is about the same as in the raw water.

4. Therefore that whatever good is done by lime is completed in the first day, and is imperfect without the use of another agent as a finisher.

5. That the water is made too alkaline for most purposes unless neutralised.

This method has, however, been of considerable use in several places. At Cincinnati, Ohio, in 1899, sufficient lime was applied to the river water supply to give an excess of about 3 or 4 grains per gallon of CaO after settling. The result was satisfactory as to removal of bacteria and organic matter, and the product was afterwards re-carbonated to remove alkalinity. At Winnipeg, Manitoba, cream of lime is added automatically, the water is then settled, passed through filter presses, and afterwards re-carbonated by washed CO_2 from burning coke.

At Columbus, Ohio, a softening plant of 30 million gallons capacity was erected in 1906 for treating with lime the water supply from the Scioto river, and is stated to remove nearly all the bacteria. The caustic alkalinity is neutralised by sulphate of iron with final mechanical filtration. This has the fault of leaving calcium sulphate in solution as a resultant, which as we have seen in the last chapter is a most objectionable form of hardness. A similar plant for 40 million gallons is dealing with the Mississippi at New Orleans. Fuller mentioned in 1906 the use of "raw water" sterilised with sulphates of iron for removing residual caustic alkalinity. Dr. Burlureaux of Paris is quoted as having shown that bacteria are actually destroyed in the softening with lime.

Dr. Houston in his Seventh Research Report to the Metropolitan Water Board stated in a footnote, p. 73, "I have found that quicklime (about 75 per cent. CaO) added to raw Thames water in the proportion of one part of quicklime to 5000 parts of water (0·02 per cent.) kills B. coli in five to twenty-four hours," and the idea of applying the method on the large scale was hastened by the failure to acquire parliamentary powers for the complete scheme of storage in the New Works Bill, 1911, on account chiefly of the immense outlay. In his Eighth Report, 1912, he records further experiments on "excess lime" as a water steriliser, and summarises strongly in its favour, saying, "Its complete fulfilment would raise the Metropolitan Water Supply to a pitch of perfection never before attained by any waterworks authority in the world, dealing with sources comparable with those of London." "Fifteen pounds of quicklime, costing 1½*d.*, would be added to 7500 gallons of raw unstored Thames water. This would kill within twenty-four hours the B. coli, and inferentially, but certainly, the microbes also of epidemic water-borne disease, *e.g.* the typhoid bacillus. The water would also be improved considerably as judged by chemical and physical standards. The excess of free lime (about 0·007 per cent. = 4·9 grns. per gal. of CaO = a hardness of 8·8° Clark) would then have to be neutralised with 2500 gallons* of adequately stored water, which, according to all my experiments, would not contain any of the microbes of epidemic water-borne diseases. Rapid filtration alone would then be required to remove the

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* 2500 in 7500, that is, one-third of its volume.

precipitate of inert carbonate of lime." According to the data given, the initial average hardness of 15° Clark is reduced in the final mixture to about 5·3°, but of course the sulphates are left, so that there would appear to be no danger of the water being rendered lead solvent, like soft waters generally, though this point is not mentioned. But "the disadvantages of the excess lime method *grafted on to an existing purification* are many and serious," mainly because "the mere cost of lime would probably be about double that of the present sand filtration." The expense, however, has been much lower in practice, and if it secures public safety, it is to be demanded.

Dr. Houston's experimental colicide success with one part of quicklime added to 5000 parts of water amounts to 20 parts per 100,000 or 14 grains per gallon, equal to 1·2 ton of this quicklime per million gallons. The proportion of free lime neutralised and rendered inert by the carbonic acid of the water would vary from time to time, and the quantity required to give the effective bactericidal excess would have to be regularly tested, also the volume of stored water required to neutralise the excess lime.

In his Eighth Research Report to the Metropolitan Water Board, 1912 (p. 13), it is learnt that this stored water is not safe, and the question is dealt with (p. 11) as to the sterilisation of the 50 or 25 per cent. of water needed to be used to neutralise the excess of lime. He says, (p. 14), "With hard waters it is a case of adding an excess of lime to the major proportion of the total volume, rendering the minor proportion safe by adequate storage, ozonisation, chlorination or other method, and mixing the two together so as to neutralise the excess of lime, and render the whole perfectly innocuous. With soft waters the procedure is to treat the whole bulk of water with an excess of lime and neutralise with carbonic acid, sulphate of alumina or acid. The former operation incidentally involves 'softening,' and the latter may involve 'hardening' the treated water."

"Speaking generally (p. 14), the bactericidal dose with hard waters would seem to be 1 in 5000, and with very soft waters about 1 in 50,000." Actually "the B. coli in London crude sewage (Barking outfall) were killed by a dose of one part of quicklime (about 75 per cent. CaO) in 2000 parts of sewage."

He finally recommends using (p. 15) :—

(1) Enough lime to combine with the temporary hardness in the whole of the water, but adding it to such portion of the whole as would leave an excess of about 0·007 per cent. (5 grains per gallon) of CaO in the portion.

(2) Sterilising with chlorine or ozone the remaining portion, and then :—

(3) Mixing the two together and removing the inert carbonate of lime by rapid filtration.

Much further detail is given in the Eighth Report, which should be consulted.

It is very important, and ought to be obvious that the indispensable after-neutralisation must be effected in such a way as not to again contaminate the water. The methods in use are :—

1. Passing in CO_2, as at Winnipeg from burning coke. The gas would have to be carefully washed.

2. Adding sufficient of a solution of sulphate of iron (which, if moderately strong, would be sterile) and then filtering.

3. Dr. Houston's idea of mixing with a proportional, and very large, volume of water *presumed* to have been rendered safe by storage. The latter requires much time and space and other needs, with final doubt as to security, as is proved by Dr. Houston's own remarks in the fourth paragraph on p. 3 of his Eighth Report, and conclusively by the following :—

(*a*) Wilson and Dickson * found the typhoid bacillus alive after twenty-three days' storage.

(*b*) Gotschlich † found the cholera germ surviving after three months.

(*c*) Vincent ‡ observed the bacillus of dysentery alive after one week's storage.

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* *J. Royal San. Inst.*, xxxii, 472, 1911.

† *Kolle-Wassermann's Handbuch der Path. Mikroorg.*, i, 195, 1903.

‡ *Revue de Hygiene*, 545.

(*d*) Schwartz [*] found Bacillus tetani alive after 152 days, and still virulent.

Therefore it is very much better:—

4. To sterilise at once with certainty the subsequent water used for neutralising, by a reliable means such as ozone or chlorine. It will occur to every one—why not sterilise the *whole* of the water in this way, as has been successfully done in America, France, and other countries?

Compounds of Heavy Metals

are many of them germicidal, but are generally too expensive for this use except in special lines. Their value cannot be estimated by their activity in pure solution, since they are precipitated by the earthy carbonates of ordinary waters. The precipitate, however, often carries down the organisms and sterilises them.

Copper has been dealt with in Chapter VI. Its salts have long been known to possess bactericidal and especially algicidal powers. In 1893 Kroncke [†] showed that 1 in 20,000 of cuprous chloride together with some ferrous sulphate sterilised water in six hours, after which time one part of lime in 100,000 was added to precipitate the copper oxide. This was removed by sedimentation followed by sand filtration.

In 1904 S. Rideal suggested the use of copper vessels for the automatic sterilisation of water by simple contact. Kramer [‡] in 1906 found that the period of contact required by copper with the surrounding water to produce sterility was from two to four hours.

In 1904 and 1905 Moore and Kellerman at Washington showed that copper sulphate was, in the strength of 1 in 10,000, a good algicide and a fair bactericide, sterility being obtained after three hours.

Clark and Gage [§] found copper sulphate rather uncertain in

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[*] *Arch. Science Méd.*, xv, No. 8.

[†] *Jour. fur Gasbeleucht.*, xxxvi, 513; also Rideal's "Disinfectants," p. 157.

[‡] Kramer, *Amer. Journ. of Pharm.*, 78, 140.

[§] Clark and Gage, *Journ. Infect. Diseases*, Supplement 2, p. 75, 1906.

its action, sometimes as much as 3 in 1000 being required to ensure sterility. The general conclusion is that copper sulphate in the strengths 1 in 100,000 to 1 in 50,000 is an efficient algicide, but only of doubtful value as a germicide.

Silver salts in solution are bactericidal. Ordinary waters precipitate them as chloride, $AgCl$, a part of which remains suspended and retains activity. In our laboratory B. coli was killed in 24 hours by 0·1 per cent., but the same strength failed to kill Staphylococcus pyogenes aureus in the presence of only a small quantity of chloride and organic matter. In diluted wine the former organism was not destroyed by the addition of 0·4 per cent. of silver nitrate.

According to Paterno and Cingolani,* 1 in 400,000 to 1 in 500,000 of silver fluoride ("tachyol") was fatal to non-sporing bacteria in half to one hour; with much organic matter 1 in 200,000 was necessary. Sodium silico-fluoride ("isotachyol") was similarly effective. Hetsch † with 1 in 500,000 of silver fluoride destroyed cholera germs, but not those of dysentery or typhoid; with 1 in 200,000 he killed cholera in ten minutes, typhoid and dysentery in twenty minutes.

Traetta-Mosca ‡ extended this work and found silver sulphate, chlorate and perchlorate all "strong and effective for sterilising water." The action was influenced by the silver ion content, but was also affected by the nature of the acid radicle, the fluoride and silicofluoride being the most energetic.

Fluorine Compounds.

The soluble ones are strongly antagonistic to moulds, and in a less degree to bacteria. The former character has led to their being added to brewery waters. Objections are that if acid (when their activity is greatest) they corrode silicious materials, such as glass and others, and that they all give with natural water a rather intractable precipitate containing

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* *Gaz. Chim. Ital.*, 1907, xxxvii, 1, 313.

† *Gedenkschrift f. Leuthold*, Berlin, 1906, 1, 216.

‡ *Gaz. Chim. Ital.*, 1909, xxxix, 1, 69, and *Chem. Centralblatt*, 1909, 1, 780.

calcium fluoride. The fluorine reagent might be recovered from the precipitate by distilling with sulphuric acid if it could be done economically.

Dr. Frank [*] uses a silicofluoride of aluminium for sterilising water, necessarily followed by filtration.

Fluorine compounds even in larger quantities have no injurious action on health. See Perret, *Public Health*, Oct., 1908.

The Peroxides and Persalts.

Hydrogen peroxide, H_2O_2, an inodorous and neutral liquid, which in the dilute state is neither irritant nor poisonous, and can break up with facility into water and nascent oxygen, would at first seem an ideal water steriliser. Paneth [†] found it a violent poison to many lower forms of animal life; all ciliate infusoria (some of which occasion, as we have seen, bad tastes and odours) were killed by one part of H_2O_2 in 10,000.

Reichel [‡] investigated its sterilising action on typhoid in proportion to time; 1·5 per thousand was fatal in six hours, 1·0 per thousand in 12 hours, 0·5 per thousand in 24 hours, while B. coli required a greater strength.

Although peroxide of hydrogen is useful for purifying water on the small scale on account of its power of oxidising organic matters and iron and of bleaching the sample, and has the advantages over permanganate and some other agents that it does not introduce anything foreign to the natural liquid, nor form any precipitate, its action on bacteria is rather slow and at least 1 per 1000 is necessary, an impossible proportion on a large scale, when its cost and instability, the impurities of the commercial article, and the expense of transport of large quantities of fluid, are additional objections. The last item may be fairly judged from the following comparative table, since germicidal power chiefly depends in this

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[*] *Wasser u. Abwasser*, Dec., 1910.

[†] *Chem. Centralblatt*, 1890.

[‡] *Zeit. f. Hyg.*, 1908, lxi, 49.

class of sterilisers on the amount of active or available oxygen that they can yield.

1 kilogramme of substance taken.	Grammes of available oxygen.
Usual commercial strength ("10 volumes") of hydrogen peroxide	14·3
Bleaching powder 33 % av. chlorine	149
Potassium permanganate in the ordinary reduction to MnO_2	152
Potassium permanganate when reduced energetically to MnO	253
Sodium peroxide, Na_2O_2	205
Calcium peroxide, CaO_2	222
Magnesium peroxide, MgO_2	286

Therefore the weight of hydrogen peroxide reagent that would have to be carried to effect an equal oxidation would be more than ten times that of the others.

For these reasons the solid peroxides, which are white substances easily soluble, and not changing for a long time if kept dry, have been advocated for water sterilising. They are now made wholesale by electrical methods at a reasonable price and employed in dyeing and colour industries.

Sodium peroxide, Na_2O_2.—Its utility in water purification was investigated by S. Rideal about 1900.* Either when used alone, or in conjunction with usual softening agents such as lime or soda, its advantages were that it sterilised as well as softened. The following are two examples:—

A. London tap water containing an average of thirty organisms per c.c.: permanent hardness 2·6° Clark. To separate quantities were added (1) 3 parts per 100,000 of caustic soda; (2) 3 parts per 100,000 of sodium peroxide.

B. Somewhat impure water containing 93 organisms per c.c.: permanent hardness 2·8° Clark. Added (1) 3 parts per 100,000 of caustic soda; (2) 1·5 of caustic soda and 1·5 of sodium peroxide.

Blanks were mounted in each case, and all the waters after the first shaking were allowed to settle, in series A at

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* Rideal's "Disinfection," p. 369.

about 10° C., in series B at 18° C. The number of organisms per c.c. was as follows :—

Hours.	Series A.			Series B.		
	Blank.	(1)	(2)	Blank.	(1)	(2)
1	31	28	11	115	94	62
$3\frac{1}{2}$	27	18	1	103	100	34
24	19	16	—	173	117	2

When the hardness is moderate, sodium peroxide can be used alone, and then has the dual function of precipitating the lime and magnesia with a large proportion of the organisms and organic matter, and of also inhibiting or killing any bacteria remaining. In hard waters the hydrogen peroxide required for sterilising is less than the amount produced from the quantity of sodium peroxide that would be needed for softening, and it is therefore more economical to mix the reagent with ordinary cheap softeners such as lime.

We will place together the reactions occurring between the soluble peroxides and the free carbonic acid and earthy bicarbonates of natural waters.

$$\left.\begin{matrix}Na_2\\Ca\\Mg\end{matrix}\right\}O_2+H_2CO_3=\left.\begin{matrix}Na_2\\Ca\\Mg\end{matrix}\right\}CO_3+H_2O_2$$

$$\left.\begin{matrix}Ca\\Mg\end{matrix}\right\}CO_3, CO_2+H_2O+Na_2O_2=\left.\begin{matrix}Ca\\Mg\end{matrix}\right\}CO_3+Na_2CO_3+H_2O_2.$$

$$CaCO_3, CO_2+H_2O+CaO_2=2CaCO_3+H_2O_2$$

$$\left.\begin{matrix}MgCO_3, CO_2+H_2O+CaO_2\\CaCO_3, CO_2+H_2O+MgO_2\end{matrix}\right\}=CaCO_3+MgCO_3+H_2O_2$$

$$MgCO_3, CO_2+H_2O+MgO_2=2MgCO_3+H_2O_2$$

In each case the hydrogen peroxide subsequently can decompose into water and nascent oxygen. The other peroxides can also act directly on oxidisable matters.

Sodium peroxide generates sodium carbonate which removes permanent hardness, as for instance :—

$$Na_2CO_3+CaSO_4=Na_2SO_4+CaCO_3.$$

Above these quantities it produces alkalinity. The calcium and magnesium peroxides only effect an ordinary Clark's softening, as seen above, and may even cause a hardening of soft waters.

Calcium peroxide, CaO_2 (see Jaubert's patent, 17,460 of 1900), is sold under the name of "bicalzit." According to Hetsch, under certain conditions it acts more energetically than H_2O_2, and 0·5 grm. per litre is fatal to typhoid organisms. Freyssinge and Roche in August, 1905, suggested the use of small quantities for sterilising drinking water. They state that the action is not extremely rapid, but after two or three hours water containing large numbers of B. coli communis and B. typhosus is completely sterilised. "The addition of a small amount of sodium bicarbonate greatly accelerates the action, and the hydrogen peroxide and calcium carbonate produced are removed by filtering the water through manganese dioxide."

Magnesium peroxide, MgO_2, now much used for sterilising bottled mineral waters, is made by the Oxidinsterilisierungswerken, Germany. A commercial preparation is stated to be a combination of the formula $4MgO_2$, $16MgO$, CO_2, containing about 33 per cent. of pure peroxide. It does not injure the taste and is physiologically harmless. The usual quantity employed is equivalent to 1 grm. of MgO_2 per litre, and it has been favourably reported on by Dr. Proskauer and others at Berlin. Dr. Park at the Institute of Public Health, New York, found that MgO_2 rapidly destroys typhoid bacilli, and Prof. Schattenfroh, at Vienna, records similar results with B. coli. Croner[*] obtained sterilisation *generally but not always* with 0·7 to 1·0 grm. MgO_2 per litre. See Thöni, *Mitt. f. Leb. u. Hyg.*, 1911, 1, 390; Young and Sherwood, *J. of Ind. and Eng. Chem.*, 1911, 3, 495; also an article in the *Mineralwasser Fabrikant* translated in the *Therapist*, March 14th, 1908.

Persulphates and percarbonates made electrically have been tried for sterilising water, but the results have been disappointing.

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[*] *Zeit. f. Hyg.*, 1908, lviii, 487.

The Halogen Group.

Iodine, although less active as an oxidiser than bromine or especially chlorine, combines more readily, in dilute solutions, with the protoplasm of organisms, thereby poisoning them. It is not a good deodorant, and it produces brown or blue stains on organic materials. Being a solid it is convenient and portable, but the solubility in water is only about 1 in 7000 (iodine water). Vaillard[*] suggested its use for water-sterilisation in campaigns, setting it free by the double decomposition by an acid of a mixture of iodate and iodide, similarly to Braithwaite's earlier method for bromine, which will be mentioned presently. The water is previously acidified with tartaric acid, and afterwards sodium thiosulphate is added as an "antiod" to remove excess of iodine. The reagents were put up in the form of tabloids. The process is negatived by the complication, cost, and the physiological action of iodides. See also Kossowicz and Loew, *Zeit. f. Gärungsphysiol.*, 1912, ii, 87; and 1913, ii, 158.

Bromine.—In 1897 Braithwaite proposed the use of a mixture of bromide and bromate of sodium, treated with acid sulphate of soda to liberate free bromine. Schumberg[†] employed free bromine (6 parts per 100,000) dissolved in potassium bromide. In each case the excess of bromine is removed as above by thiosulphate. The investigations of Schüder[‡] and others show that its action is unreliable, and experience is against it as a drinking water steriliser.[§]

Chlorine

is the only halogen that has been made use of for sterilising water on a large scale, either as free chlorine, as bleaching powder, or as sodium hypochlorite of chemical or electrochemical (Chapter XI) manufacture.

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[*] *Arch. de Méd. et Pharm. militaire*, 1, 40, 1902.

[†] *Deutsche Med. Wo.*, 145, 1897.

[‡] *Z. f. Hyg.*, 3, 307, 1901.

[§] See further S. Rideal's "Disinfection," p. 374.

Chlorine gas may be obtained compressed in cylinders and can easily be injected directly or added as chlorine water separately made.

In June, 1910, Major Darnall,* M.D., of the U.S. Army began a series of experiments on the availability of commercial liquefied chlorine for purifying water, considering that "if an apparatus could be devised for accurately dosing water with the dry gas the method would be much superior to those using hypochlorites or chlorine water, because of the uniform strength of the purified, dry, compressed gas . . . also . . . a slight excess of hypochlorite imparts a disagreeable taste and unpleasant odour to the water." Chlorine is now made in large quantities by the electrolysis of salt, and is in fact a bye-product in the manufacture of caustic soda. Most of it is used in the production of bleaching powder and other hypochlorites, but a considerable quantity is purified, dried, liquefied by pressure, and sold in steel cylinders holding about 100 lbs. This article is of great purity, and must be anhydrous to prevent corrosion of the steel envelope. The internal pressure varies from 54 lbs. per sq. in. at 0° C. to 216 lbs. at 50° C., and the price was then *6d.* to *7½d.* per lb.

At ordinary temperatures water absorbs in solution about twice its volume of chlorine, equivalent by weight to 400 parts per 100,000. As with other oxidising agents, a portion will be rapidly consumed in some bad waters by ferrous iron, organic matter, or sulphur compounds, and although this action is valuable for purifying, only the excess or "free chlorine" is available for sterilising the liquid. The immediate consumption of chlorine can be approximately calculated from the usual permanganate determination of "immediate oxygen absorbed" if the figure be multiplied by 2·21 (O 16 : Cl 35·4). During work the amount is easily (and must be) ascertained at intervals by the ordinary titration with iodide of potassium and starch (Chapter XII); or by the chlorometer (Chapter XII). Major Darnall finds that with an average unfiltered river water such as that of the Potomac, about 0·5 pt. by weight of Cl per

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* *J. Amer. Public Health Assoc.*, Nov., 1911.

million would be required, while for clear lake waters 0·3 to 0·4 would be sufficient, equal to from 3 to 4 lbs. Cl per million gallons of water of average purity. The apparatus used for the application of liquid chlorine is figured in his paper and is designed to be automatic when once adjusted, so that the effluent water just develops a blue tint with a mixture of starch paste and potassium iodide, showing a slight remaining excess of chlorine. In use it would be difficult to prevent this apparatus from becoming corroded.

Where concentrated and portable energy is the main object, as in military operations, liquid chlorine has similar attractions to those we have already seen in bromine and iodine, but costs according to Major Darnall four times as much as hypochlorites. The latter derive a great part of their commercial use as "bleaching powder" or "bleaching liquids" from the fact that they are more active oxidisers than this free elementary or molecular chlorine. The reaction with hypochlorous acid—

$$HClO = HCl + O$$

occurs more rapidly than that with chlorine—

$$Cl_2 + H_2O = 2HCl + O$$

apart from the point that the first gives twice as much oxygen in proportion to the chlorine. The hypochlorous acid is easily set free from its compounds: we shall recur to this subject later.

Hypochlorites

in the commercial preparations are associated with chlorides; and also with excess of base for the sake of stability: the solutions are alkaline. The "available chlorine" is that which is active in oxidising or germicidal capacity, and is indicated by the potassium iodide and starch test, and measured quantitatively by standard arsenious acid solution (Chapter XII).

"Chloride of Lime" or bleaching powder has the essential nucleus $CaOCl_2$ or $Ca\begin{cases}Cl\\OCl\end{cases}$ half chloride and half hypochlorite.

As commercially made by passing chlorine gas over slaked lime, $Ca(OH)_2$, till absorption ceases, the composition of dry bleaching powder in the freshly prepared state and when fully charged with chlorine, corresponds to the formula $2CaOCl_2Ca(OH)_2$ (Clowes and Coleman), that is, half a molecule of slaked lime. The powder must be kept dry and away from light and air, and should contain about 33 per cent. of available chlorine. Market samples are sometimes as low as 20 per cent.

The corresponding soda preparation is met with as "chloros" and as "oxychlorides," the former made chemically and the latter electrically; both are alkaline liquids containing normally 10 per cent. of available chlorine.

The lime compound has been most frequently used for waters, but the soda solutions have several reasons for preference. The former increases the most objectionable form of hardness by leaving a residue of calcium chloride, while the latter cause a softening. Weighing out a solid and stirring with water till dissolved involves more labour with risk of uncertainty than measuring out a small quantity of a standardised liquid. Comparative tests with bleaching powder (lime) and electrolytic hypochlorite (soda) for sterilising water have proved that the latter is more efficient and in the end cheaper (especially when the liquid is made electrically to requirements at the waterworks as can easily be done, although the first expense is higher). One part per million of available chlorine is usually sufficient for sterilisation and sometimes less. The cost *for the reagent alone* is approximately calculated at 1*s.* 3*d.* per million gallons when from chloride of lime, and 1*s.* 10*d.* when from sodium hypochlorite.

Liberation of Hypochlorous Acid.

A general observation is that activity is usually connected with instability, and in consonance with this the full action of hypochlorous acid is only exerted in the free state. In its salts, such as those of lime or soda, it is fairly stable and almost inactive—an initial fact in the commercial value of these preparations, that they can be easily stored till wanted. Some old experiments are illustrative :—if water coloured with litmus be treated with a solution of bleaching powder or sodium hypochlorite it is turned blue, showing alkalinity, but is only slowly decolorised. On adding a drop of acid the litmus turns red and the solution is almost instantly bleached. Neutral solutions of other pigments, such as indigo, remain for a considerable time unaffected by alkaline hypochlorites, but change at once on acidifying.

For this reason in the bleaching of fabrics the liquid is "soured," generally by dilute sulphuric acid.

The affinity of hypochlorous acid for bases is very low, even less than carbonic acid, which, in fact, according to physico-chemical measurements, is about 10 times as strong :—

$$K_{17^\circ \text{C.}}\ HClO = 3{\cdot}7 \times 10^{-8}$$
$$K_{17^\circ \text{C.}}\ H_2CO_3 = 3{\cdot}0 \times 10^{-7}$$

Therefore in treatment of ordinary waters, which contain dissolved CO_2, with small quantities of hypochlorites, the hypochlorous acid is at once liberated :—

$$\begin{aligned} Ca(ClO)_2 &+ \overbrace{CO_2 + H_2O}^{H_2CO_3} = CaCO_3 \quad + 2HClO \\ NaClO \quad &+ CO_2 + H_2O = NaHCO_3 + HClO \end{aligned}$$

For effective sterilisation the liquid to be treated must obviously contain enough acid to neutralise the alkali of the hypochlorite solution added.

In general the natural carbonic acid is more than sufficient, but it may not be so in some waters, and in these exceptional cases it is necessary to increase the acidity. This has been done by :—

1. Forcing in CO_2 obtained from burning coke ; the gas requires to be carefully purified by washing with water from SO_2 and other impurities.

2. The addition of an acid salt such as those of alumina or iron, as in processes we describe.

To exemplify the need of acidifying in some cases, we found that one of these waters gave the following results with different proportions of a bleaching powder solution, in parts per million, immediately after adding.

Without adding acid.	Dilute acid added.
Available chlorine.	Available chlorine.
1·0	1·0
2·0	2·5
3·2	5·0

showing that in the first case the natural CO_2 had just been sufficient for the small quantity of hypochlorite; but that in the others additional acid was required.

Residual Chlorine.

In cases of emergency due to outbreaks of water-borne disease, hypochlorites have often been employed justifiably in larger proportion than is found necessary for routine practice in American cities and elsewhere. The epidemic was arrested, as we have seen, but the water sometimes acquired a faint taste or odour which tended to a general prejudice against the treatment as this effect was thought to be its common feature, called "residual chlorine." Dr. Thresh at the Congress of Applied Chemistry, 1909, said that "the process which appears to me to be most successful is the use of chlorine or hypochlorites. These chemicals have been used in emergencies, but on account of the disagreeable effect on the palate of the residual chlorine, their use has been abandoned as speedily as possible."

The same paper supplies an interesting example of the effects of hypochlorite:—A polluted well water treated for thirty minutes with 1·75 mgm. of available Cl per litre (1·75 parts per million) gave the following results:—

	Untreated water.	Treated water.
Chlorine in chlorides	12·0	12·1
Hardness	8°	8°
Free ammonia	0·004	0·000
Albuminoid ammonia	0·006	0·003
Oxygen absorbed	0·072	0·033
Bacteria growing on agar	180	2
B. coli	Found in 1 c.c.	Absent in 20 c.c.

Lederer and Bachmann * state that 0·6 part per million of available chlorine is the least quantity that can be tasted "except by sensitive people." Dittoe and McDowell consider 0·3 part per million the maximum safety limit to obviate complaints.

We find that these tastes and odours are not occasioned so much by chlorine or hypochlorites themselves as by inorganic and organic chloramines, and possibly other chlorine-substituted compounds formed by interaction with the organic matters present in waters. They have not been yet completely investigated, but we have noticed that whereas chloramine gives an immediate blue-reaction with potassium iodide and starch, and therefore ranks chemically with "available chlorine," the higher homologues react much more slowly; while they are all germicidal, and all possess a more or less disagreeable odour. Consequently under certain conditions a water may taste and smell although the usual chemical test does not at once show any indication of free chlorine. Such waters invariably contain large amounts of organic matter, and it is very advisable that the germicidal action should here be more prolonged.

The problem of elimination of this disagreeable after-effect has been solved more or less successfully in a variety of ways.

1. The simplest and most obvious is on the old lines of "prevention is better than cure"; *i.e.* constant control and regulation of the dose so that the small excess of chlorine required for sterilisation shall have disappeared before the water reaches the consumer. Regular testing with potassium iodide and starch is rather troublesome, and consequently is often neglected.

To obtain this important test easily and constantly, an instrument, the "Chlorometer," has been designed by E. K. Rideal and U. R. Evans, which continuously indicates on a dial, in the same way as an ordinary boiler guage, the actual amount of available chlorine in the water in parts per ten millions ("An Electrochemical Indicator for Oxidising

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* *Eng. Record*, 1913, lxvii, 12, 317.

Agents," *Analyst*, August, 1913). It enables the chlorine treatment to be regulated constantly without trouble, and would also be applicable to ozone and other oxidisers.

2. One of the simplest ways of remedy is by storage. Experiments on a chlorinated water indicated that 0·5 mgm. per litre (half a part per million) of available chlorine could not be tasted after three hours' storage at room temperature; this period was reduced to two hours when the water was agitated with air. Such agitation, with aeration, is easily effected by the ordinary method of cascades, but it is evident that expenses of pumping required by differences of level have to be taken into account.

3. Passing the treated water through a bed of sand covered with a thin layer of iron turnings (Dr. Thresh),* or a bed of charcoal and coke over sand, are also effectual methods of treatment, but rough charcoal and coke themselves impart at first a taste to the water. The Candy "De Chlor" process must be mentioned as conspicuously successful.†

4. The method of using chemicals as "antichlors" has occasionally been adopted for waters, the usual ones employed being either a solution of sodium bisulphite, $NaHSO_3$, or sodium thiosulphate, $Na_2S_2O_3$. The former possesses disadvantages of instability and uncertain composition: the latter is cheap, stable and definite as a solid, and effective. "Antichlors" immediately stop the chlorine from working, and, therefore, before adding them, sufficient time of contact must be given for the process of sterilising.

But the practice of adding another chemical to correct a fault caused by the first leads to carelessness, in this case leaves sulphates in the water, and is to be rejected when we have the simpler, and equally effective methods of control and storage.

A difficulty in the use of oxidising agents for sterilisation has always been the waste of the agent occasioned through its consumption by otherwise inert organic and inorganic matters. But during this oxidisation there is a decided action

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* *Internat. Congress of Applied Chemistry*, 1908.

† *Surveyor*, June 7th, July 12th, 1912.

on organisms, because the products of change are generally inimical to them. With regard to chlorine compounds the reason was elucidated by one of us[*] from the observation that the first rapid consumption of chlorine or hypochlorite was followed by a slower action continuing for hours or even days, and attended by germicidal action after free chlorine or hypochlorite had disappeared. He proved that chlorine, in supplement to its oxidising value, which had been exhausted, was working by substitution for hydrogen in ammonia and organic compounds, and yielding products of higher germicidal power than chlorine itself. Among those identified were chloramine, NH_2Cl, and hydrazine, N_2H_4. Refer Raschig,[†] also Cross, Bevan and Briggs,[‡] who noticed that chloramines combine with the nitrogenous molecules and have a tendency to become fixed on cellulose: in this way they attack the envelopes of organisms and soon kill them. Chlorinated albuminous substances have a great affinity for organic colouring matters (Knecht-Milnes) [§]; this property, and their viscidity, are concerned in the clearing effect on polluted liquids of chlorine and hypochlorites, which in emergencies caused by invasions of pathogenic organisms have so often proved of immediate value, as at Lincoln and Maidstone. They are now used regularly for sterilising public and private supplies in many countries. As examples of large plants in the U.S.A., one treats 30 million gallons per day at a cost of 27·6 cents per million gallons, including chemicals, labour and power; and another 15 million gallons per day at a cost of 96 cents per million gallons for chemicals, labour, power and supervision. The process has been found very useful in checking water-borne typhoid epidemics locally: portable plants, capable of being sent out and erected in a few hours, have been in operation in Indiana, Michigan, Minnesota and Kansas. It may generally be said that where filtration alone removes 97 to 98 per cent. of bacterial contamination,

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[*] *J. R. San. Inst.*, xxxi, 2, 1910.

[†] *Chem. Zeit.*, xxxi, 926, 1907.

[‡] *J. Soc. Chem. Ind.*, 1903, p. 260.

[§] *Ibid.*, 1892, p. 131.

hypochlorite in conjunction with filtration removes between 99 and 99·9 per cent. At Omaha, Nebraska, the typhoid death-rate had risen to 67 per 100,000, when in May, 1910, hypochlorite treatment of the water was commenced, and the rate fell to 13 for 1911, and 12 for 1912, with no autumn recrudescence as formerly. Minneapolis had 58·7 typhoid deaths per 100,000 in a population of about 300,000 (McLaughlin).* It was using raw Mississippi water without any treatment. At the end of 1910 it began, and has since uninterruptedly continued, to chlorinate the water, with the result that the typhoid rate was reduced 95 per cent. This proves distinctly that the water was responsible for almost the whole of the disease, and that sterilisation overcame the infection.

Hypochlorites are often supplemented by other chemicals. Clark and Gage,† in the case of dirty Merrimac water, found that the use of bleaching powder with aluminium sulphate and mechanical filtration, besides the greater purification clarified more cheaply than aluminium sulphate alone. The proportions decided on—14 grms. $Al_2(SO_4)_3$, 11 grms. NaOH, and 1·19 grms. available chlorine, per cubic metre,—gave better and cheaper results than the old quantities of 28 grms. of $Al_2(SO_4)_3$ and 22 grms. NaOH. The water passed through a coarse pre-filter required 0·5 to 1·0 part per million of Av. Cl. to produce a very low bacterial count. A. Walden ‡ gives a similar experience. In England the process is now used on the Severn water at the Cheltenham Waterworks, Tewkesbury, and at other places.

At the St. Lawrence Testing Station it was found that the dirty Merrimac water could be purified with 99 per cent. bacterial reduction by adding per million 5 parts of potassium permanganate and 1 part of bleaching powder, but "completed sterilising needs a great excess."

The "Ferrochlor" process of Duyk adds usually to a million parts of the water 8 parts of ferric chloride and an amount of bleaching powder equivalent to 0·1 or 0·2 of

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* *Boston Med. J.*, May, 1912.

† *J. New England Waterworks Assoc.*, xxiii, 3, 1909.

‡ *Eng. Record*, 1909, 59, 773.

available chlorine ; proportions varied according to tests. (*Bull. Soc. Belg. de géol. et d'hydrol.*, 1909, xxii, 98.) There must be enough base, either naturally present or separately added to throw down ferric hydrate from the iron salt, which helps the purification. The aim is to combine purifying processes in one. Objections are that it is advisable to do all coagulation and sedimenting before sterilisation, in order to avoid recontamination, also that trouble may arise through iron remaining dissolved. It was reported that an experimental plant at Paris completed the sterilisation of the water at a cost of £3 per million gallons, and that the expense would be less on a larger scale. The process is stated to be working successfully at Middelkerke and Hasselt in Belgium, at Lectoure and Larbresles in France.

Chlorine water and hypochlorites are decomposed by sunlight into chlorides and nascent oxygen, hence the reaction on the treated water has been hastened by causing it to flow down a series of cascades. Precautions against recontamination are, of course, essential.

See also a paper by S. Rideal on "Recent Advances in the Treatment of Water with Hypochlorites," *Chemical World*, September, 1913.

See also Joseph Race, *J. Soc. Chem. Ind.*, 1912, p. 611, and a paper by Dr. Adolph Kemna, Antwerp, on "Recent Advances in the Science of Water Purification," *Trans. Inst. Water Engineers*, 1912, p. 206.

Valuable cautions as to the treatment were given earlier by Prof. C. Winslow.* After stating that at that time (1910) some hundred cities and towns in the U.S. were receiving chlorine treatment, he points out that waters so heavily polluted as to approximate sewages cannot be made potable by this method any more than by filtration, on account of very resistant organisms (*vide* the paper). He concludes that disinfection with bleaching powder is best as a double safeguard in connection with one of the other recognised procedures. "Taking an ordinarily polluted stream as the original source of most water supplies there are now three processes by which it can

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* *Proc. Illinois Water Supply Assoc.*, 1910.

be treated, storage, filtration and disinfection. A fairly well stored water, which is generally pretty safe but not always quite safe, can be rendered unexceptionable by chlorine treatment. When a surface water is not stored, but filtered, disinfection again furnishes a double safeguard."

One of the most striking examples of improvement by filtration and sterilisation was at Pittsburg, which before the installation of the water filtration works in December, 1907, had a typhoid mortality far in advance of other American cities. The introduced treatment included sterilisation of the filtrate by calcium hypochlorite. As a sequence, registered typhoid death rates were: 1906, 141; 1907, 135; 1908, 53; 1909, 13; 1910, 12; 1911, 10.

Injectors.

Chemicals, solid, liquid or gaseous, must be added in such a way that strict proportionality is observed, *with efficient mixing;* at the same time the apparatus should be "fool-proof" and economical. These essential conditions are fulfilled by a number of apparatus now at work, by different makers. One of the most recent is the "Tiltometer" of the Hon. R. C. Parsons, described and figured, with his "High Pressure Chemical Injector," in the *Journ. Soc. Chem. Ind.*, May 30, 1914.

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CHAPTER XI.

ELECTRICAL MODES OF STERILISATION.

ALL direct electrical processes have the difficulty that their action is almost entirely restricted to the liquid in the path of the current; that is, flowing between the electrodes; therefore all the water must be made to pass through this narrow space. Elaborate devices for circulation do not get rid of the certainty in ordinary practice that some of the water will pass outside uninfluenced by the current.

Several early patents aimed at sterilising water physically by a static current of high tension, the idea being to give organisms "a shock" and kill them, but uncertainty occurred in the electrocution and the expense was impracticable.

A galvanic current, with electrolysis, proved more hopeful, but is still attended by the above inherent difficulty. The ordinary strength that can be commercially supplied, if used between terminals such as platinum, exerting no chemical action in themselves, not only does not kill or even antagonise lower organisms, but even stimulates them as it does with plants. Hydrogen liberated at one pole may trouble aerobic bacteria, and a small quantity of ozone or peroxide of hydrogen generated at the other may eliminate species and cause a little oxidation of organic matter, but the outcome, as mentioned humorously in an American report, is to make the bacterial population smile.

Hence the use of electricity has been supplemented by chemical action. The terminals are made of a metal which shall oxidise and produce a coagulant for the water, and the suitable metal has been *iron*. This was the basis of the old

Webster process with iron plates. It has been revived in America with good results by the Electric Water Sterilising Co. of Scottdale, Pennsylvania. Their plant has three parts: (1) the electrode box; (2) the coagulation chamber; (3) the filter beds. The former contains about twenty "pure iron" plates in parallel circuit, slotted to allow circulation and better contact of the water. It is asserted that "a plate 10 × 10 inches square will perfectly treat ordinary water at the rate of 400 gallons per hour, consuming only half an ampère at 110 volts." Their machines have received very good bacterial and commercial reports, showing that this method of making and applying ferric hydrate for coagulation and purifying, works very well on the small scale.

On the large scale it comes in competition with the Duyk and other processes, and raises the question of cost as well as efficiency.*

Electrolytic Hypochlorite,

an indirect method, has been referred to in the last chapter. As made by the "Oxychlorides Co.," it was found by Dr. Rideal and by Dr. Houston to act well at Guildford, and there are several advantages in working in this way independently on the spot:—

1. The solution is only required to be made weak, economising power, while as more dilute it is easier to measure out for accurate dosing.
2. Power from waterfalls, wheels or turbines can be utilised.
3. The agent can be made as wanted, with no carriage from a distance, or storage with consequent depreciation.
4. In the case of hypochlorite, experiments have indicated that the electrolytic is slightly more active against bacteria than the chemical preparations.

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* See further a paper by S. L. Campbell on "Electrolysis of Water by Iron or Aluminium Electrodes," *Electrical Age*, 1909, 5, 111.

The following are statistics for one kilogramme of chlorine * :—

Machine.	Kgms. of Salt used.	% NaCl decomposed.	KW hrs. required.	Energy yield.	% Strength of Solution.
Haas and Oettel .	10·70	15·5	8·4	21·0	14 grm. per litre.
Kellner . . .	6·00	27·5	6·6	26·5	25 ,, ,,
Hermite . . .	11·20	14·5	6·34	27·0	—
Mather-Platt . .	10–11	13·6	6·07	28·6	5-6 ,, ,,
Theoretical . .	1·65	100	1·74	100	—

COSTS.

Source.	
	£ s.
1 ton Cl_2 as Ca(OCl)Cl, bleaching powder	14 2
,, ,, NaOCl from Leblanc soda, containing Na_2SO4 . .	20 5
,, ,, ,, ,, electrolytic soda	22 12
,, ,, electrolytic (Kershaw) from salt	21 7
,, ,, ,, (Engelhardt) from salt.	23 0
,, ,, sodium-magnesium hypochlorite	80 11

Other electrochemical methods are ozone and ultra-violet rays: they are rather more expensive than hypochlorite, but have the great advantage that they do not add any solid material to the water.

Ozone

is an allotropic form of oxygen having the molecular formula O_3, ordinary oxygen being O_2. At common temperatures it is about the most energetic of all oxidising agents, acting in a manner that may be represented as

$$O_3 + \text{oxidisable matter} = O_2 + \text{oxidised matter}.$$

When applied to water the impurities are in this way destroyed, while the ordinary oxygen dissolves and improves the aeration.

Just as we spoke of "available chlorine," we now speak of

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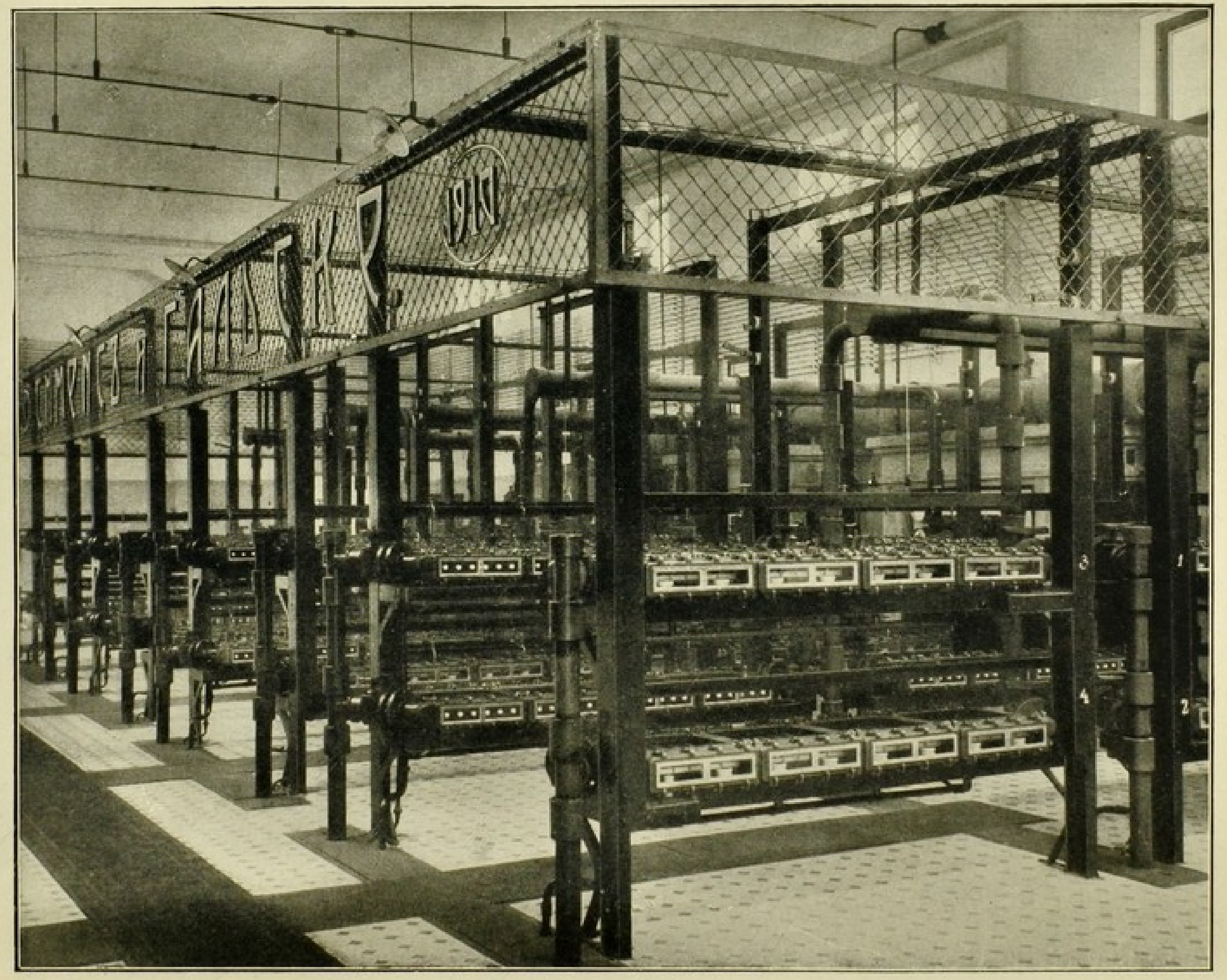
* Kershaw, *Journ. Soc. Chem. Ind.*, 1912, p. 59, and *Chem. Zeit.*, 1913, p. 358.

PLATE XIX.



Ozone Batteries, Petrograd, Russia.

"active oxygen" (a term already used in connection with the peroxides in Chapter X), which is the third or odd atom in the molecule O_3. It is evident that as the molecule of ozone weighs 3 × 16, or 48, it will only give one-third of its weight, or 16 of active, sometimes called nascent, oxygen.

Pure ozone is very expensive and difficult to obtain: it has been liquefied, but is then violently explosive. Commercially it is always applied in a diluted form as *ozonised air*, made by passing the silent electric discharge across a space through which air is made to travel. The details of manufacture have been worked out in a number of researches. The chief points are:—

1. The air should be previously dried: this is done by passing through a desiccating chamber filled with quicklime or with anhydrous calcium chloride, or less completely by cooling to freezing point when nearly the whole of the aqueous vapour condenses. Steyne's[1] process of artificial refrigeration is said to be very efficient, as the lower temperature causes a greater yield of ozone.

2. Sparking must always be prevented, as it not only occasions a waste of power through heat-decomposition of the ozone already produced, but causes formation of oxides of nitrogen, which hinder the production of ozone (Chassy, Moissan, and Hautefeuille), and are also for other reasons not allowable. The silent discharge occurs when the difference of potential between two electrodes placed close together is just sufficient to overcome the air-resistance, so that a current passes with a uniform violet light. If the voltage rises beyond a critical point there will be sparking.

Sterilising water by ozone was begun on the large scale by the firm Siemens-Halske near Berlin in 1908, using a Siemens' silent-discharge tube. Since that the aim of different apparatus has been:—(1) economical production (Siemens-Halske); (2) thorough mixture of the ozonised air with the water (Otto emulsifier); passing back and using again any ozone not absorbed in the first contact (De Frise), needed by the fact that the ozone being so much diluted with air is only

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[1] *Eng. News*, 1910.

under a partial pressure and therefore dissolves less easily. These essential points have now been combined by an amalgamation of the companies. Other methods that have been tried are the Vosmaer and the Howard-Bridge. See S. Rideal, "Sterilisation of Public Water Supplies," *Local Gov. Review*, 1910; *R. San. Inst.*, January, 1909.*

The process is an ideal one, sterilising the water without adding any foreign matter to it, and has been adopted at a number of large centres, Paris, Philadelphia, Nice, Petrograd; and the cost found reasonable. Twenty-six other plants in 1913 were in operation in France. It is at work at Wiesbaden, Paderborn, Hermenstad and Chemnitz in Germany; Charteres and Dinard in France; Madrid in Spain; Milan and Florence in Italy; and some cities in the United States; also 4 in Roumania, 7 in Germany, 5 in Italy, 3 in Russia, 1 in Spain, and 3 in South America. The smallest and largest installations at present are Ravenna in Italy, 32,400 gallons daily, and St. Maur (Paris) Waterworks 24,300,000 gals. per day, where the water is first sand-filtered then ozonised by the Siemens-De Frise and Otto systems.

The Nice installation was started in 1904 with 480,000 gallons daily, and was so successful that Nice ordered a second plant at Rimiez of capacity 3,700,000 gallons. It complied with the stringent conditions laid down as to bacteria "(*a*) no pathogenic; (*b*) harmless not to exceed 10 per c.c.; exception made for B. subtilis."

At Paderborn, Germany, following experiments at Berlin in 1896, and at Martinikenfeld in 1898, an installation for 500,000 gallons per 24 hours was set at work in 1902, and operating ever since "no pathogenic organisms have remained." Similar results were obtained at Schierstein Waterworks for the supply of Wiesbaden, and at the Neva Waterworks, Petrograd.

The mixing of the ozonised air and the water is effected by jets or "emulsifiers," and also by passing through a bed

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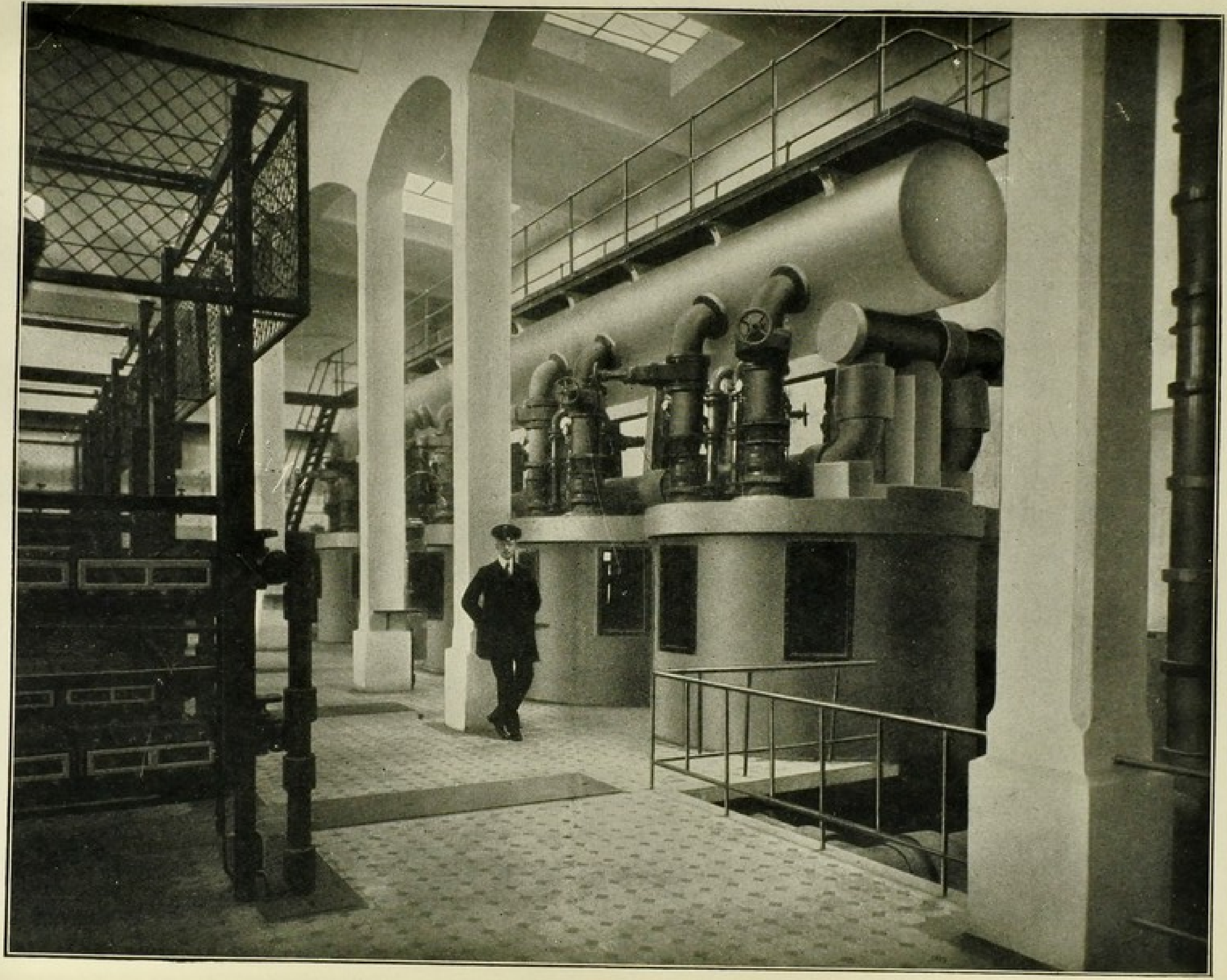
* See also Don and Chisholm, "Modern Methods of Water Purification."

PLATE XX.



Sterilising Towers and Ozone Emulsifiers, Petrograd.

of an inactive material. Broken flints, crushed quartz, and washed gravel have been used with about equal efficiency. "Ozonair, Ltd." states that their mixing tower follows the usual course of construction, and the ozone is recovered as much as possible as in the De Frise system. The ozoniser consists of plates of metal placed close together between which the air is forced, and in large plants the air has to be cooled.

At Hermannstadt, Hungary, the details reported are :—

(1) Tyndal-De Frise system; (2) 1·3 grm. ozone per cubic metre; (3) 160 cubic metres of water per hour; (4) cost one penny per kilowatt per hour, 0·24 pence per cubic metre.

At Chemnitz, Siemens-Halske system, 450 cubic metres per hour; cost 0·30 pence per cubic metre.

Petrograd, same system preceded by aluminium sulphate precipitation: 2·5 grms. ozone per cubic metre sucked in under 0·4 atmosphere; 500 periods, 7000 volts; cost 0·16 to 0·18 pence per cubic metre complete. The Duma have lately extended the work to a second site.

Kansas City, U.S., has been making trials and finds the process satisfactory but objects to the expense. (*Eng. News*, 1912.)

In September 1908, one of us examined in detail the working of De Frise's installation at the St. Maur Municipal Waterworks of the City of Paris. The report with comments is given in Vol. xxx., No. 1 (1909) of the *Journal of the Royal Sanitary Institute*, who have kindly lent us the blocks for the next four figures.

Fig. 6 shows the arrangement of the plant, and Fig. 7 illustrates an ozoniser. The next two figures represent the sterilising tower and the arrangement for sampling.

The effect of the treatment may be summarised as follows :—

A. *Physical.*—The change in the look of the liquid was very striking, from the dull greenish-brown of the sand filtrates to the bright sparkling and colourless or faint bluish tint of the treated water, which has at first a distinct odour of ozone, but evolves numerous bubbles of oxygen and rapidly becomes inodorous and tasteless. The process did not heat the water,

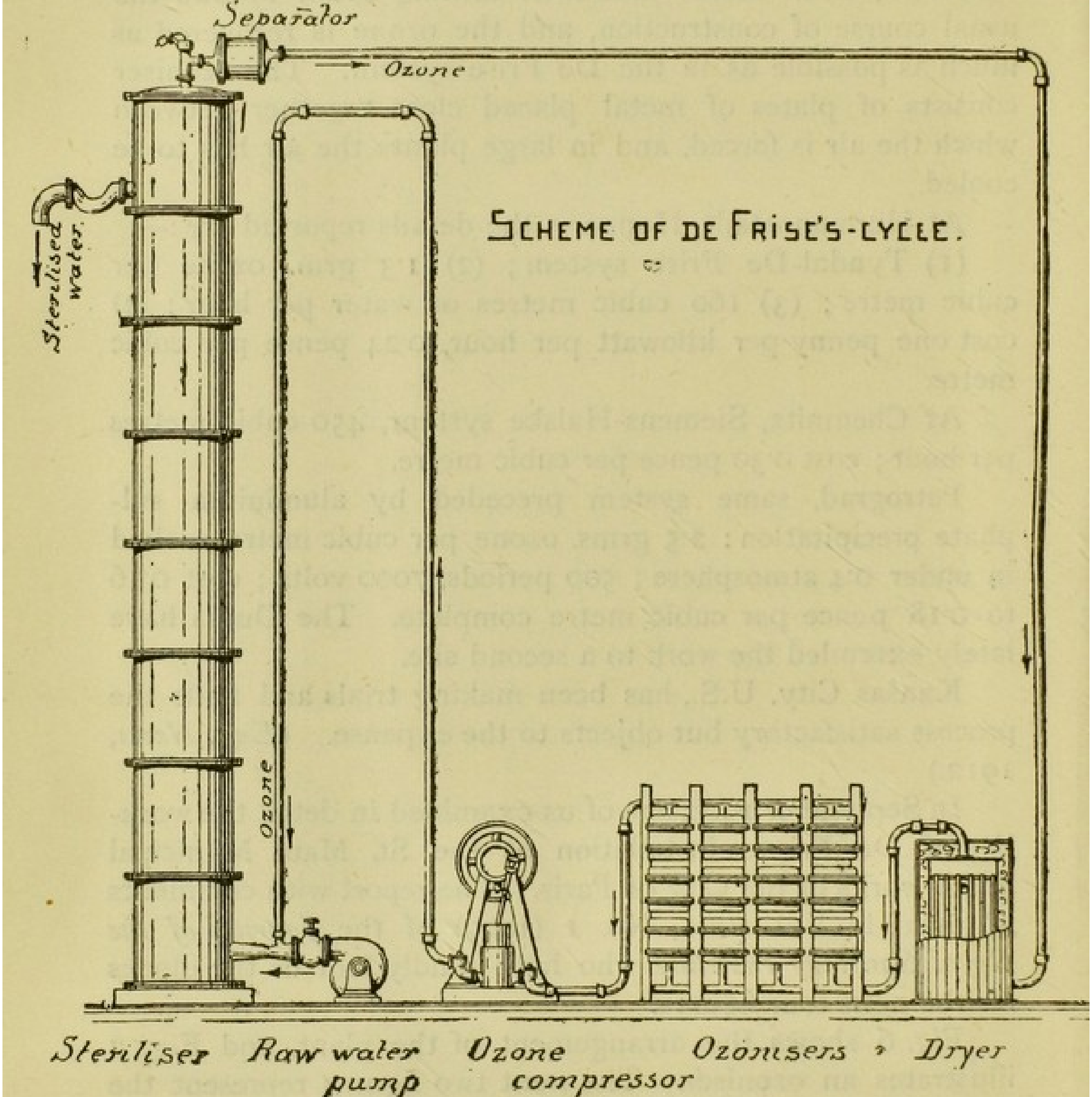


FIG. 6.

The ozone compressor draws the ozonised air from the ozonisers and forces it into the steriliser; from the top of the steriliser the air returns to the ozonisers, passing on its way through a separator and a dryer in which it comes in contact with calcium chloride, which is cooled down in hot weather. A small suction valve on the inlet of the separator admits fresh air to make up for the loss through absorption by the sterilised water.

The compressor used at St. Maur is a vertical double-acting pump, with 150 mm. diameter of cylinder and 200 mm. stroke of piston, and was worked at 140 revolutions per minute.

but on the other hand slightly cooled it, and it emerged at a very steady temperature.

B. The question as to whether any corrosion of the apparatus by the ozone occurred which could cause metallic contamination. Tests is this direction were entirely negative.

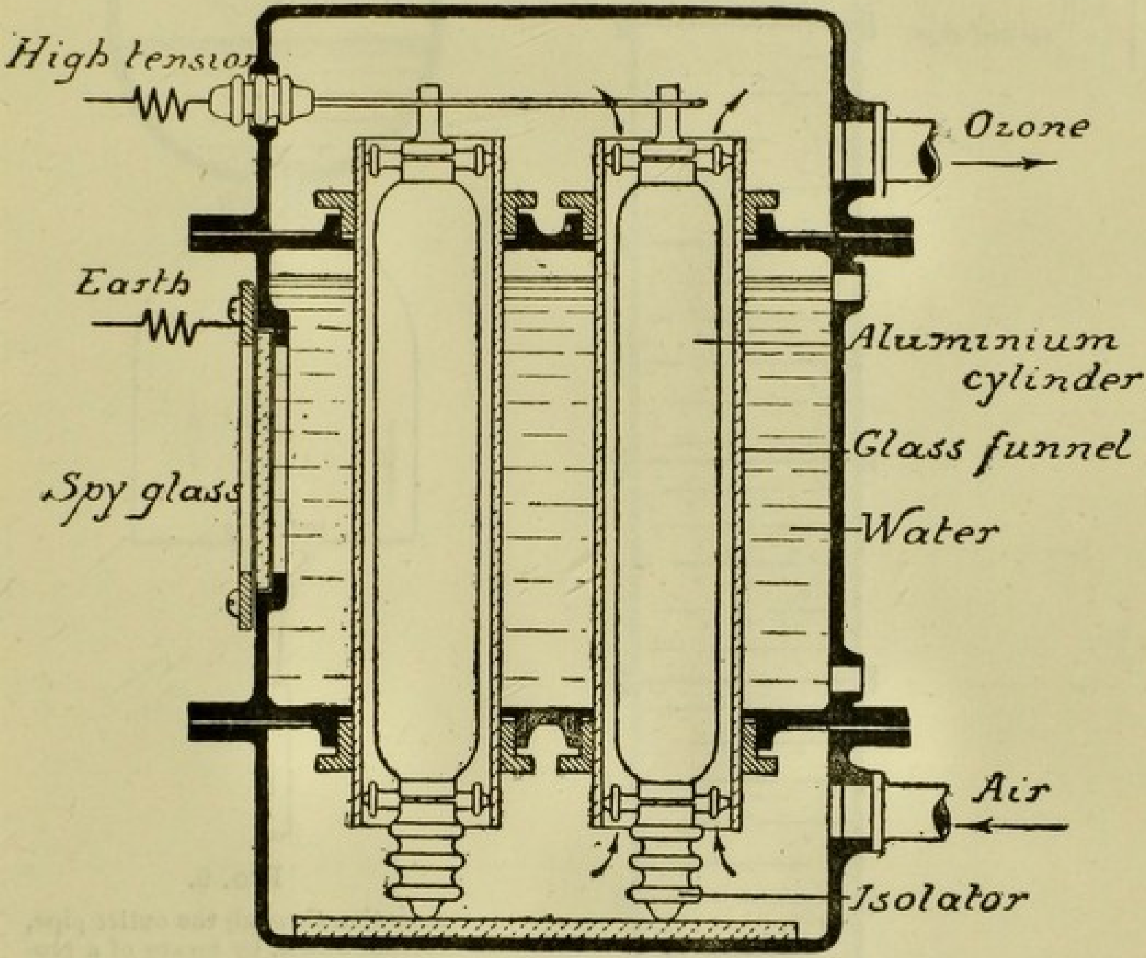


FIG. 7.

An ozoniser, consisting of a rectangular cast-iron box divided into three compartments by two tube plates into which glass cylinders are packed by means of screwed glands. Aluminium cylinders, closed at both ends, are placed concentrically to the glass ones. The aluminium cylinders are connected with one of the terminals of a step-up transformer, the second terminal of which is earthed. Cooling water circulates through the central compartment, which is earthed. Silent discharge takes place in the space, one-sixteenth of an inch wide, between the glass and aluminium cylinders. The air enters through the bottom compartment, traverses the silent discharges, and leaves the ozoniser through the top compartment. There are eight sets of cylinders per box.

C. *Chemical.*—Oxides of nitrogen and oxychlor-compounds were not formed; neither chlorine nor nitrate showed any increase over the ordinary amounts; a faint trace of hydrogen

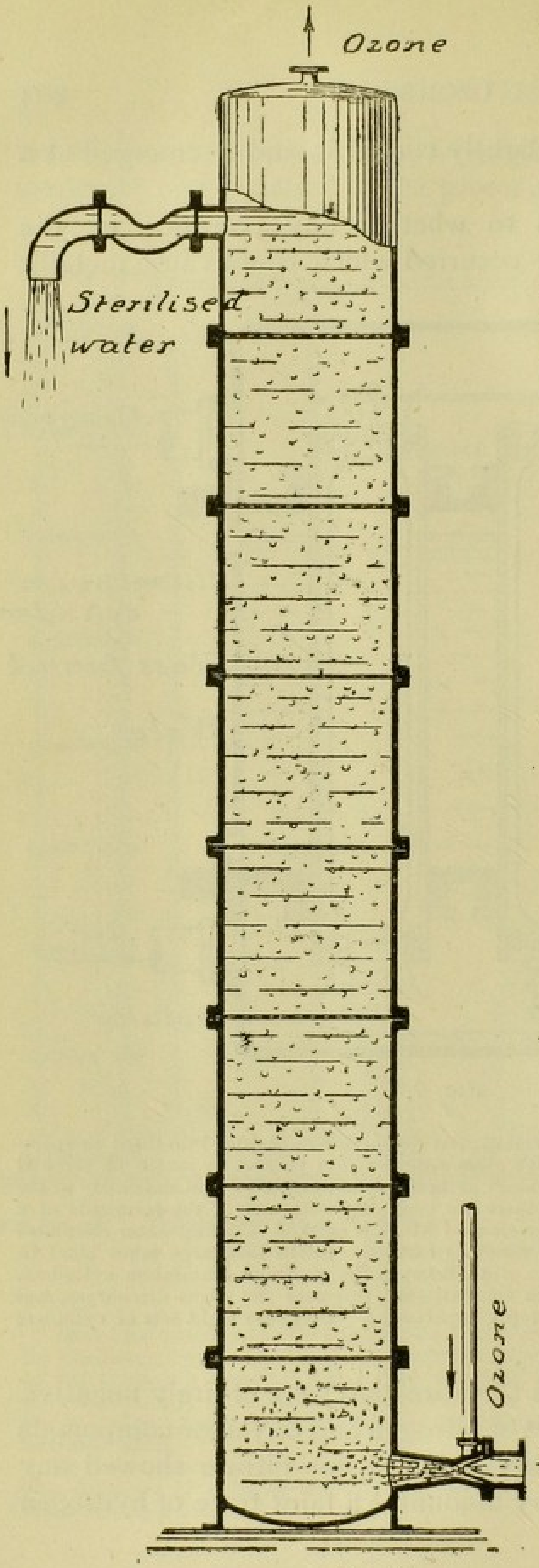


FIG. 8.

The steriliser at Saint Maur has a diameter of 1 metre, and a height of 8 metres between inlet and outlet.

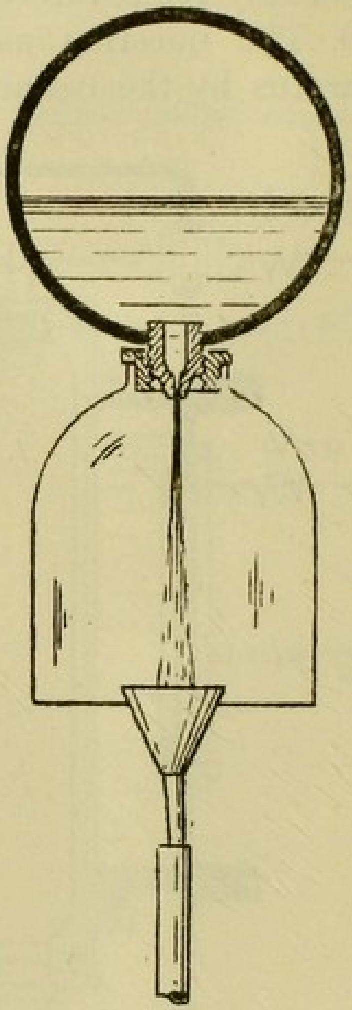
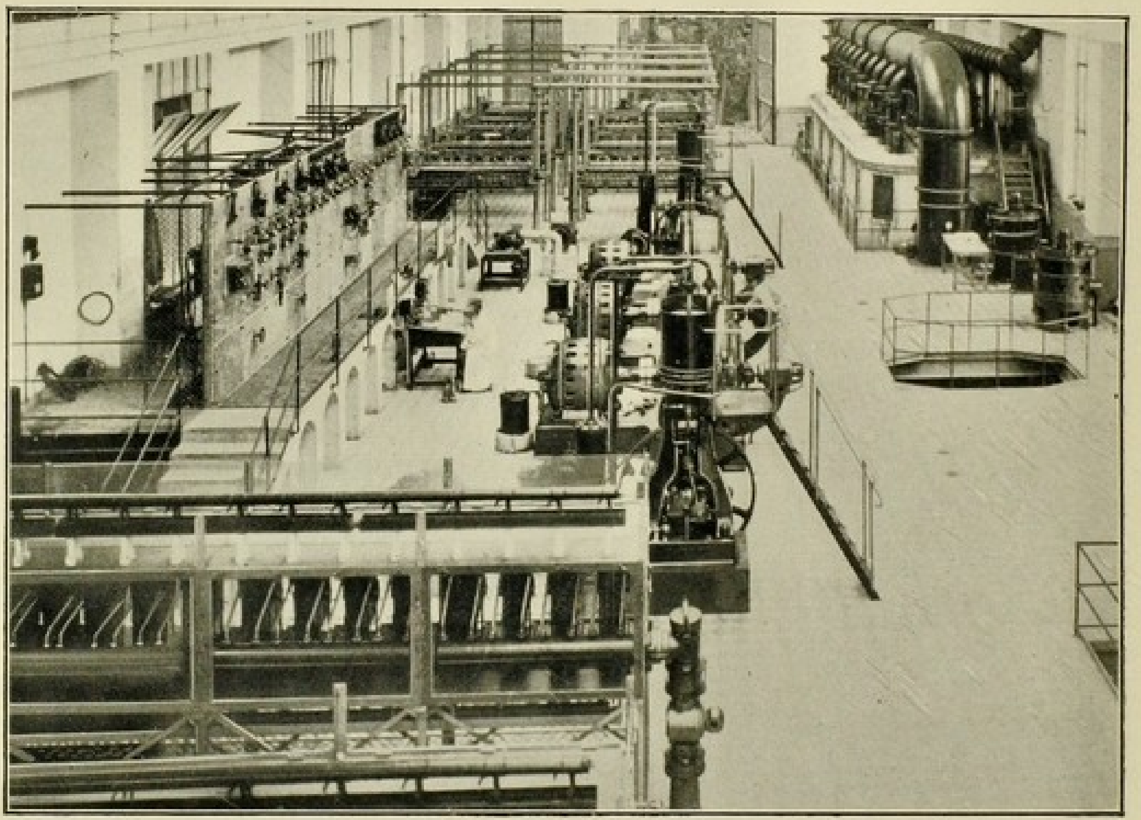


FIG. 9.

A section through the outlet pipe, from which, by means of a protected jet, a regular fraction of the ozonised water is withdrawn for testing.

PLATE XXI.



Ozone Sterilising Plant, St. Maur, Paris.

[*To face p.* 205.

peroxide was found in only one instance (it need hardly be said that this rapidly disappeared). The hardness was not altered. The organic matter, as judged by the oxygen-consumed standard, was reduced by an average of 43 per cent.

It was found that 73 per cent. of the ozone was immediately utilised in purification, 7 per cent. remained dissolved in the water and during its disappearance in one or two hours storage effected a further oxidation, while about 20 per cent. passed off with the air current. The latter fact proves that the De Frise cycle, in which the residual ozone is used again, is essential for economical working.

D. *Bacterial.*—Two sets of observations were made each day, in morning and afternoon and the detailed figures are given in the above report. The total number of organisms in the filtered water varied from 320 to 40 per c.c. with coli present in 100 c.c. After ozonisation the total organisms were 2, 1 or less than 1, per c.c.; and these corresponded to innocuous spore-bearing organisms of the subtilis type; coli were always absent.

The results of the bacteriological examination prove that the ozone treatment destroys all but the more resistant spore forms of bacteria present in the filtered water: coli and allied intestinal organisms are entirely eliminated, and subsequent contamination being excluded, there is no recrudescence of this class of organism. The ozonised water during the period of the tests showed a uniformly constant degree of sterility as against a very variable bacterial content of the unozonised filtered water.

It is important to recall the fact that both the ozone and the chlorine treatment share the common advantage that an immediate chemical test, iodide of potassium and starch, gives the safety factor which is required for successful working in such a way that there can be no doubt as to the water issued being freed from deleterious organisms; whereas under a system completely depending on storage and filtration, although the safety change may be assumed to take place in the reservoirs, the uncertainty of the quality of the water on leaving the filter beds still remains.

The ozonisers were working throughout in a very steady and quiet way and without sparking. The electrical energy required for the production of the ozone during this period averaged 1·31 kilowatt-hour per 104 cubic metres of water sterilised. In addition 1·675 kilowatt-hour per 100 cubic metres was used in compression. Together, this gives a requirement of 1 kilowatt-hour for every 33 cubic metres, which, at the ordinary rate of 1*d.* per kilowatt-hour, would be equivalent to 0·03*d.* per cubic metre (220 gallons), = 0·136*d.* per 1000 gallons, cost of electrical energy for production and for compression.

The most efficient yield of ozone has been obtained with an alternating current of a periodicity lying between 200 and 500 periods per second, with a voltage as high as possible, limited by rise of temperature. The practical points to be kept in mind for economic working are as follows :—

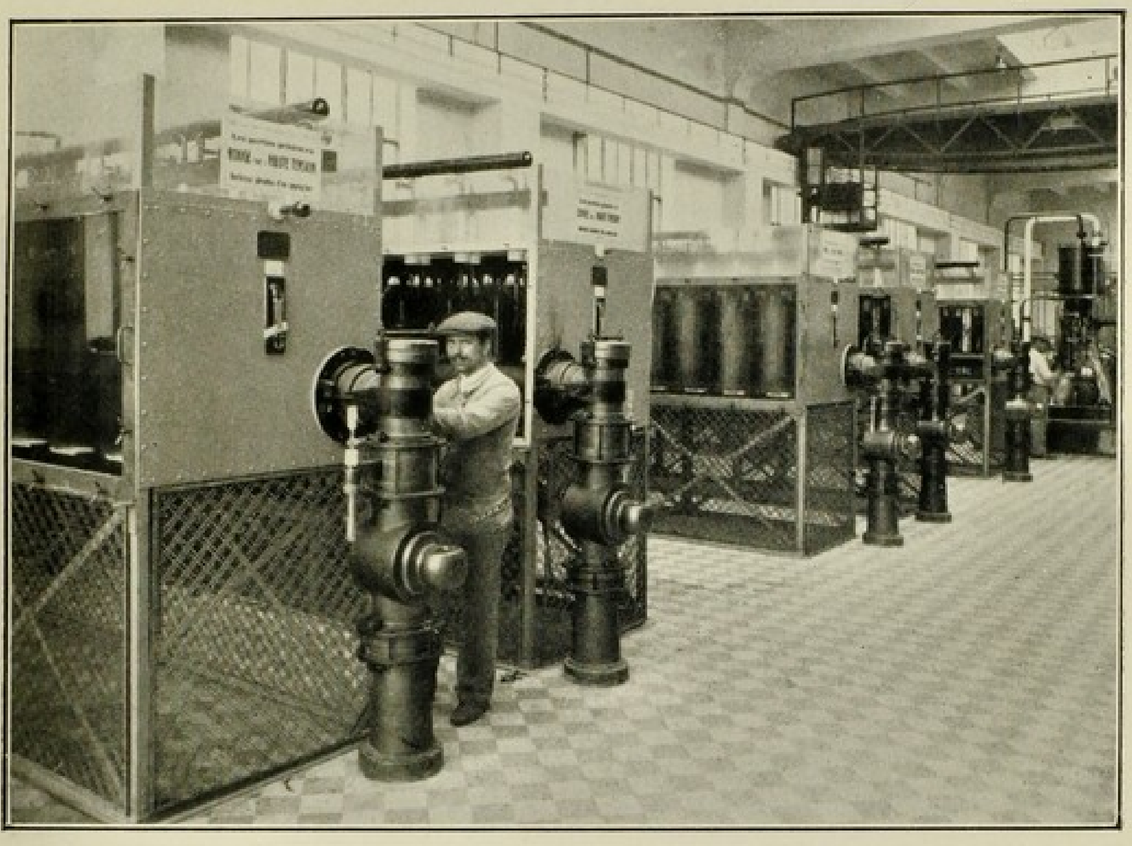
The machine *must* use dry air ; should have cooled electrodes ; it is safer to work with a moderate concentration than to aim at maximum strength ; the voltage should be kept as high as possible without sparking.

By calculation, the conversion of 96 grammes of oxygen into ozone requires 68,200 calories, which is equivalent to the expenditure of 1 kilowatt-hour for the formation of 1·2 kilogrammes of ozone. Existing generators fall so extraordinarily short of this yield that evidently the subject awaits further work. It is stated that the best results ever obtained with a silent discharge apparatus gave 36·7 grammes of ozone per kilowatt-hour, showing about 3 per cent. yield and 97 per cent. loss. A considerable part of this is accounted for by the diversion of the energy into the formation of the violet light, accompanied by the ultra-violet rays which have been proved so energetic. Regener * showed that the presence of ultra-violet light limits the concentration of ozone to within certain limits, above which it actually exerted a de-ozonising effect. But both ozone and ultra-violet light are sterilisers, therefore the sterilising energy is still maintained.

E. Rideal designed an apparatus (British patent 18680 of

* *Ann. d. Physik.*, ix, 1033, 1906.

PLATE XXII.



Emulsifiers at the St. Maur Ozone Plant.

[*To face p.* 206.

1910), in which the ultra-violet light produced at the same time in the silent discharge is made use of to sterilise water instead of merely decomposing the ozone. The apparatus is so arranged that the water is first partly sterilised by the ultra-violet light, and then finished by the ozone formed at the same time.

Many institutions and private houses where electrical power is available sterilise their drinking water separately by ozone, and an apparatus for the purpose is made by the Lahmeyer Co. (Otto process).

Dr. A. Sauna, at the International Congress of Applied Chemistry, London, 1909, gave notes of the chemical and bacterial effects he had observed in treating with 4 mgm. of ozone per litre the water of the river Po, which resulted in satisfactory purification. Nitrites, a part of the ammonia, and 15 to 43 per cent. of the organic matter were oxidised. The ozone was most active on pathogenic organisms.

Ultra-violet Light.

Early trials at Marseilles started from the fact that the output from sand filters could be considerably increased by the provision of an efficient sterilising apparatus to deal with undesirable microbes which may appear in the filtrate owing to increased speed of the filters. De Mare (patent 1906) immersed a mercury-vapour quartz lamp producing ultra-violet rays in the current of water and produced a certain amount of sterilisation. In 1908 the subject was practically investigated in a number of laboratories, particularly in France, and the researches of Courmont and Nogier at Lyons, and of Recklinghausen, Henri and Helbronner at the Sorbonne, Paris, were published at the end of 1909.

As we have already mentioned, the sterilising action of sunlight chiefly resides in the ultra-violet rays, and attention was directed to obtaining these as far as possible separately, from artificial sources of light. The biological effect was first studied by Finsen and his pupils, who applied the bactericidal effect of the rays, artifically produced, to the curing of lupus and other fungoid diseases.

The germicidal power having been proved, the next point was, as always, economical generation and use. Ordinary gas burners, incandescent mantles or glowing filaments are very poor in such radiations, but, on the other hand, incandescent *vapours* are rich in this actinic light, especially those of iron, aluminium and mercury. The earlier experimenters used electrodes of iron, or iron with aluminium cores, for the production of an electric arc between the ends. The water was allowed to run in a thin film exposed to the rays, but in the time of exposure to the light the effect was generally not sufficient, and difficulties occurred in the removal of the oxides of iron or aluminium formed.

See a paper by Urbain, Seal and Feigl, *Comptes Rendus*, October 31, 1910. At the Neuilly-sur-Marne Waterworks they employed an aluminium rod with an iron core, and a negative electrode of carbon. The water was made to flow round in a spiral, occupying three minutes in its course, and sterilisation was effected by 20 watts per cubic metre.

Mercury vapour lamps generate the light of short wavelength without difficulty, but obviously have to be enclosed, as the metallic vapour is likely to be oxidised or lost if the arc is formed in the open. Leo Arons * was the first to make use of glowing mercury as a source of the light. His apparatus consisted of a glass tube one metre long, containing a little mercury: on tipping the tube the mercury made contact between the opposite electrodes at the ends, permitting a current to pass which vaporised the metal. Its glowing vapour is a sufficiently good conductor of electricity to permit the steady and continuous use of the lamp at moderate voltages. D. Berthelot records that in 1895 M. Chas. Lambert submitted to the Paris Service des Eaux the description of his process for subjecting water to an intense illumination, while opposing no obstacle to the ultra-violet rays of the spectrum, and later M. de Mare patented the use of quartz lamps with mercury vapour for sterilising potable liquids such as water. In 1909 Drs. Courmont and Nogier communicated to the Academy their research on the

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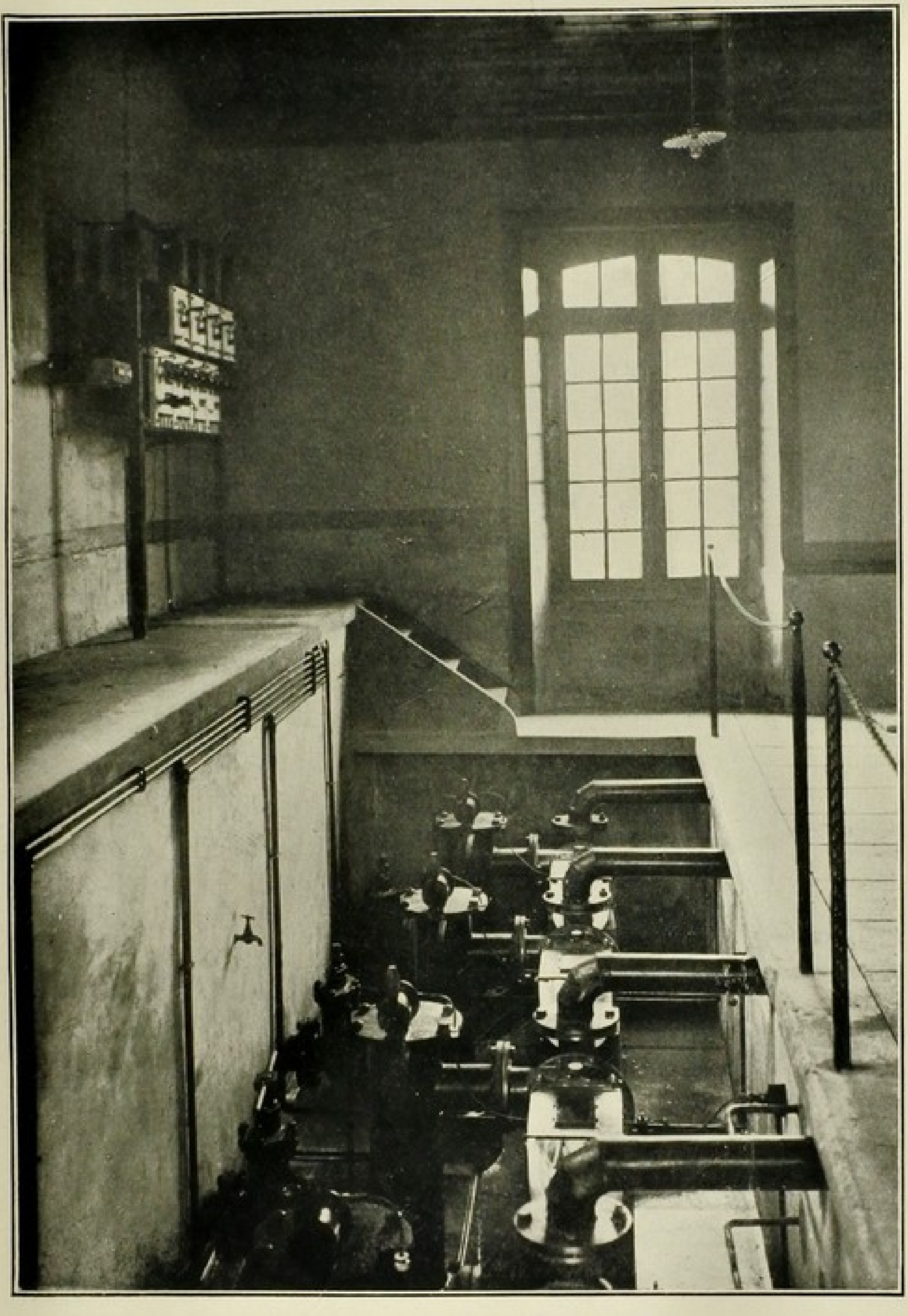
* *Wied. Ann.*, xlvii, 767, 1892.

PLATE XXIII.



ULTRA-VIOLET LIGHT STERILISING PLANT, ST. MALO.

[*To face p.* 208.

subject, which was followed by many others, proving that the bacilli of typhoid fever are radically sterilised by a short irradiation, which is in no way connected with ozone formation, as has been supposed; but the water must be limpid, as suspended particles present a screen to the irradiation. J. Courmont [*] also found that liquids containing colloids, such as wine, beer, peptone solution, etc., absorb the ultra-violet rays rapidly, and confine the sterilisation to the surface layer. Grimm and Weldert's [†] experiments were made with a mercury lamp of 1200 candle power enclosed in a double-walled quartz vessel through which the water was passed. Clear water containing less than 100 bacteria per c.c. could be sterilised when flowing at a rate of 0·55 cubic metre per hour, but if the numbers were much greater the rate must not exceed 0·45 cubic metre per hour. Turbidity or peatiness destroyed the efficiency.

It is because ordinary glass, though transparent, absorbs a great part of the rays, that the lamps are constructed of fused quartz (silica). The researches of Cooper Hewitt, the American engineer, improved the form and extended its practical use, and the apparatus is now made industrially by the Westinghouse Cooper-Hewitt Co. in London and Paris, and the Quartzlampen Gesellschaft in Hanau. The Compagnie de Eaux has obtained satisfactory sterilisation with Nogier-Triquet lamps immersed in the water, and an expenditure of energy between fifty and sixty watt-hours per cubic metre (220 gallons).

As the light is emitted radially, it will have its whole effect when it is in the middle of the water. This was very difficult with the earlier glass lamps on account of cracking, but was made easier on the introduction of quartz tubes, which had a different coefficient of expansion, and with moderate care, did not break. In most cases they were protected by a thin transparent envelope, which of course involved a small air space and some absorption of the rays. Two difficulties occurred: (1) after a while the lamp became

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[*] *Chemiker Zeitung*, xxxv, 806, 1911.

[†] *Chem. Zentr.*, xv, 1454, Berlin, 1911.

covered with a scale of deposited earthy carbonates and iron, blocking the rays; this could be cleaned off by hydrochloric acid at intervals, but the operation gradually injured the transparency of the tubes; (2) the temperature was considerably lowered by the immersion, and the light emission seriously reduced, so that the current necessary to produce sufficient incandescence of the vapour for sterilisation was very largely increased. Consequently, it is now found necessary that the lamp should not directly touch the water. At the same time, placing the lamps above the water involves a sacrifice of energy. Dr. Recklinghausen * remarks that "in such a system, and in spite of reflectors, only perhaps 30 or 40 per cent. of the light emitted entered the water and obtained its effect."

A number of competitive trials were made at Marseilles, France. See *Engineering News*, lxiv, 633, 1910; *Water*, February 15th, 1911; and Trans. Inst. Water Engineers, London, xvi, 90, 1911. The Westinghouse Cooper-Hewitt Co. furnished an apparatus which sterilised 158,500 gallons of water per 94 hours by means of a single Westinghouse silica lamp of 200 volts and 3 ampères, with an expenditure of rather less than 98·4 watt-hours per 1000 gallons. It is admitted that the cost of preliminary treatment to ensure the absolute clarification that is necessary, must be taken into account in comparing the ultra-violet light method with other processes of sterilisation.

The system of Henri, Helbronner and Recklinghausen has been installed in the following towns in France, with the annexed outputs in gallons per day:—

Maromme-les-Rouen, 55,000; Isle-sur-Sorgues (Vaucluse), 220,000; Amiens, 3,740,000; Luneville, 1,650,000; St. Malo, 308,000. The general rate is 130 gallons per hour, with a *direct* current of 110 to 250 volts tension. It is arranged to have a small air space between lamp and water, so that the lamp should not touch the water directly, for the reasons mentioned above. Baffle plates make the water pass several times under the influence of the rays.

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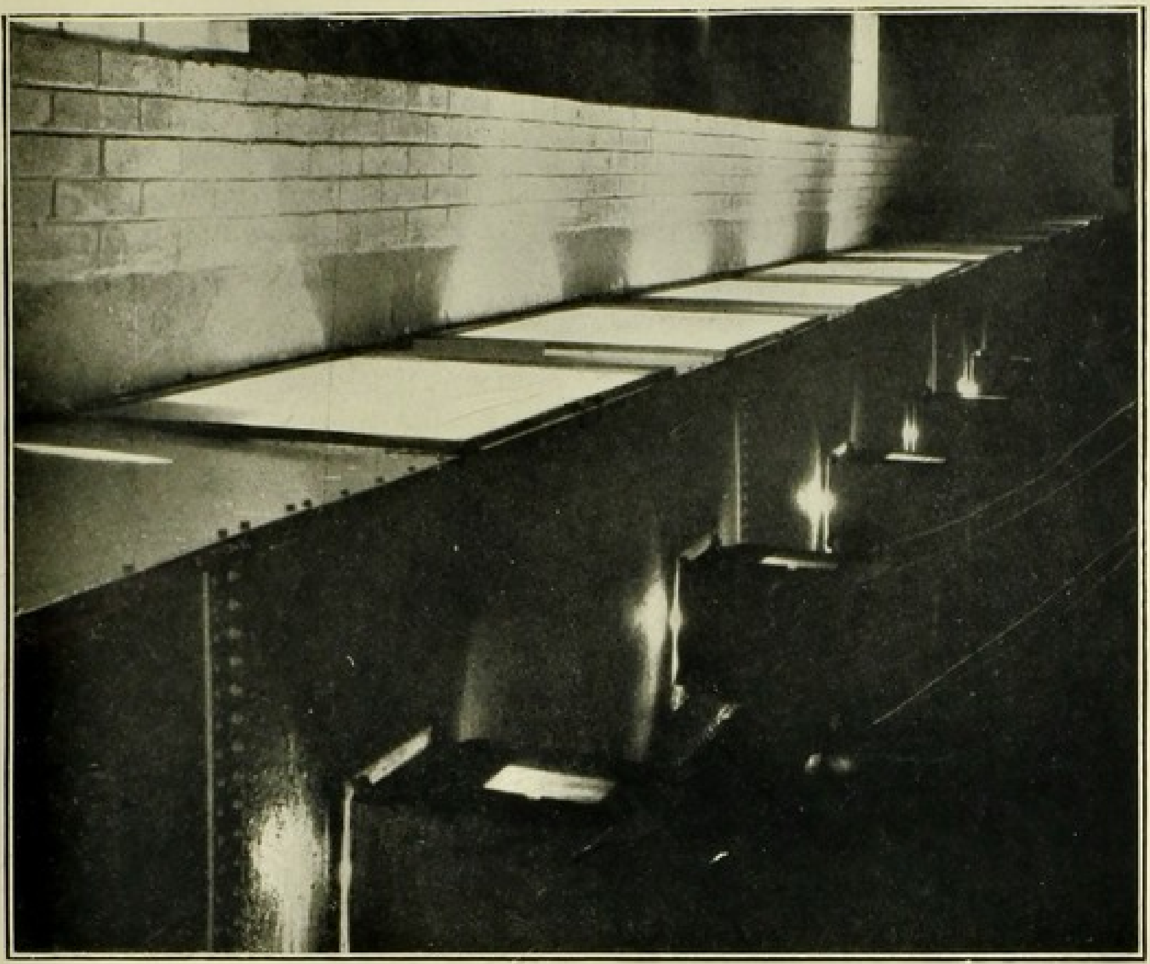
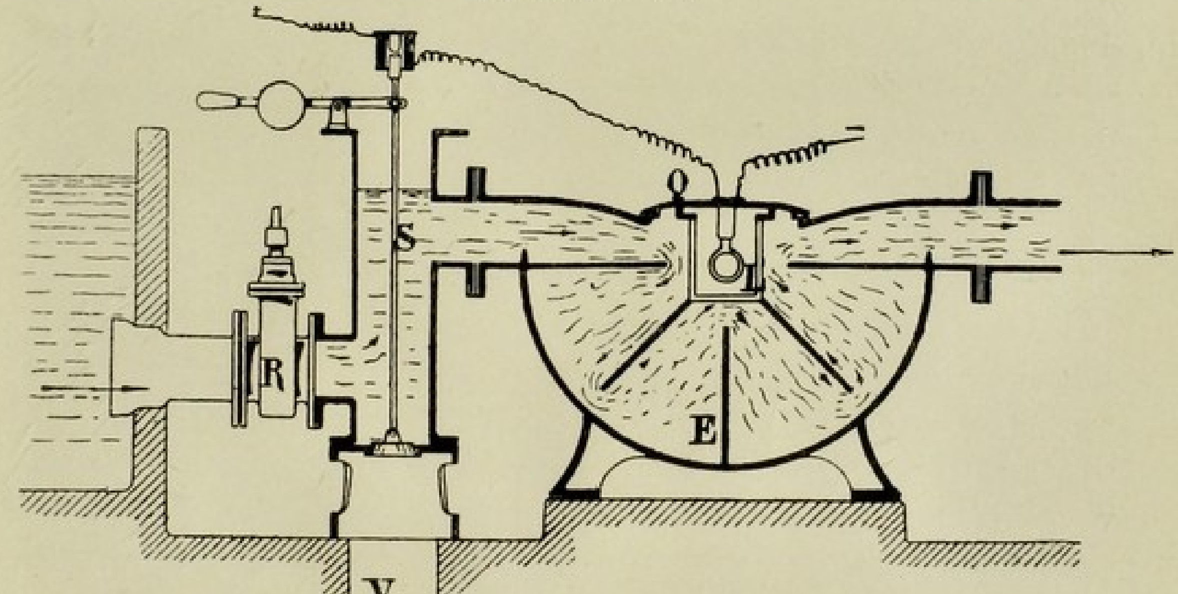
* *Trans. Inst. Water Eng.*, *loc. cit.*, p. 105.

PLATE XXIV.



Battery of Mercury Vapour Lamps treating 1,650,000 Gallons per Day at Luneville.



Section through an Ultra-violet Light Sterilising Unit.

L. Mercury vapour lamp. E. Baffle plates. S. Control valve (automatic).

[*To face p.* 210.

The action is very little affected by the temperature of the substance operated upon; even ice, if transparent, can be sterilised in about the same time as water. It is independent of the amount of dissolved oxygen, and is not due to the production of ozone, nor of hydrogen peroxide, as was once suggested, since only a trace of this is formed after some hours, whereas the sterilisation takes only a short exposure, and appears to be simply a physical action which is exceedingly rapid under certain conditions.

It follows optical laws in dependence on translucency, and also on the distance and power of the light, as is shown by the following results with a water infected with B. coli and subjected to Westinghouse Cooper-Hewitt silica lamps:—

Distance from lamp.		Number of seconds required to sterilise.	
Centimetres	= inches.	Lamp 110 volts.	Lamp 220 volts 3 ampères.
10	4	4	1
20	8	10	4
40	16	100	15
60	24	300	30

These tests are made on B. coli. It was found that the various classes of microbes are not all equally sensitive to the rays, just as they are not equally sensitive to heat or to chemical agents. In the Sorbonne experiments with a 220-volt lamp the comparative times necessary for killing were in seconds:—Staphylococcus (species), 5 to 10; choleræ, 10 to 15; coli, 15 to 20; typhosus, 10 to 20; dysenteriæ, 10 to 20; pneumobacillus, 20 to 30; subtilis, 30 to 60; tetani, 20 to 60.

M. Recklinghausen in *Le Genie Civil*, 1911, estimated that the process would give water suitable for domestic purposes at an expenditure of less than 98·4 watt-hours per 1000 gallons using an apparatus with a capacity of about 160,000 gallons per 24 hours.

The mercury light is the best source of ultra-violet rays we have at present. It, however, gives off rays of other degrees of refrangibility, the percentage ratios of the different colours having been measured as :—yellow 22, green 33, blue 8, violet 4, ultra-violet 28, red, etc. about 5 ; = 100. To increase the proportion of ultra-violet other substances have been amalgamated with the mercury with more or less success. It has been mentioned that ordinary glass absorbs the ultra-violet, therefore fused quartz has to be used. Lately a special glass called "uviol" has been made at Jena as a substitute for quartz, but is said to be not so good.

An illustrated description of existing plants for ultra-violet sterilisation by Dr. Orticoni of the French Army is given in *La Science et la Vie*, of December, 1913.

In using a V-shaped lamp the inner wall at the bend becomes excessively heated, as the arc takes the shortest path and therefore passes closer to the inner wall. To avoid troubles so caused, the part is made thicker, or is provided with protecting ribs which divert the arc. French patent 453,191 of 1912, with an addition by Recklinghausen, Henri, and Helbronner ; other patents of theirs for the apparatus are, English, 12947 of 1910 ; U.S. 1,068,898 of 1913. In A. Blavinhac's French patent, 453,912 of 1912, the water is treated with a small quantity of calcium hypochlorite and then submitted to the ultra-violet rays.

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CHAPTER XII.

ANALYSIS AND INTERPRETATION OF RESULTS.

THE results of a bacteriological or chemical analysis of a sample of water, expressed numerically and in a technical way, lead to definite conclusions which, with a little trouble, are clearly understood.

The minute proportions in which some of the most significant impurities exist in drinking waters render the analysis exceedingly difficult and delicate. The difference between a pure and an impure water may only be indicated by a few parts in 100,000; and the problem is further complicated by the fact that, as animal and vegetable substances contain practically the same elements, it is often difficult for the chemist to decide whether the pollution is of animal or vegetable origin. As the quantities are so small, it is very rarely that their exact nature can be ascertained, so that usually the decomposition products only are determined. But the information furnished by an analysis gives valuable suggestions as to the quality of a water, especially if its source be known and the data of its normal composition have been previously ascertained; regular analyses are needed for public supplies.

Results are still often expressed in grains per gallon of water, *i.e.* in parts per 70,000. The method of stating in parts per 100,000 is, however, far preferable, inasmuch as being founded on a decimal system, they are at once comparable with analyses made in other countries. Continental results are sometimes stated in grammes per litre (parts per 1000), whilst occasionally parts per 1,000,000 (milligrammes per litre), have been adopted. Results expressed as grains per gallon can be converted into parts per 100,000 by dividing by seven and multiplying by ten, and *vice versâ*. A committee of the British Association recommended that all water analysis results should be expressed in parts per 100,000, and many authorities have since adopted that plan, which is the one used in this book.

Samples of water for analysis should be taken in the stoppered half-gallon bottles known as "Winchester quarts," which are obtainable at most chemists. They should be free from any adhering dirt, and washed out with concentrated sulphuric acid when purchased, then filled up with common water and rinsed several times, finally with distilled water.

In collecting the sample precautions are necessary. The bottle should be filled to the top with the water, then rinsed out with it, filled, and the stopper rinsed and inserted. Except when the gases dissolved in the water are to be examined, it is best to leave a small air-space below the stopper. If possible the temperature of the water should be observed at the time of collecting the sample. Any surrounding circumstances—distance of dwelling, etc., nature of soil, depth of well, presence of plants, etc.,—should be noted. After the sample is collected it should be despatched as quickly as possible to the analyst, since many waters change very considerably on keeping.

Samples required for bacteriological examination should be separately taken in sterilised bottles, about six ounces in capacity, and immediately packed in ice and forwarded for examination. For an ordinary chemical analysis one Winchester quart of the water is sufficient, but when a mineral analysis is required two or three times this amount will be found necessary.

The interpretation of results of analysis is often a matter of considerable difficulty, as the analyst judges of the purity or otherwise of a water upon all the factors presented to him, and not on any single constituent. Some authorities insist upon withholding from the analyst particulars as to the source and possibly contaminating influences of a water sent for analysis, thinking that by so doing his opinion will not be biassed in any way. Such procedure is, however, most undesirable, as it must obviously be to the interest of the senders to arrive at the truth, and any circumstances which are leading to suspicion may be very helpful to the analyst, as explaining some of the figures which he may obtain, which otherwise he might consider not sufficiently condemnatory to warrant his pronouncing against the supply.

Complete examination of a water includes inquiry into physical, chemical and biological data.

I. Physical

features should, as far as possible, be ascertained at the time of collection, with notes as to surroundings and on the following points :—

(*a*) *Temperature* is frequently a matter of great importance. Fermentations of the organic sediments are much more active when the liquid is warmer, therefore a water which is innocent in winter may become foul in summer. The conclusion would be that the source was not a safe one, as shown by analyses in winter and summer. Great fluctuations in the temperature of a source generally prove that it is not sufficiently protected.

(*b*) *Motion of the Water.*—In a river, the rate of flow ; in a lake, direction of the currents and winds ; with a spring or well, depth and yield ; details of the strata and their dip from a geological map.

(*c*) *Appearance and Odour.*—All characters are apt to undergo change when there is a considerable interval between collection and analysis ; therefore a sample should be forwarded as quickly as possible, and an observation taken on the spot.

(*d*) *Abundance and Nature of the Visible Aquatic Life.*—This we have dealt with in Chapter II.

At the laboratory the physical examination relates to :—

1. *Taste.*—In common with odour, no exact scientific measurement, or classification, has been yet attained, and they still remain empirical, and subject to a disputable

opinion. But on the other hand the causes can be determined and defined in the laboratory. The taste may be affected by gaseous, organic or mineral constituents. Absence of dissolved gases makes the water "flat"; this, and the flavours originating from salt, sulphur, iron, magnesia, or peaty matters correspond with the analytical figures.

2. *Odour.*—Warm to about 60° C. in a stoppered bottle half-full, shake, and smell. We have sometimes detected petroleum oils by this test; aromatic and fishy odours may be due to organisms, and occasionally to effluents from works. The smell of urine is very persistent and may now and then be distinctly identified. Fractional distillation at a gentle heat will concentrate the impurity; and without this it can sometimes be separated by shaking with *pure* ether, separating and distilling the latter to a low bulk and gently evaporating the last portions. It goes without saying that such waters will not be suitable for drinking, but the cause must be ascertained.

3. *Colour.*—Pure water has a bluish tint, rather intensified by various forms of finely-divided suspended matter owing to reflection from the sky, as noticed in some Swiss and other lakes. This colour is also connected with dissolved oxygen or ozone: we observed that in ozone treatment at St. Maur the purified water looked a clear, light blue in the white enamelled tank. A standard way of judging the colour of a sample is in a 2-feet tube with glass plates cemented-on for ends, and a side tube for introducing the water. If pure it will be transparent and have the pale blue tinge, but in most ordinary waters the impurities give shades of mixed yellow, green and red, resulting in a miscellaneous brown. It is often very serviceable to analyse this by a Lovibond's Tintometer, with reference to the origins of the tint, and their separate proportions.

Many conventional standards of colour have been suggested. Comparison with the tint produced by the Nessler test with definite amounts of ammonia only measures depths of brown, but may be sometimes useful. Crookes, Odling and Tidy, with the object of obtaining definite figures that could easily be repeated by any observer and made universally comparable, employed hollow glass wedges containing liquids of complementary colours and known strength, etched on the face with the thickness of layer. One wedge was filled with a mixture of cupric sulphate and cobalt chloride, the other with ferric chloride. They were made by a rackwork with index to slide over one another in front of a circular hole admitting diffused daylight, until the colour matched that of the water in a 2-feet tube. The figures were stated in millimetres of blue and brown solution of definite strength.

The method was used by Crookes and Dewar in their official monthly reports on the London waters under the Metropolis Water Act, 1871. Dr. Thresh (*Examination of Waters and Water Supplies,* 1913, p. 91) shows that there is some general correlation between the colour and the amount of organic matter as indicated by the "oxygen consumed."

Thus in the returns of 1910–1911 the averages for the year are:—

Source of water.	Colour.		Oxygen absorbed from permanganate. Parts from 100,000.
	Brown.	Blue.	
New River	11·0	20	·049
East London (Lea) . .	17·0	20	·084
,, ,, (Sunbury) .	18·0	20	·078
Chelsea	21·0	20	·101
West Middlesex . . .	21·0	20	·100
Lambeth	21·0	20	·101
Grand Junction . . .	16·0	20	·079
Southwark and Vauxhall	19·0	20	·092
Kent wells	0·0	20	·008
Raw Thames water . .	75·0	20	·240
Raw Lea water . . .	82·0	20	·246
Raw New River water .	38·0	20	·090

But on the other hand the results of *daily* examinations prove that there is no regular connection between the depth of brown and the amount of organic impurity. A reason is that the brown colour, although it indicates impurity, is ambiguous as to its source. It may be due to:—

1. Remains of sewage.

2. Humous matters from moors, or from trade processes.

3. Iron oxides ; sometimes manganese.

In American reports we find the colour registered in terms of Allen Hazen's "platinum-cobalt standard." A standard solution is prepared containing half a gramme of platinum (as chloride) and a quarter gramme of cobalt (as sulphate or chloride) in a litre of distilled water. This is diluted quantitatively, and on the Lovibond principle a set of tinted glass discs is made to correspond with the different grades, "One part of metallic platinum in 10,000 parts of water forming the unit of colour." The actual test is similar to nesslerising, with two tubes standing on a white surface ; one tube contains the sample, the other distilled water ; and different discs are placed under the second one until the colour is matched, then the figure is read off. Of course the standard solution can be applied as in ordinary nesslerising. We may comment that in comparison with this method, which ignores *blue*, a natural constituent of water colour, and only includes it by chance as a part of the cobalt spectrum, the Lovibond method, and also the Crookes-Dewar, are distinctly superior.

The approximately quantitative determination of colour is necessary, but not diagnostic as to cause of contamination.

W. T. Burgess's apparatus (*Analyst*, October, 1902) is mechanically very easy to work. Light is reflected by an inclined white plane through two horizontal two feet tubes, one containing distilled water and the other the sample. At the end an inclined mirror reflects the ray upwards through two cylinders of colourless water standing over holes in a platform. The colour is matched, like nesslerising, by adding measured quantities of a brown solution, similar to the American one, except that potassium dichromate is used instead of platinic chloride (1 grm. pure crystallised cobalt sulphate and 0·05 grm. of potassium dichromate in 1 litre). This apparatus is used by the Metropolitan Water Board, and the results are recorded in millimetres of brown. It is obvious that it can be used with any standard solution.

4. *Turbidity*.—Liquids affect a beam of light in three

ways: (*a*) as to colour, by selective absorption of rays of different wave-lengths (last section); (*b*) occasionally by fluorescence or change of refrangibility, caused at times in waters by the chlorophyll of green algæ, or by a petroleum oil; (*c*) through reflection and scattering by suspended matter. The third is properly called turbidity. A regular approximately quantitative estimate was included in United States reports, both Government and local, for a very long time before its value was recognised in other countries, where waters were merely put down as clear, nearly clear, or turbid, and so on; and sometimes the weight of suspended matter was given, but this figure does not take into account the nature and size of the particles.

A Pittsburg Filter Commission determined the amount of interference of turbidity with the life of a sand bed, and found as an average:—

Turbidity.	Delivery.
0·05	400
0·1	270
0·2	180

In Europe it was observed at Antwerp that the turbidity of the water is of the utmost importance when following the purification effected by the passage through a system of sand filters, since by this means a rough estimate of the purification effected in the previous filter and the head required in the next filter, can be obtained.

With mechanical filters using aluminium salt G. W. Fuller proved at Louisville and Cincinnati (*U.S. Techn. Quarterly*, June, 1899) that marked turbidity calls for a dose of coagulant entirely beyond that required for decolorisation. Therefore this physical property requires a special optical determination. "Silica standard" methods compare the water with suspensions of kaolin, or of the finely-ground frustules of diatoms (Whipple and Jackson, *Eng. Record*, January 27, 1900).

A general principle is that for any given object under water there will be a maximum length of vertical distinct vision for the normal eye. This has been determined with fair consistence by lowering a white disc or an electric lamp. Hazen (*J. Franklin Inst.*, 1899, cxlvii, 147) used a platinum wire 0·04 inch diameter fixed at right angles to the end of a graduated rod, which is pushed down into the water until the wire just becomes invisible. The distance from the surface is then read, and the degree of turbidity is inversely proportional to it. When it was one inch the turbidity was called 1·0; when two inches, the figure was 0·5, and so on, giving very small decimals for clearer waters. The U.S. Geological Survey adopts as a standard "the index 100 to a water in which a $\frac{1}{25}$ inch (0·04) platinum wire is just distinctly visible under direct vertical illumination when held horizontally beneath the surface at a depth of 100 millimetres." The method has become a general one on account of rapidity and convenience. The subject is very fully discussed in Hazen's book on *The Filtration of Water Supplies*.

Anthony's Turbidimeter or Diaphanometer measures the property more exactly in the laboratory by applying the principle of polarisation. It has two parallel tubes 50 centimetres long: one closed at the ends by glass plates contains the water sample, the other is an empty tube with a Nicol's prism at the lower end. The eyepiece, carrying another Nicol's prism and an angular measure, is so arranged that when white light is sent through, half the field is illuminated by the one tube and half by the other. The angle is then observed, and the eyepiece rotated till the two fields are alike, when the number of degrees through which it has to be turned is a measure of the opacity. This instrument has been adopted for London waters by Dr. Houston (*Studies in Water Supply*, 1913, p. 5), who uses for comparison definite dilutions of "saccharated carbonate of iron, B.P.," and plots out a curve by which he reads to hundredths.

5. *Electrical Resistance.*—It had been shown by Faraday that the conductivity of pure water was very low, and Kohlrausch investigated its increase by electrolytes and found that

in dilute solutions it had a direct quantitative relation to the amount of substance dissolved. When, therefore, the composition of the dissolved matter is known, the conductivity of the solution is a measure of the quantity of the salts present in the liquid. Digby and Biggs pointed out the advantage of regularly determining the conductivity of trade water, for rapidly detecting changes in composition, and they devised a serviceable apparatus called "the Dionic Water Tester" for the purpose. This instrument has many applications, such as the control of feed water for boiler purposes, testing the tightness of condensers, detecting priming, as well as furnishing an index in oil eliminating and water-softening plants.

II. Chemical.

The total solids are ascertained by carefully evaporating a measured volume of the water (generally 250 c.c.), drying the residue at 120° C., and weighing it. The solids in a good drinking water should not amount to more than 30 or 40 parts per 100,000, and should be white and crystalline, or finely granular, and not coloured in any way. Frequently a water sample contains matter in suspension, and it becomes a question whether the suspended matter should be included in the total solids or separately recorded. As a water sample is often taken by inexperienced persons, it is exceedingly unlikely that the suspended matter collected in a Winchester quart represents fairly the average amount of matter in suspension in the water, so that, in most cases, the analyst prefers to separately estimate this amount. The total solids are therefore determined upon a sample of the water taken from the bottle after it has been allowed to stand for some hours, when the grosser particles will have subsided to the bottom of the bottle.

The loss on ignition represents the amount of loss which the total solids undergo when the dish containing them is heated to low redness. If there is much organic matter present the solids blacken, and when the organic matter is of animal origin an odour of burnt feathers, indicating the presence of much nitrogenous matter, is noticed. The ash may be coloured brown if iron is present in the water, but is usually white, and consists of the mineral salts present. Many mineral salts, *e.g.*, magnesium chloride, lose acid on being heated in this way, so that the loss on ignition is not an absolute measure of the amount of organic matter present in a water. To overcome this difficulty some analysts add a known amount of sodium carbonate to the solid residue before igniting, in order to fix any such acids which might otherwise be evolved.

The total amount of chlorine as chlorides is determined volumetrically by a standard silver solution. The result is returned as chlorine, and also in terms of sodium chloride. It must not be forgotten, however, that many waters naturally contain other chlorides, so that the return of the whole of the chlorine as sodium chloride is only conventional. Potassium chloride is significant of *animal* muscular débris, therefore a separate potassium determination is frequently required. A high chlorine, however, usually raises a suspicion of contamination with sewage, as urine contains about 1 per cent. of sodium chloride (about 1·5 to 3·0 parts of chlorine per 100,000 is a normal amount); but in districts where there are salt deposits, as in Cheshire, or in wells in the new red sandstone or in proximity to the sea, the water may normally contain a higher amount without indicating sewage pollution. In the United States the influence of the sea on land water has been carefully studied, and Dr. Brown, in his reports to the Massachusetts State Board of Health, has shown that it is possible to map out a country by lines nearly parallel to the coast line, in which the ground water shows equal amounts of chlorine. Such lines he terms "isochlors," and in his hands they proved of considerable value, since an excess of chlorine found in any well water above the natural "isochlor" points at once to local contamination. (Bulletin U.S. Geological Survey, No. 148.) E. B. Kenrick gives a "chlorine map" of the Winnipeg district, which proved very informing, in *J. Soc. Chem. Ind.*, 1902, p. 747.

The amount of chlorine found in a water can be converted into its equivalent amount of sodium chloride, NaCl, by multiplying by the factor 1·65. Although chlorine as chlorides may give a measure of the amount of sewage pollution that the water has received, it does not give any information as to when such pollution took place, since, by filtration and oxidation, the organic matter of the sewage and the pathogenic organisms possibly present may have long since been entirely removed from the water.

The term oxygen consumed, or *oxygen absorbed*, by the organic matter in a water, means the reduction which an acidified solution of permanganate of potassium undergoes when brought into contact with a known volume of the water. This test, originally introduced by Forchammer, has had many variations in detail, as to strength of solution, time, and temperature. The red colour is gradually destroyed, very polluted waters removing it almost instantaneously. Using a solution of permanganate of ascertained strength, the amount remaining unreduced at the end of the test is determined by adding a slight excess of potassium iodide, and titrating the liberated iodine with a standard solution of thiosulphate in the usual way. Dr. Tidy advocated estimating the amount of oxygen consumed at 80° F. in two stages:—

1. In fifteen minutes: this figure includes the nitrites and any ferrous salts, sulphides, and any very easily reduced organic matter.

2. In four hours: after this time the whole of the organic matter will have been oxidised from most waters, but with very bad waters a longer time is still required to finish the oxidation.

The Metropolitan Water Board record the "oxygen absorbed from permanganate in three hours at 80° F."

A blank with pure distilled water should always be mounted under the same conditions.

Attempts have been made to calculate the relation between the amount of oxygen required and the amount of carbon present in the water as found by combustion, but no definite relation seems to exist, since the factor varies with waters of different characteristics. Where, however, consecutive determinations are made on the same supply, the oxygen absorbed approximately represents the carbonaceous matter, and varies, like the albuminoid ammonia and the chlorides, with the fluctuations of the seasons, so that any abnormal deviation at once points to some new source of pollution.

The condition in which *the nitrogen* derived from animal organic matter exists in a water is one of the chief points which a full chemical analysis determines. A water contaminated with sewage will contain a determined amount of chlorides and nearly all nitrogenous matter with which such chlorides were originally associated. If, after pollution, the water has been under the influence of bacteriological action, the nitrogen may have been converted into oxidised forms; and, therefore, in most cases a water contains nitrogen in the several forms of organic compounds, ammonia, nitrites, and nitrates. Fresh sewage is practically free from nitrates, whilst a deep well, or well-oxidised river water, contains the nitrogen almost entirely in the form of nitrate. The ratio of the oxidised to unoxidised nitrogen in a water, gives a measure of the amount of purification which has taken place, and the total nitrogen of all kinds indicates generally the amount of pollution which the water has sustained. Under certain conditions, however, some of the nitrogenous compounds are so completely destroyed by bacterial agencies that nitrogen gas and the lower oxides of nitrogen are evolved, and a loss of total nitrogen is therefore caused. When the quantities of nitrogen in a water are compared with the amount of chlorine, it is found that the chlorine is largely in excess, although in urine the amount of nitrogen is slightly greater than the amount of chlorine. This difference between theory and the amount actually found is due to the absorption of nitrates by plants, and only in raw sewage do we find that the amount of nitrogen at all approaches the amount of chlorine.

The term *albuminoid ammonia* is given to the quantity of ammonia which can be obtained from a water after the removal of the saline, or free ammonia, when such water is boiled with an alkaline solution of permanganate. The process was first devised by Wanklyn and Chapman, who showed that, although the total organic nitrogen was not obtained in this way in the form of ammonia, all polluted waters gave off a fraction of the nitrogen in this form, so that the relative amounts of albuminoid ammonia fairly represent the amounts of unoxidised organic or polluting matter actually present. Before determining the albuminoid ammonia, it is necessary to remove the free ammonia, so that a determination of the amount of free ammonia is first made.

Free Ammonia and Albuminoid Ammonia.—For this determination half a litre of the water, made alkaline with carbonate of soda, is distilled until the free ammonia has passed over, and the amount estimated by the brown colour given by Nessler's reagent.* To the remainder in the retort a solution of potash and potassium permanganate is added, and the distillation continued until the "albuminoid ammonia" has all come over; the amount is estimated by means of Nessler's solution, as in the case of the free ammonia. A large quantity of free ammonia is generally indicative of recent sewage contamination, as it is frequently formed directly from urea by bacteria. Vegetable matter gives rise to little or no ammonia on decomposition.

As already mentioned, the albuminoid ammonia is only a relative quantity, and does not give the absolute amount of organic nitrogen present in a water. In some of the recorded cases of water-borne typhoid the amount of albuminoid ammonia found in the water was so extremely small that the supplies would seem from the chemical analysis alone to be of high organic purity. It has been shown that Bacillus typhosus actually flourishes better in a water which is pure and free from other matter which has undergone nitrification. In an inoculated water Pearmain and Moor found no less than 900,000 bacteria per cubic centimetre, but the amount of pollution produced by adding the broth culture to the water

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* The reaction has been elaborately examined by Buisson, *Comptes Rendus*, cxliii, 289; cxliv, 493.

was so small as not to appreciably raise the amount of albuminoid ammonia.

Nitrites are usually looked for qualitatively by colour reactions, and are returned as strong or slight, according to the intensity of the colour produced. They are a bad sign when present to any appreciable extent, as they either indicate that the organic matter is only then undergoing oxidation, and is therefore recent in character, or point to a reduction of nitrates present in the water by reducing organisms and fresh contamination with organic matter. In this way a river water containing a large quantity of nitrates may suddenly lose them owing to admixture with fresh sewage, but the change is usually detected by the simultaneous production of nitrites. The presence of nitrites, therefore, indicates temporary or unstable conditions of the nitrogen contents of the water, and points either to incomplete nitrification of the ammonia, or to a reduction of the nitrates previously present.

Nitrates.—Rain-water contains them in traces derived from the air, by the direct combination of atmospheric oxygen and nitrogen, as in thunderstorms. Mainly, however, they are the product of nitrifying organisms. Dr. E. Frankland's original description of nitrates as "previous sewage contamination" is thus to a great extent justified, for moorland waters and those containing vegetable *débris* are almost free from nitrates. In deep well-waters from the chalk the nitrates are often high ; here the water, originally derived from the surface, has passed through a perfect natural nitrification and filtration. But nitrification can take place in a polluted water so rapidly that nitrates may accumulate after transit through a layer of soil quite inadequate to remove the germs of either typhoid or cholera. Nitrates encourage the growth of organisms. Therefore a water which contains over 0·5 or 0·6 part of nitrogen, as nitrates or nitrites, in 100,000, may be certified as dangerous, even if for the time the free and albuminoid ammonia are not excessive, especially if the chlorides are also present in undue proportion. Nitrate and nitrite determinations are often recorded together as "oxidised nitrogen."

The results obtained as above, with a microscopical examination, are a general basis for an opinion on the quality of a drinking water. But as germs of disease are so excessively minute that they may be actually present, and yet yield no weighable or measurable quantities to chemical analysis, the latter alone can never assure that a water is perfectly safe, although it gives valuable information, and for the following reasons should never be omitted :—

1. Changes in the chemical composition of a water reveal the presence of active bacteria.

2. When pathogenic organisms are present in small numbers, their detection by bacteriological methods is very difficult.

3. Bacteria, as a rule, do not thrive without nitrogenous food, which is at once detected by analysis.

4. Their entrance into a water supply is almost always accompanied by sewage products ; these reveal themselves to the chemical examination, which in cases of doubt should always be supplemented by a bacteriological test.

For domestic and industrial purposes the *hardness* of water is an important item, and has been explained in Chapter IX. The determinations are always made on a standard volume of 100 c.c. of fluid. Stoppered bottles of 200 c.c. capacity are taken, and marked at 100 c.c. The most definite results are given in the neighbourhood of 10 c.c. of soap test, therefore a preliminary idea of the hardness of the water must be obtained by qualitative tests, so as to know what percentage of it will make an easily titratable strength. Then usually 50 c.c., but with hard waters 25, or even 10 or 5 c.c., are measured into the bottle, made up with pure distilled water to 100 c.c., and Clark's soap test gradually dropped in from a burette with glass tap, shaking vigorously at frequent intervals. The end point is when, after shaking, the lather stands for at least a minute. The reaction should always be overdone to make sure, since a large number of waters give a "pseudopoint," due to saturation of lime, but not magnesia, which without care will lead to a mistake.

For permanent hardness, generally 100 c.c. are boiled in a Jena flask covered with a funnel for half an hour, then cooled, filtered into the 200 c.c. bottle mentioned above, made up to 100 c.c. with distilled water, and titrated with soap solution.

In every case 1 c.c. is deducted from the burette-reading to allow for the amount required to produce a lather in 100 c.c. of pure water.

The soap solution is so made that, when 50 c.c. of water are taken, each c.c. of soap used represents 1 grain per gallon of hardness, "one degree Clark." Multiplying by 10 and dividing by 7 gives the parts per 100,000. If 100 c.c. of water be taken, as in the permanent hardness above, the c.c. of soap must be divided by 2; if 25 c.c., the soap figure must be multiplied by 2, and so on, remembering always to first deduct 1 c.c. from the burette-reading.

The hardness figures give an insight into the mineral composition of the "total solids," whether the water contains much lime or magnesia, and whether they are present as carbonates (temporary), or as sulphates, chlorides, or nitrates (permanent hardness). The chlorine and nitrates ("oxidised nitrogen") will have been already determined; the sulphates can be tested for by comparison with a water of known composition, *e.g.*, the tap water of the place. If the total hardness be deducted from the total solids, the difference is approximately the amount of sodium and potassium salts, which in some samples are a leading feature, and when excessive render the water laxative, of a bad taste, and unfit for drinking (see Table A in Appendix). The presence of *potassium* is significant in suspicious cases. Urine contains sodium salts, fæces yield mainly potassium compounds; hence the latter in large quantity point to pollution by solid excreta. *Phosphoric acid*, as a rule, is practically absent from pure waters, though traces occur where the strata contain coprolites. As phosphates are a characteristic ingredient of both urine and fæces "heavy traces" condemn a water; "traces" are suspicious. In sewage effluents which have been treated with alum and lime, phosphates are usually absent, having been precipitated as the insoluble phosphate of alumina. They may sometimes also be low in sewage effluents and undoubtedly polluted waters, if aquatic plants have had time to remove them in their growth.

Kjeldahl determination of the total nitrogen is sometimes required, as follows :—

A measured quantity, about 500 c.c., is boiled down in a Jena flask to near dryness with a crystal of pure K_2SO_4 and a very small globule of mercury, and 10 c.c. of *pure* H_2SO_4. Cool, and wash out into a retort with 500 c.c. of *pure* water, alkalise with NaOH (free from NH_3), add a drop or two of NaHS solution (also free from NH_3) to precipitate mercury, and a little ignited pumice or broken pipe. Distil, and nesslerise successive portions of the distillate as in the Wanklyn process. This gives a near approach to the total nitrogen (except the dissolved gas). After deducting the free ammonia, the rest is calculated into "organic nitrogen (Kjeldahl)." The results are about double those from the albuminoid ammonia.

No method at present devised yields with certainty the *whole* of the organic carbon and nitrogen in a water, and any that did so would still furnish little certain information as to its composition. With time and sufficient quantity it is possible to isolate definite organic compounds from waters by known chemical methods.

H. Fleck evaporated one or two litres to dryness with tartaric acid, extracted with absolute alcohol, again evaporated, and moistened with potash solution. With polluted waters he obtained a distinct odour of fæces (*skatol*), or trimethylamine.

M. Baudrimont extracts the original water with ether : on spontaneous evaporation of the solvent characteristic odours, fatty residues, etc., are left.

Zune concentrates the suspected water at a gentle heat until a few cubic centimetres are left, then extracts with warm alcohol. In the case of pollution by urine or fæces, he finds urea and biliary matters in the alcoholic solution, and uric acid (by the murexide test) in the insoluble portion. Such a discovery would, of course, be proof positive of admixture with fresh sewage. But these methods mainly apply to recent and extreme contamination, and odours are liable to great divergence of opinion.

Products of manufacture at times find their way into drinking water. Soap, petroleum, various fibres, traces of metals and chemicals have been detected in domestic supplies. These occurrences have sometimes been of service, as pointing to a leakage into wells or pipes that might also admit pathogenic organisms. Poisonous metals, like lead, copper, and zinc, should be entirely absent. Not more than a trace of iron is admissible. Arsenic, barium, manganese, etc., have been occasionally recorded.

The *determination of dissolved oxygen* is valuable in showing the purification or pollution of rivers during flow and in filtration experiments. Diminution in its amount generally indicates low *vegetable* life, usually attended by an unpleasant odour and taste, besides retarding natural purification. A fully aerated water will contain about 7 c.c. of dissolved oxygen per litre, the amount, however, varying with the temperature from about 6 c.c. in summer to over 8 c.c. in winter. See Roscoe and Lunt's table, Chapter I. A sewage or badly polluted water contains little or none. The figure is most easily ascertained by Rideal and Stewart's modified Winkler process (*Analyst*, June, 1901).

The following are fairly valid inferences:—

Free ammonia.	Albuminoid do.	Chlorine.	Indications.
High.	Moderate.	Small.	Sewer gas.
High.	Very high.	High.	Sewer water.
High.	Rather low.	Very high.	Urine.
Rather high.	Low.	Very low.	Vegetable matter, perhaps marshy.

Dr. Smart has pointed out that, in the albuminoid ammonia process, fermenting vegetable matter gives a yellow colour with carbonate of soda, and a greenish tinge with the Nessler test. This, coupled with the oxygen consumed and the rate of evolution of the albuminoid ammonia, led to the following discrimination :—

NH_3 evolved slowly = recent organic matter.
Oxygen consumed low = animal.
" " high = vegetable.
NH_3 evolved rapidly = decomposing organic matter.
Oxygen low: Nessler colour, the normal brown } = animal.
Oxygen high : Nessler greenish, Na_2CO_3 yellow } = vegetable.

The above differences of colour have been for a long time observed, and have been attributed to different causes. Water containing notable amounts of sewage always gives a peculiar aromatic odour in the first albuminoid distillate.

Wanklyn's standards for albuminoid ammonia are :—

High purity, 0 to ·0041 parts per 100,000.
Satisfactory, ·0041 to ·0082.
Impure, over ·0082.

In the absence of free ammonia, he does not condemn a water unless the albuminoid exceeds ·0082, but a water yielding ·0123 he condemns under any circumstances. This frequently condemned the waters of the London companies.

Frankland and Tidy's standards for oxygen consumed are :—

High organic purity, ·005.
Medium, ·05 to ·15.
Doubtful, ·15 to ·21.
Impure, over ·21.

Rigid universal limits for waters are, however, impossible. So much depends on the locality.

In a research on the distinct actions of sodium peroxide and of permanganate on the organic matter in water,* S. Rideal showed that different kinds of "albuminoid ammonia" are possible, remarking that waters containing fresh sewage which has been partially oxidised by the peroxide yield the remainder of their ammonia to the alkaline permanganate much more rapidly than when the

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* *British Association Reports*, 1893.

water has not been so treated, indicating the presence in waters of organic nitrogenous matters which, when partially oxidised, are then in a condition to be completely broken up by the stronger reagent. When the albuminoid ammonia process was introduced it was well known that there was a varying relation between the quantities of albuminoid ammonia and the amounts of different kinds of organic nitrogenous matter. The works of Preusse and Tiemann, Mallet, Leffmann and Bean, P. Frankland, and others, have confirmed the inference that, although a useful indication, too much importance must not be placed on this item of the analysis.

Barnes * compared the effects of acid permanganate and of acid bichromate on different bodies, and showed that the latter was far more energetic towards starch, glycerine, sugar, and gelatine ; that with albumen and its congeners the permanganate used increased, while in solutions containing tannin or peaty matters the amounts of permanganate and of chromate consumed approached equality. Woodman † applied Barnes' ratio to the discrimination of the nature of organic matter in waters. The processes are described in the papers quoted. For equal volumes of water, the number of c.c. of permanganate used, divided by that of bichromate, gives the "oxygen ratio." For example :—

I. PEATY WATERS, with high "oxygen consumed," but known to be free from sewage :—

	Colour.	Ratio.
Boston tap-water, July, 1897	0·3	0·656
" " January, 1898	0·7	0·646
" " March, 1898	0·48	0·649
Dark swamp water diluted	5·0	0·833
" "	1·8	0·689
Reservoir, Orange, Mass.	0·58	0·659
" Athol (full of algæ)	—	1·132
" " (filtered)	1·7	0·750
Infusion of dried leaves	10·0	0·656
Solution of humus in ammonia	—	0·692

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* *J. Soc. Chem Ind.*, 1896, 83.

† *J. Amer. Chem. Soc.*, 1898, xx, 497.

	Colour.	Ratio.
II. SEWAGES :—		
Sewage from Marlboro' (filtered, old) . . .	—	0·543
,, ,, Boston (decanted, fresh) . . .	—	0·389
Filtered sewage, Boston	—	0·470
Same, diluted with 5 vols. distilled water . .	—	0·490
,, ,, 10 ,, ,, ,, . .	—	0·460
Well, contaminated with sewage . . .	—	0·449

Peaty waters, therefore, give a ratio above 0·600, whilst sewage and waters polluted by it are below that limit, although urine alone, according to Barnes, gives 0·621.

A well-water suspected from the high "oxygen consumed" gave a ratio of 0·957; hence it was concluded that vegetable matter, and not sewage, had entered, which was confirmed by examination of the site.

Action on Metals.

The subject has been generally discussed in Chapter IV under "Distribution." We shall now shortly describe the tests. In judging waters this property is of considerable importance, but its quantitative determination requires many precautions. Commercial metals ordinarily contain impurities, and are to a certain extent alloys, and although general tests may be made, it is often desirable that they should be carried out with the sample of metal actually in use. Two separate features have to be investigated—the first one technically called *erosion*, relating to the metal which is converted into a surface-crust of oxides or salts; of course, in this way the substance may finally be entirely corroded, or the film first formed may protect the body of the material. This action does not necessarily injure the quality of the water.

The second one is called *solvency*, when the metal becomes actually dissolved in the liquid. The two actions often occur together. Any of the tests may be made with a slip of the thin sheet metal about 2 inches by 1 inch, rubbed bright and free from grease, weighed, and placed in a 250 c.c. wide-mouthed bottle containing 150 c.c. of the water, and covered loosely by a filter paper or a plug of cotton wool. At the end of a specified time, 24 hours or more, the slip is taken out, and any crust cautiously removed. Three items can be determined, if required :—

(*a*) The cleaned metal can be carefully and quickly dried, and weighed again, giving the loss of weight.

(*b*) The liquid is filtered, the insoluble matter added to the crust scraped off the plate, and the metal in question quantitatively estimated. This gives erosion.

(*c*) A similar estimation is made on the filtrate, giving the solvent power.

Each figure is then calculated on a square foot per 24 hours.

For ferruginous action iron tacks are very convenient. For lead, Dr. Houston in his examination of moorland waters made the water percolate upwards through a column of specially pure lead shot, then collected successive portions of 50 c.c. and estimated the lead in each, to discover whether the action persisted or decreased. See his report to the Local Government Board, 1895. The acidity of the water is determined by *lacmoid* on 100 c.c.

Determination of the "available chlorine" or "ozone" content by means of the "chlorometer." *—This apparatus was designed to detect and measure small quantities of oxidising agents in drinking water. It consists essentially of a platinum-copper couple of special construction connected to a sensitive micro-ammeter. Under normal conditions the couple is polarised and no current flows through the meter; immediately, however, any trace of ozone or free chlorine is present in the water passing through the instrument a certain amount of depolarisation takes place (the chlorine or ozone taking the place of the bichromate of potassium in the ordinary bichromate cell) and a small current flows. The dial of the micro-ammeter is calibrated in parts of available chlorine or ozone per ten million of water (see Fig. 10).

Measurement of Radio-activity.

The most general method for rapidly determining the amount of radio-activity in waters consists in boiling out the

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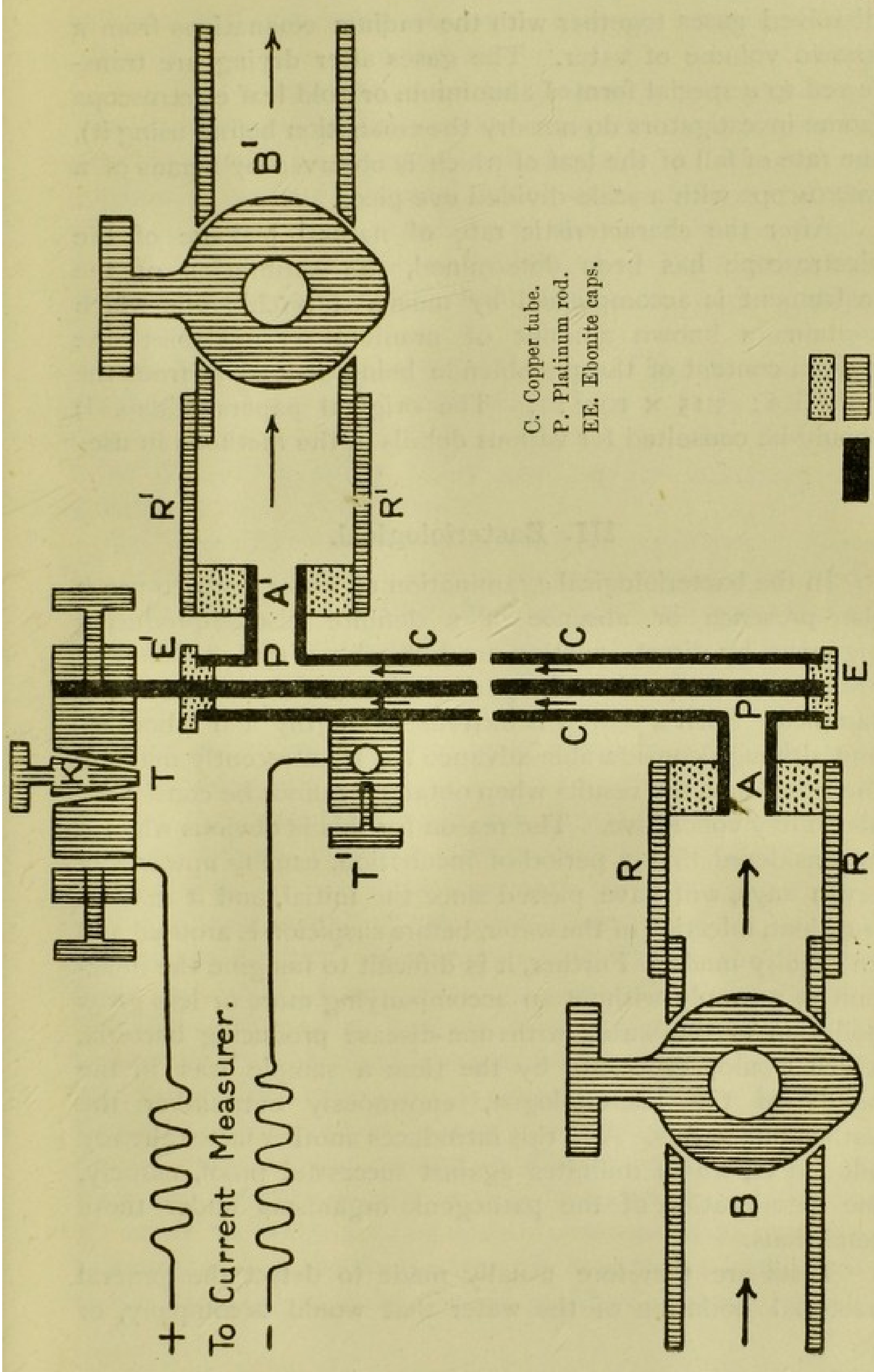
* *Analyst*, August, 1913.



C. Copper tube.
P. Platinum rod.
EE. Ebonite caps.

FIG. 10.
Section through "chlorometer."

dissolved gases together with the radium emanations from a known volume of water. The gases after drying are transferred to a special form of aluminium or gold leaf electroscope (some investigators do not dry the emanation before using it), the rate of fall of the leaf of which is observed by means of a microscope with a scale-divided eye-piece.

After the characteristic rate of natural leakage of the electroscope has been determined, the calibration of the instrument is accomplished by means of pitchblende which contains a known amount of uranium on analysis; the radium content of the pitchblende being arrived at from the ratio Ra : $3{\cdot}15 \times 10^{-7} : 1$. The original papers (Chap. I) should be consulted for various details of the methods in use.

III. Bacteriological.

In the bacteriological examination of water, tests to prove the presence or absence of a definite disease-producing organism by direct isolation are but seldom undertaken, and are never attempted in the periodical routine examination of samples. Such a search is extremely lengthy and laborious, and although considerable advance has been recently made in the procedure, the results when obtained cannot be considered absolutely conclusive. The reason for this is obvious when it is considered that a period of incubation, usually upwards of seven days, will have passed since the initial, and it may be transient, infection of the water, before suspicion is aroused and an inquiry made. Further, it is difficult to imagine the infection of a supply without an accompanying more or less gross pollution of the water with non-disease producing bacteria, which would, especially by the time a sample was in the hands of the bacteriologist, enormously outnumber the pathogenic germs. And this introduces another factor already alluded to, which militates against successful proof, namely, the deterioration of the pathogenic organisms under these conditions.

Tests are therefore usually made to detect the general bacterial pollution of the water that would accompany, or indicate the possibility of, any dangerous contamination. These routine tests are as follows :—

(1) The determination of the "number of organisms." This includes the bacteria capable of growth in the nutrient gelatine medium at room temperature. A number of gelatine plates are prepared with various volumes of the water up to 1 or 2 c.c., according to the nature of the sample, mixed with the gelatine and solidified in Petri dishes, the number of colonies being counted after 2, 3, or 4 days' incubation at 20° C.

(2) The determination of the number of rapidly-liquefying organisms. This is a subdivision of (1). It is usual to prepare surface gelatine plate cultures for this test, only those colonies growing freely and rapidly liquefying the gelatine at 20° C. being counted.

(3) The determination of blood-heat organisms. These are capable of growing freely at the temperature of the body and are counted from nutrient agar plate cultures after 24 to 48 hours' incubation at 37-38° C.

(4) Tests for the presence and frequency of certain characteristic indicators of pollution. The most important of these are organisms of the coli group, B. enteritidis sporogenes and streptococci.

For the determination of coli in water modifications of MacConkey's medium are now commonly employed. The original MacConkey's fluid was made up with 0·5 per cent. sodium taurocholate, 0·5 per cent. glucose and 10 per cent. peptone in distilled water tinted with litmus, the cultures being made in test-tubes containing a small Durham fermentation tube and incubated at 37–40° C. for 48 hours. In the presence of coli the fluid becomes turbid with reddening and bleaching of the litmus and gas collects in the inner fermentation tube. MacConkey fluid of greater strength than above can be prepared and stocked so that large volumes of the water may be conveniently tested ; for example, quantities of 50 c.c. of the water may be added to culture flasks each containing 50 c.c. of the double strength fluid thus diluting down to the strength originally devised by MacConkey. It is not advisable to attempt to prepare a medium of greater than double or treble strength. Further modifications include the addition of agar to form a solid medium, the use of other sugars than glucose, especially lactose, and the addition of neutral red and other indicators.

These culture media are capable of inhibiting the growth of the great majority of the common water bacteria so that many potable waters will give no reaction, that is no visible growth at all when tested in quantities up to 50 or 100 c.c., but it must be remembered that a positive reaction is only presumptive evidence and by no means conclusive proof of the presence of B. coli communis. There are other organisms capable of yielding positive reactions in the MacConkey medium which, though not common in pure water, have not the significance of B. coli communis. In order therefore to prove the presence of the latter it is necessary to isolate organisms from the positive MacConkey test, and make an examination of these in pure culture microscopically and for special reactions including—non-liquefaction of gelatine, production of gas and indol, coagulation of milk.

The spores of B. enteritidis sporogenes (Klein) are tested for in water by means of anaerobic milk cultures. A measured volume or concentration of the sample is mixed with at least twice its volume of fresh, sterilised milk and all organisms except spores are killed by heating for ten minutes to 80° C. The culture is then cooled and incubated anaerobically at 37-40° C. for two days. If B. enteritidis sporogenes spores are present in the water, after upwards of twenty hours' incubation the milk is completely coagulated with abundant production of gas, the whey becoming nearly clear and the curd being very compact. Other organisms giving similar reactions are B. butyricus and cadaveris (the latter after prolonged incubation), neither of which are normally present in potable water. B. enteritidis sporogenes does not form spores in the milk cultures : it is pathogenic.

Tests for streptococci are laborious and it is difficult to prove a negative. Surface agar plates are prepared with concentrations of the sample, and after 24 to 48 hours' incubation at 37·5° C., they are examined for the appearance of the minute colonies of streptococci. Suspicious growths are picked out into both tubes and after further incubation examined under the high power of the microscope.

Although greater importance is being attached to the bacteriological examination of water, few hard-and-fast rules can be given for the interpretation of the results. The number of organisms growing at 20° C. obtained from the gelatine plates, obviously does not include the total bacterial content of the water ; besides those incapable of growth in the gelatine, others growing slowly may be left out according to the number of days' incubation before the plates are counted. There are very few natural waters which would not show bacteria present in 1 c.c., deep-well waters may contain less than 10 per c.c., but the majority of drinking waters yield more than this. Koch suggested a limit of 100 organisms per c.c. for potable waters, which may serve as a rough guide, but strict adherence to this limit would condemn many waters now used with impunity. The London Metropolitan Water Board report that during 1912 the average numbers of organisms per c.c. present in the filtered water, excluding samples containing 100 or more per c.c. were as follows—Thames-derived 15·4, Lee-derived 33·4, New River-derived 14·5. The determination is of great value for controlling filtration of water ; the efficiency of the filters can be calculated from a series of counts made from various points on the works. The filtration of organically pure water, such as may be required after a softening process, will often increase the total bacteria. In one instance the writers found that a deep-well water containing only a few organisms per c.c., but very hard, after softening and passing through the filters contained several hundred per c.c., though showing no other sign of pollution.

The number of rapidly-liquefying organisms present in a water can often be roughly determined from the ordinary gelatine plates, in fact with impure samples they are frequently present in such numbers as to interfere with the total counts. A large number of room-temperature putrefactive bacteria are rapidly liquefying, and although liquefying bacteria are usually met with in potable water, the presence of a large proportion and variety of rapidly liquefying organisms should be considered as requiring explanation. The number of organisms growing at 37-38° C. is always only a small proportion of those growing at room temperature, usually less than one-tenth; with good waters they are frequently absent from 1 or 2 c.c.

Coli organisms are normally absent from pure water and constantly present in great numbers in sewage, and the test for their presence gives one of the most useful and sensitive indications as to the bacterial purity of a water. The number of coli present in sewage varies from 10,000 to nearly a million per c.c.; taking the low average of 100,000 present in a sewage, a water containing one part of the sewage in a million would give a coli reaction for 10 c.c. making this test far more delicate than any chemical test. The determination of coli organisms is of great value in the examination of waters not only because they are invariably associated with excremental pollution, but also they are more resistant than water-borne pathogenic organisms such as B. typhosus and S. choleræ: hence the destruction or removal of coli is regarded as a safe indication that there would be no possibility of the survival of these and other disease-producing organisms.

The extent to which the coli test is carried must depend upon the nature of the work in hand. For routine examinations, controlling the efficiency of water purification by filters or by partial sterilisation, the MacConkey reaction is often all that is required; also the limits adopted for the frequency of coli are dependent on the degree of refinement employed during the test. In other words the presence of an organism corresponding in all respects to the pathogenic B. coli communis in a small volume of the water is more serious than the presence of organisms only bordering on the coli group. For this reason there has been a considerable amount of work and discussion as to what is and what is not B. coli. In the examination of all classes of waters coli-like bacteria are met with which perhaps only differ from typical coli in some one point such as the capability or rate of fermenting certain sugars. But a loss or suspension of certain powers of reaction may in some cases be accounted for by an enfeeblement, due to prolonged sojourn in an unsuitable environment, of an organism originally conforming in all respects to typical coli. These bacteria may gradually merge into the coli group making it difficult to draw a hard-and-fast line. Since the original method of Parietti for isolating coli—using media acidified with hydrochloric acid and carbolic acid as inhibiting reagents, which are now to a great extent displaced by the bile-salt medium—an almost endless number of special tests to which the various types of coli may or may not react, have been brought forward.

In order to deal briefly with the numerous reactions obtained with coli-like organisms isolated at the Metropolitan Water Board's laboratories, Dr. Houston in his reports and summaries designates each series of reactions with words such as "presumptive" coli (MacConkey medium only), "flaginac" coli (fluorescence with neutral red, acid and gas with lactose, indol and acid clotting of milk), typical B. coli "sagin" (gas with saccharose and with lactose, indol) or "agin" (not producing gas with saccharose). As the majority of the B. coli present in human fæces are not capable of fermenting saccharose with the production of gas this "agin" type is placed as more indicative of dangerous pollution.

The figures obtained for coli in the London Water Supply during the year April, 1912, to March, 1913 (inclusive), at the Metropolitan Water Board's laboratories, are given in tabular form. The average results of tests with the various quantities of the different waters examined are expressed in percentages of positive or negative reactions. The figures are derived from an aggregate of over 10,000 water samples.

ANALYSIS OF COLI TESTS WITH LONDON WATER, YEAR ENDING MARCH, 1913 (METROPOLITAN WATER BOARD REPORTS).

Typical B. coli.

	Negative on 100 c.c.	Positive on 100 c.c.	Positive on 10 c.c. or less.
Filtered and well waters	82·8	13·8	3·25

Raw waters.	+ 100 c.c.	+ 10 c.c.	+ 1 c.c.	+ 0·1 c.c.	+ 0·01 c.c.	+ 0·001 c.c.
River Thames	0·8	9·5	34·9	44·0	9·5	1·2
River Lee .	2·9	12·0	45·2	31·1	7·9	0·8
New River .	9·9	41·9	39·4	7·5	1·2	—

Typical B. coli in Total Number of Coli-like Organisms Isolated.

	Typical.	Non-typical.
Raw waters . .	84·8	15·2
Finished waters .	45·6	54·3

Typical B. coli "agin."

Raw waters . .	River Thames 69·8	River Lee 67·5	New River 65·2
Finished waters .	" " 63·6	" " 55·9	" " 59·8

It will be seen that with the three river waters typical B. coli is invariably present in 100 c.c. and usually to the extent of 1 to 10 per c.c. In the finished waters, including those derived from wells, coli is absent from 100 c.c. in the majority of cases, but further than this removal of coli, it is interesting to notice that the purification has also altered the relation of the types of coli present. In the total number of coli-like organisms remaining in the treated waters the proportion of typical B. coli is considerably reduced and also a diminution occurs in each case with the perhaps most objectionable B. coli corresponding to the "agin" tests.

Varieties of streptococci and the spores of B. enteritidis sporogenes (Klein), similar to organisms of the coli group, are not as a rule found in uncontaminated waters but are constantly present in sewage though not in abundance, especially enteritidis spores, the number of which may fall to 100 per c.c. A search for the presence of either of these two organisms does not therefore form such a delicate indication of impurity as the coli test. The results in conjunction with the figures for coli are helpful in forming an opinion, but have not assumed the great importance of the latter.

Streptococci forms met with in sewage are very delicate organisms, many of them being pathogenic, and they appear to quickly die out on dilution, though there is evidence that in the crude sewage some do even survive the coli organisms; this has led to their presence in water being described as indicative of *recent* contamination by either fresh or old sewage. On the other hand it would not be expected from the nature of the spores of B. enteritidis sporogenes, that their frequency would be quickly changed by storage, and positive results for enteriditis, together with absence of coli and streptococci would point to a remote contamination of the water.

Recently attempts have been made to employ the streptococci test for distinguishing between human and animal pollution. It has been found that the varieties of streptococci derived from man and from cattle differ in certain fermentation tests. Final confirmation of these results would produce a test of great value.

When it is decided to undertake a search for the presence of a specific disease-producing organism it is preferable for the analyst to have large samples, several Winchester quart bottles, of the water submitted to him without any delay. In order to overcome the difficulty of dealing with such comparatively large volumes as are necessary, a method of bacterial concentration is almost invariably resorted to, such as filtration through a germ-proof material, the washings and residue from the filter having the bacterial content of the original volume of water filtered; or precipitation and sedimentation of the water by a coagulant, thus carrying down the great majority of the bacteria into the sediment, or by a centrifugal machine; when possible any deposit settled out of the samples without addition of chemicals may be also examined. Sometimes a method of enrichment of the water is adopted, possibly as well as concentration, by the addition of nutrient material favourable to the growth of the particular organism and incubation at the optimum temperature. The latter process is generally employed for the detection of the cholera spirillum; by the addition of 1 per cent. of peptone and 0·5 per cent. of salt to the already faintly alkaline water, it is converted into culture material in which the spirillum will multiply very rapidly on incubation at 37° C. After twelve hours these cultures are microscopically examined from time to time, especially any pellicle that may form on the surface, for the presence of spirilla, followed by plating out for the isolation of the organism.

Especially in reference to the detection of typhoid in water, notwithstanding the large amount of work that has been done and the accumulating records of a number of cases in which B. typhosus has undoubtedly been recovered from water, such an investigation is still of the nature of research work, and the value, if any, of negative results doubtful: even in the event of the isolation of typhoid-like bacteria their absolute identification is most difficult. After the concentration process the problem is to bring about a multiplication of the pathogenic organisms, and at the same time eliminate the non-pathogenic varieties, which will of course be present in large numbers. B. typhosus as well as coli grows freely in bile salt media ; as already noted this salt is capable of inhibiting most of the common water and non-intestinal bacteria, and forms the basis of several proposed culture materials. Many substances have been brought forward as inhibiting reagents and indicators, but unfortunately no satisfactory reagent has yet been found which, while allowing free growth of a possibly enfeebled typhoid organism, inhibits the other intestinal forms present in the concentration of the water. Of these special culture media those which have been more extensively used are Elsner's potato-gelatine containing potassium iodide, Conradi and Drigalski's agar containing nutrose, lactose, and crystal violet, Endo's fuchsine-lactose-agar with sodium sulphite, and with caffeine (Gaehtgen), Loeffler's malachite green agar and Conradi's medium (also modified by Fawcus) containing brilliant green and picric acid. The latter is claimed to entirely prevent the growth of coli organisms and certainly has a marked inhibitory effect.

Typhoid and cholera have hitherto been almost exclusively considered the chief water-borne diseases and though they are undoubtedly the most important, instances are accumulating of the isolation of other disease-producing organisms from water. More attention has been recently directed to dysentery and forms of diarrhœa conveyed by infected water. A prolonged search with large samples of raw Thames and Lee river waters was made during 1910 at the London Metropolitan Water Board's laboratories for the presence of B. typhosus, B. enteritidis (Gärtner), and Morgan's No. 1 bacillus, which resulted in the isolation in one instance of an organism corresponding to B. typhosus in all the tests, and an organism closely resembling Gärtner's B. enteritidis. For Morgan's bacillus, associated with infantile summer diarrhœa, negative results were obtained.

APPENDIX.

APPENDIX.

TABLE A.—EXAMPLES OF WATER ANALYSES.

Parts per 100,000.

WATER.	Source or Locality.	Physical Characters.	Total Solids.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates and Nitrites.	Nitrites.	Total combined Nitrogen.	* Percentage of Nitrogen Oxidised.	Phosphates.	Total Hardness.	Permanent Hardness.	† First Oxygen Consumed.	‡ Second Oxygen Consumed.	Organic Carbon.	Organic Nitrogen.	REMARKS.
Rainwater from Tank	Guildford	Inodorous, nearly colourless, not clear.	2·9	0·55	·045	·0256	No nitrate.	Trace	·082	Trace to nitrite.	None	Slight	..	..	..	..	..	A fair sample of rainwater as ordinarily collected.
Average of 71 Rainwaters	Rothamstead ..	.. .. ..	3·42	0·33	·049	..	·007	..	·068	10·3	..	0·5	..	..	..	·005	·021	Solids ranged from 0·62 to 8·58.
Rainwater, Land's End	Cornwall	Slightly turbid ..	42·8	21·8	None	..	·020	..	054	37	..	10·0	..	..	..	·131	·034	Mixed with sea-spray.
Town Rain	London	Slightly sooty ..	3·8	0·6	·110	·032	·008	Distinct	·148	5·4	..	1·5	1·5	..	..	·383	·040	Trace of free sulphuric acid. Arsenic ·020 (Frankland).
LONDON WATERS. §																		
River at Sunbury (intakes)	Thames	Turbid	31·24	1·8	·002	..	·305	Distinct	·356	86	..	..	..	..	..	·314	·049	
River at Hampton (,,)	,, ...	Brownish turbid ..	29·74	1·9	·012	·0280	·273	,,	·335	81·5	Slight	21·5	5·0	·064	·140	·258	·052	Microbes per c.c. 18,330.
Chelsea Water Co.	,, ...	Clear, pale yellow	29·92	1·8	None	·0098	·236	V.F.T.	·276	85·5	Very slight	23·0	4·6	·040	094	·177	·035	,, ,, 278.
West Middlesex Water Co.	,, ...	Clear, pale amber	30·1	1·8	,,	·0124	·254	None	·272	93·4	,,	22·4	4·4	·069	·160	·150	·018	,, ,, 38.
Southwark ,, ,, ...	,, ...	Clear, straw-coloured.	29·58	1·8	Trace	·0100	·225	V.F.T.	·241	93·4	,,	22·4	4·5	·090	·126	·170	·040	,, ,, 56.
Grand Junction ,, ,, ...	,, ...	Clear, pale amber	27·96	1·9	·003	·0060	·211	None	·237	92·8	,,	21·7	4·1	·077	·099	·179	·026	,, ,, 270.
Lambeth ,, ,, ...	,, ...	,, ,,	29·1	1·9	None	·0074	·237	,,	·261	90·8	,,	22·1	4·4	·020	·086	·162	·035	,, ,, 160.
Intake New River Co.	Lea	Turbid, pale yellow	32·3	1·7	·002	·0216‖	·324	V.F.T.	·344	94·2	,,	25·0	6·5	·030	·144	·099	·018	‖ ,, ,, 8,660.
New River Co.'s Supply	,, and wells ..	Clear, nearly colourless.	28·5	1·8	·0003	·0050	·287	None	·295	97·3	,,	24·0	6·0	·053	·077	·056	·008	,, ,, 28.
Intake East London Co.	Lea	Turbid, pale brown	40·9	2·3	·030	·0221	·255	,,	·346	73·7	Slight	26·6	6·4	·043	·150	·295	·066	,, ,, 23,010.
East London Co.'s Supply	,, and wells ..	Clear, very pale yellow.	32·24	2·1	·004	·0140	·285	,,	·309	92·2	Very slight.	23·6	6·1	·047	·077	·135	·024	,, ,, 214.
Kent Co., New Cross	Wells in Chalk ..	Clear, bluish ..	32·9	2·4	None	·0006	·227	,,	·235	96·6	None	24·5	7·0	·004	·009	·067	·008	,, ,, 8.
,, ,, ...	,, ..	,, ..	39·0	2·0	,,	·0010	·450	,,	·461	97·6	Trace	..	..	..	..	·072	·011	
,, Deptford	,, ..	,, ..	38·8	2·3	,,	·0015	·329	,,	·345	95·4	None	29·2	7·1	·006	·013	·069	·016	,, ,, 11.
Midstream, Crossness (average) ..	Thames	Turbid, brownish	..	..	·102	·0394	..	..	..	..	..	..	..	..	·274	..	..	"Organic elements" 1·221.
SEWAGE EFFLUENTS.																		
Average London Sewage	.. .. ..	.. .. ..	..	10·5	4·52	·547	None	..	4·26	0	..	..	..	..	4·30	..	..	
Raw Sewage	Yeovil	Very turbid and fetid.	80·6	12·64	9·00	1·135	,,	..	9·39	0	Very heavy.	..	..	..	5·86	..	..	A blackish flocculent sediment.
,, ...	Weybridge ..	Cloudy, strong smell.	84·6	10·0	10·15	1·05	..	..	10·21	..	..	..	..	..	4·00	..	..	
,, (after treatment with Alum, &c.).	Coventry ..	Turbid, rather offensive.	63·6	7·01	0·34	0·104	No nitrate.	Strong	·480	Distinct to nitrite.	Heavy	..	..	..	1·67	..	..	Sewage diluted, and partly oxidised.
Fish Manures Factory Effluent ..	Wembley ..	Brown colour, very offensive.	245·8	16·7	52·0	2·50	None	None	47·1	0	,,	..	..	..	9·36	..	..	Contained trimethylamine and fish-oil.
Sewage Farm Effluent	Wembley ..	Blackish, turbid, and fetid.	133·4	12·6	0·85	0·63	0·75	Very strong.	1·54	48·7	..	..	..	..	1·79	..	..	From sewage farm. Nitrification in progress.
Sewage Effluent..	Aylesbury ..	Cloudy, strong sewage odour.	80·0	8·9	4·4	1·3	0·08	Trace	5·95	1·3	..	..	..	..	7·83	..	..	A bad effluent. Nitrification very sluggish.
Sewage Farm Effluent..	Croydon	Nearly clear ..	46·0	3·25	·455	0·07	0·88	Very strong.	1·40	63	..	..	..	..	1·29	..	..	Shows active nitrification in progress. A good effluent.

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* This column has reference to the remarks on p. 16. In rainwater, the oxidised nitrogen has mainly been derived from the air.

† The "First Oxygen consumed" indicates the loss from permanganate in a short time (5 minutes or 15 minutes, as the case may be).

‡ "Second Oxygen consumed," the maximum amount obtained under the conditions used by the analyst.

§ These vary from time to time. For complete series, see reports of Metropolitan Water Examiners, also London County Council Reports.

‖ This and the next furnish a good example of the improvement effected by subsidence and filtration.

[*See continuation of this* TABLE *on following sheet.*]

[*To face page 246.*

TABLE A.—EXAMPLES OF WATER ANALYSES—Parts per 100,000—*continued*.

WATER.	Source, Locality, or Date.	Physical Characters.	Total Solids.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates and Nitrites.	Nitrites.	Total combined Nitrogen.	Percentage of Nitrogen Oxidised. *	Phosphates.	Total Hardness.	Permanent Hardness.	First Oxygen Consumed. †	Second Oxygen Consumed. ‡	Organic Carbon.	Organic Nitrogen.	REMARKS.
Sewage Effluent, Ripley Green, Guildford.	January 13, 1896	.. .. ..	39·5	9·11	·300	·086	None	Very strong.	·414	To nitrite only.	Heavy trace.	..	..	..	1·18	..	..	Nitrification not satisfactory.
Farm Effluent, Ripley Green, Guildford.	" "	Distinct sewage odour.	59·9	8·48	1·42	·128	"	None	1·41	0	Very strong.	..	..	..	1·52	..	..	In bad condition. No nitrification.
Sewage Farm Effluent	.. .. ..	.. .. ..	77·7	7·05	·380	..	·441	..	·908	48·5	..	..	..	..	..	·980	·154	Suspended matter: organic ·28, mineral ·76. Nitrification active.
Fresh Sewage: average from 16 Water-Closet Towns.	(Frankland) ..	.. .. ..	72·2	10·66	6·70	..	·003	..	7·80	0·04	..	..	..	..	..	4·70	2·20	Suspended matter: organic 24·2, mineral 20·5.
Fresh Sewage from 15 Midden Towns.	" ..	.. .. ..	82·4	11·54	5·43	..	None	..	6·50	0	..	..	..	..	..	4·18	1·97	Suspended matter: organic 17·8, mineral 21·3.
River Avon, Coventry	February 6, 1896..	Turbid, marshy odour.	51·6	2·2	Trace	·032	·025	Strong	·079?	31·6	H.T.	..	..	..	·240	..	..	Polluted with sewage, altered by flow and vegetation.
UPLAND SURFACE WATER.																		
River Exe above Town, May 28, 1895	Exeter	Clear, very pale brownish.	9·0	1·3	None	·011	·107	V.F.T.§	·133	80·5	V.F.T.	4·21	4·14	..	·270	·400	·063	Peaty matter.
	Millstone Grit ..	Brownish, slightly turbid.	7·9	0·95	Trace	·009	·035	None	·060	58·3	None	3·5	3·0	..	·380	·250	·025	Very peaty.
Lower London Tertiaries, &c. ..	Bagshot Beds ..	Nearly clear ..	8·4	2·06	·004	·010	·007	V.F.T.	·059	11·8	V.F.T.	3·8	3·5	..	·220	·379	·048	Very little nitrification.
	Mountain Limestone.	Brownish, clear ..	17·7	1·24	·001	·006	·011	None	·059	18·6	None	12·7	7·0	..	..	·370	·047	Peaty.
	Magnesian Limestone.	Slightly turbid ..	17·8	1·40	·001	·004	None	..	·037	0	"	14·7	8·3	..	..	·172	·036	
	Calcareous Soil ..	Turbid, brownish, faint odour.	110·4	12·75	·030	..	1·005	..	1·337	75·2	H.T.‖	67·3	42·1	..	..	1·34	·307	Highly polluted with manure.
	New Red Sandstone.	Clear, nearly colourless.	38·5	2·30	·001	..	·449	..	·466	96·3	..	31·3	10·9	..	..	·040	·016	Probably polluted with surface drainage.
DEEP WELLS.																		
Bore Hole, 575 feet, Coventry (see also Kent Waters above).	Red Sandstone ..	Clear, nearly colourless.	706·9	117·7	·100	..	·119	..	·239	49·8	..	151·5	36·3	..	..	·041	·036	Example of a saline and undrinkable water.
Artesian Well	Chalk under London Clay.	Clear, nearly colourless.	106·7	38·8	·118	..	·645	..	·681	94·7	..	48·5	25·4	..	..	·195	·067	High mineral constituents. Shows the difference mentioned at p. 251.
SPRINGS.																		
From Granite and Gneiss Rocks ..	.. .. ..	.. .. ..	5·94	1·69	·001	..	·106	None	·115	92·2	None	3·0	2·6	..	..	·012	·008	
Lower Greensand and Gault Clay ..	Shefford, March 13, 1896.	Clear and colourless.	99·4	12·4	Trace	·0022	·90	Trace	·904	99·5	Trace	..	..	..	·105	..	..	A bad water from its mineral constituents. Shows some signs of organic pollution.
Tideswell Spring, Derbyshire	Mountain Limestone.	Clear and colourless.	28·5	1·4	·001	·005	·25	..	..	..	..	24·0	..	..	..	..	..	
Weald Clay	Charlwood ..	Brown sediment..	423·6	40·0	·020	·080	Trace	None	·157	Trace	Trace	21·8	..	..	·200	..	..	Alkaline, unfit for drinking.
Oolite	.. .. ..	Clear, colourless..	30·3	1·55	·001	·003	·402	"	·414	97	None	24·4	6·2	..	..	·043	·011	A good water.
A SHALLOW WELL	.. .. ..	Deep yellow brown, clear.	112·0	8·8	·252	·013	4·61	Abundant	4·85	95	H.T.	57·0	33·0	0·84	·112	..	..	Badly polluted.

* This column has reference to the remarks on p. 16. In rainwater, the oxidised nitrogen has mainly been derived from the air. † The "First Oxygen consumed" indicates the loss from permanganate in a short time (3 minutes or 15 minutes, as the case may be). ‡ "Second Oxygen consumed," the maximum amount obtained under the conditions used by the analyst. § Very faint trace. ‖ Heavy trace.

[*Continuation of Table A.*
To face page 246.

TABLE B.

COMPOSITION OF BOILER INCRUSTATIONS FROM DIFFERENT WATERS.

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SOURCE.	Sea Water.				Brackish Water.	River Water.				Wells.		Town Supply—Edinburgh.	Spring—Slough.	Pits & Surface—Prestonpans.	Quarry—Granton.	An Acid Water.
							Carlisle.		Thames.	Dunbar.	Slough.					
Pressures in lbs. per sq. in.	5	10	20	25(?)	...	...	...	60	80	...	...	...	...	...	...	...
$CaCO_3$	2·00	3·44	0·34	0·97	43·65	75·85	75·92	8·20	81·45	32·16	25·62	62·95	50·04	1·22	17·31	2·20
$CaSO_4$	34·00	69·77	72·85	85·53	34·78	3·68	3·16	85·01	1·63	5·64	55·92	20·80	29·76	78·32	53·76	...
$Mg(OH)_2$	58·00	22·50	18·83	3·39	4·34	2·56	...	4·36	8·10	...	...	...	...	...	...	...
$MgCO_3$	...	...	...	...	...	...	10·16	...	...	20·04	5·56	7·24	10·84	10·36	18·04	None
Na salts	...	...	...	...	...	...	0·84	...	...	3·31	...	0·86	0·86	0·64	0·54	...
NaCl	Trace	0·99	2·16	2·79	0·56	0·45	...	Trace	Trace	...	0·22	...	...	...	...	...
Fe_2O_3, Al_2O_3, and $Ca_3(PO_4)_2$ ...	1·33	1·36	2·40	0·32	3·44	2·96	2·96	0·52	2·44	7·46	5·04	2·48	2·36	4·64	2·88	83·80
SiO_2	Trace	0·16	0·80	1·10	7·52	7·66	4·94	1·91	0·87	16·94	5·26	3·76	4·28	3·22	4·36	5·28
Organic matter	4·67	1·78	2·62	Trace	1·55	3·64	0·49	Trace	4·65	7·67	1·04	0·69	0·64	0·88	2·33	8·72
Moisture ...				5·90	4·16	3·20	1·53		0·86	6·78	1·34	1·22	1·22	0·72	0·78	

NOTES.—These analyses are only comparative in a general sense, as they were done under different circumstances. They, however, furnish good examples of the effects of varying conditions.

Nos. 1, 2, 3, 4 show the increasing proportion of calcium sulphate precipitated with an increasing pressure, and therefore temperature.

In Nos. 6, 7, 9, 10, 12, the waters were of the carbonate of lime class, in which the temporary hardness is predominant.

In Nos. 8, 14, 15, the waters had a high permanent hardness, due to sulphate of lime.

No. 10 is a magnesian water. The high amount of silica is remarkable, also the action on iron.

No. 16 shows the action of a soft and acid water on iron. The small quantity of carbonate of lime has probably been protected by the iron scale.

The proportion of organic matter is seen to vary greatly.

As boiler crusts usually contain magnesium hydrate only, the magnesium carbonate found in some of the above analyses must be due to the absorption of carbonic acid from the air by the crust after removal.

TABLE C.

ORDER OF THE ROCKS, AND CHARACTERISTICS OF WATERS DERIVED FROM THEM.

Period.	Group.	Sub-divisions.	Waters.
Tertiary	Recent	Made Earth Vegetable Soil.	Waters from vegetable soil and from made earth are polluted and highly dangerous.
		Blown Sand	Waters from sand are sometimes almost pure rain water, but are often brackish.
		Alluvium	Surface waters, p. 41.
		Peat	Peaty and moorland waters are described at pp. 17 and 18.
	Post-tertiary or Pleistocene.	Glacial Drift.	Shelly sands, marls, and gravel, usually too porous to allow of proper filtration of the surface water that soaks into them. In some places beds of peat affect the character of the water. In the west of England open shallow wells in the drift sometimes form the chief supply of villages, but are gradually being superseded by less dangerous sources.
	Newer Tertiary or Pliocene.	Norwich Crag, Red Crag, &c.	
	Middle Tertiary or Miocene.	Coralline Crag.	
	Lower Tertiary or Eocene.	Barton Clay	Absent in the London Basin. In Hampshire its sandy layers yield a good water, though not abundant.
		Bagshot Sands	Water mostly very soft, but often of bad taste and colour through fossil remains, lignite, &c.
		London Clay	Impervious to water.
		Woolwich and Reading Beds.	Pebble beds, sand, loam, and plastic clay. Water very various in quality, and not usually regular nor abundant in yield.
		Thanet Sands	Occur only in the London Basin. Water often abundant and soft, but wells liable to great fluctuations and to surface infiltration.

Order of Rocks, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
Mesozoic or Secondary.	Upper Cretaceous.	Upper Chalk, with flints. Lower Chalk, without flints.	These strata, as is well known, owing to their fineness of grain, yield water of great organic purity, but of considerable temporary hardness. They form large underground reservoirs of water resting on the chalk marl. Far-extending fissures have occasionally been known to convey surface pollution, but the water is usually almost free from organic matter and life. Artesian wells are frequent, as those of the Kent Company. The water from the chalk, where covered by the London Clay, is not, however, good.
		Grey Chalk	Contains organic matter, water often ill-tasting.
		Chalk Marl	Contains clayey and siliceous matter and iron. Water usually inferior in a mineral sense. Arrival at these beds indicates the termination of a boring in the chalk.
		Upper Greensand ..	Derives water partially from the chalk, stopped by the gault. Supply not large, often turbid and hard, sometimes ferruginous. Its organic character varies.
		Gault Clay	A blue tenacious clay with pyrites and phosphatic nodules. Springs yield a scanty and inferior water.
	Lower Cretaceous.	Lower Greensand ..	Contains much oxide of iron, therefore water ferruginous, and often full of sand. Strata partly marine. Beds of clay intervene. A few wells yield, however, a soft and pure water, but in limited quantity.
	Wealden (fresh water or fluviatile strata, specially developed in the south of England).	Weald Clay	No available water.
		Hastings Sand ..	Water good where in sufficient quantity.
		Purbeck Beds ..	Mainly limestone without water. The "dirt beds" convey much vegetable organic matter and an objectionable taste.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.		Waters.
MESOZOIC OR SECONDARY.	Jurassio ..	Upper Oolite.	Portland Stone ..	Owing to the porosity of the water-bearing beds of the Oolite, the water is frequently turbid, and surface water is rare. Limestones, with hard and scanty water.
			Portland Sand ..	Water abundant, and usually good.
			Kimmeridge Clay	About 600 feet deep. Much bituminous and vegetable matter. When this stratum is reached further boring is generally inadvisable.
		Middle Oolite.	Coral Rag and Calcareous Grit.	Water commonly free from organic matter, but of high *temporary* hardness and not plentiful. Fissures frequent, leading to danger from surface drainage.
			Oxford Clay ..	Stiff blue and brown clay, occasionally bituminous and pyritous, attaining in some places a thickness of 600 feet. The water is scanty, impregnated with Ca and Mg sulphates, and sometimes medicinal. This stratum, like clay beds generally, yields water above and below it.
			Kellaways Rock	A calcareous sandstone containing little water.
		Lower Oolite.	Bath or Great Oolite (calcareous with sandstones and clayey seams).	On the whole the Oolite consists of four masses of partially permeable strata separated by thick deposits of clay, the limestones forming the ridges and the clays the valleys:—(1) Portland Oolite Limestone and Sand, Kimmeridge Clay; (2) Calcareous Grit, Coral Rag, Oxford Clay; (3) Bath Oolite, Fuller's Earth; (4) Inferior Oolite, Lias Clay. Hence springs are numerous and abundant from the porous strata under the beds of clay. The water is usually hard, and varies from clear and palatable to very turbid. In some cases a saline taste from chloride and sulphate of sodium.
			Fuller's Earth (clay).	

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
MESOZOIC or SECONDARY.	Jurassic ..	Lower Oolite. Inferior Oolite (calcareous freestone and grit).	Northampton Sands contain ironstone, and the water is ferruginous. Deep wells at Gloucester and Cheltenham are impregnated with sodium sulphate and chloride. At Bath they are gypseous, but not often saline. Some springs in the Mendip Hills are good and copious. Oolite waters of Yorkshire are much softer than those from the southern Oolite.
		Lias. Alum Shale ..	Usually acid and loaded with mineral matter.
		Marlstone. Lower Lias.	Waters of fair quality where not medicinal.
	Trias or Upper New Red Sandstone.	Rhætic or Infra-Lias	The Rhætic includes the "Bone-bed," giving ill-flavoured water containing organic matter and phosphate of lime, therefore peculiarly apt to develop organisms. The Muschelkalk is a limestone unrepresented in England.
		Upper Trias or Keuper. Middle Trias or Muschelkalk. Lower Trias or Bunter Sandstone.	When cut off locally by thin beds of clay or by clay-filled faults the Bunter Sandstone yields excellent water, as at Wolverhampton and other places. More rarely good water is obtained from the Keuper. But, as a whole, the Trias, being a marine formation, including deposits of gypsum, rock salt, and oxide of iron, yields water unfit for drinking on account of its saline constituents (analysis, Table A).
			The Lower Keuper nearly always contains water and is generally known as "Waterstones." At Stockport there are many private deep wells of very good quality in the Trias and Permian rocks.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
PALÆOZOIC or PRIMARY. (These, from their hardness, form usually mountainous districts, and are important "gathering grounds.")	Permian or "Dyas."	Magnesian Limestone or Dolomite.	Furnishes an abundant yield in places, but the water shows high permanent hardness, from the presence of lime and magnesium salts, and is apt to be salt, bitter, and unwholesome. The thickness of the strata and, therefore, depth of sinking vary very greatly, and there is also great interference from faults.
		Lower New Red Sandstone.	Water organically good, but often saline and ferruginous. The beds contain large quantities of water, and yield copious springs, but the rock being extremely porous, surface contamination is frequent.
	Carboniferous	Coal Measures (hot springs occur at Matlock, Buxton, and Clifton).	Water mostly scanty in quantity, and of bad quality, often ferruginous and acid. Mine waters are generally very inferior, even if treated with lime. (See p. 6.) In many cases, however, it would be desirable to economise them in reservoirs for small towns and villages, as the draining of mines sometimes dries up the wells of a district. Storage would effect considerable improvement.
		Millstone Grit ..	Supplies excellent water to large towns in Yorkshire and Lancashire.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
PALÆOZOIC or PRIMARY.	Carboniferous	Carboniferous or Mountain Limestone.	The black limestone gives a water of an earthy and sulphurous taste, due to the presence of organic matter. The lighter limestones yield water organically pure, and of moderate temporary hardness (Ch. IX.). The water is plentiful from fissures, but may then be mixed with much unfiltered surface water. In Mendip and Derbyshire rivers often disappear in "swallow holes." There is a regular business of stopping up these holes to prevent loss of water in dry seasons (Hughes). Mineral veins of lead and zinc sometimes contaminate the water, which always needs a chemical examination.
	Devonian or Old Red Sandstone.	Quartzose Conglomerate. Cornstone (clays and marls).	Waters usually good, but scarce. There are no wells for large supply, but where clay beds occur there is abundance at no great depth for private houses. Sometimes bituminous schists occur, containing remains of fishes; these give undrinkable water.
	Upper Silurian.	Tilestone (sandy). Ludlow Shales. Wenlock Limestone.	Tilestone water is good. The shales and limestones often give very inferior turbid and hard waters.
	Lower or Cambro-Silurian.	Caradoc Sandstone. Llandeilo Flags.	Usually very soft and pure waters of granitic character.
	Laurentian ..	(Chiefly in Canada)..	Like granitic waters, but of greater hardness, owing to the presence of crystalline limestones.

ORDER OF ROCKS, &c.—*continued.*

Period.	Group.	Sub-divisions.	Waters.
IGNEOUS and METAMORPHIC. (May be of any age, but more common in the primary.)	(Mineral veins are frequent, and may cause metallic contamination of the waters with iron, lead, zinc, or copper, and also acidity.)	Granite, Gneiss, Quartz Rock, Mica Schist, Slate.	Very soft waters, containing potass. salts and silica, but little lime or magnesia. Usually bright and clear, and slightly alkaline. From very rapid streams there may be a white turbidity. Organically of great purity. Slaty waters often contain iron from decomposing pyrites, and are acid, and of a bad taste and earthy odour.
		Crystalline Limestone or Marble.	Hard, from bicarbonate of lime, otherwise pure.
		Trap and Basalt ..	Vary, often acid, alkaline, or ferruginous from decomposing minerals. Organically pure.
		Volcanic Ash or Tufa, Trachyte.	Alkaline and silicious, or may be acid or sulphuretted from presence of sulphur. Springs from volcanic rocks are frequently medicinal, but seldom potable. The temperature is usually high.
		Serpentine	When decomposed may give magnesian waters.

TABLE D.

FERRO- AND PLUMBO-SOLVENT WATERS.

We have already referred to the action of waters on metals, especially iron, lead and zinc. The complex mechanism by which these solvent actions are brought about is now the subject of an increasing literature, but in spite of this fact each water exhibiting these characteristics presents a new problem to the water-chemist.

It is a pity that there are no analyses collected in accessible form of natural waters having these disagreeable properties.

The following, admittedly very incomplete, are a few examples taken from our laboratory note-books.

Analysis in Parts per 100,000.

A.		B.		C.	
No. 2339.		No. 2550.		A deep well in the London basin.	
Solids	17·50	Solids	113·60	Solids	76·60
$CaCO_3$	2·77	$CaCO_3$	4·00	$CaCO_3$	5·57
$MgCO_3$	0·91	$MgSO_4$	9·93	$MgSO_4$	5·52
Na_2CO_3	2·92	$CaSO_4$	60·11	$NaNO_3$	0·60
Na_2SO_4	3·41	Na_2SO_4	21·30	Na_2SO_4	16·20
NaCl	7·08	NaCl	6·94	NaCl	27·30
Org. matter, etc.	0·41	Fe_2O_3	3·68	Fe_2O_3	0·006
Free CO_2	1·20	SiO_2	1·38	Alkalinity $\left.\begin{matrix}Na_2CO_3\\CaCO_3\end{matrix}\right\}$	26·0
Ferro-solvency	4·09	Ferro-solvency three times that of New River water.			
Do. after CO_2 neutralised	3·36			Nitric N.	0·10
Tap water control	3·56			Total hardness	6·1
Plumbo-solvency	1·74			Permanent hardness	5·0
Action on galvanized iron	0·36			Corrodes iron pipes and gives a heavy deposit. Some pipes eaten through in seven years.	
Fe, trace of Zn					
Total hardness	4·9				

D.

A Yorkshire Moor water.	
Total solids	8·08
Chlorine	0·60
NH_3 free	0·0044
NH_3 Alb.	0·0230
Nitric N.	0·132
O. consumed	2·74
Acidity, H_2SO_4	0·98
Acts rapidly on Fe, Pb, Zn.	

E.

No. 3540.			
Chlorine	0·41		
Alkalinity	2·18 $CaCO_3$		
Ferro-solvency	5·43	control	3·81
Zinc solvency	0·91	,,	0·35
Plumbo-solvency	0·29	,,	0·09

F.—Effect of lime treatment on a ferro-solvent water.

Original water.		Treatment (i.).		Treatment (ii.).	Treatment (iii.).	Treatment (iv.).
		Added 7 parts CaO, aerated for 1 hour.		Added 7 pts. CaO, exposed to air for two days.	Aerated and then added 7 parts CaO.	Aerated and then added 3·5 parts CaO.
		Filtered after ½ hour.	Sedimented for 2 days.			
Total hardness	14·0					
Permanent	1·6					
Ferro-solvency	2·0	1·2	0·9	0·8	0·2	1·0
Control	0·5	0·5	0·5	0·5	0·5	0·5

These results indicate that the best method of treatment for this water is a course of aeration followed by the addition of seven parts of lime to every ten thousand of water.

INDEX TO AUTHORITIES.

INDEX TO SUBJECTS.

THE END.

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