# STERILIZATION OF WATER BY CHLORINE GAS.

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The aim of all water purification for drinking purposes is to produce a clear, tasteless water free from harmful bacteria. The very best methods of filtration can only bring about a reduction of 98 per cent of the total number of bacteria present in the water. In order to remove the remaining 2 per cent of bacteria, and thus render the water perfectly safe, a process of sterilization must be carried out. This process also acts as a safeguard in case of a breakdown of a sand-filter.

Many methods have been devised to carry out the complete sterilization of water, and they can be divided into physical and chemical methods. The physical methods, which include sterilization by heat and by ultraviolet light, although quite efficient, are more difficult to operate and are more expensive than chemical methods. Chemical methods are cheap and comparatively easy to manipulate, and are capable of very exact operation. Chlorine, either as the free element or combined, as in bleaching powder, is the chemical which is most largely used. Bleaching powder, or chloride of lime, was first used to sterilize a supply of drinking water in 1897 at Maidstone where an epidemic of typhoid was raging. Its use was attended with very successful results, typhoid being very rapidly stamped out.

Chlorine, in the gaseous condition, although used in America to a small extent for some time, has only come into general use during the last few years. The amount of chlorine, either as a gas or from bleaching powder, required to sterilize water is quite small. For a sedimented and filtered water less than half a part of chlorine per million parts of water is sufficient for complete sterilization, and for a crude water, for example, Thames water at Kew, only three to four parts per million are required, provided that this chemical is allowed to remain in contact with the water under treatment for not less than twenty minutes.

At the outbreak of war the only method of water purification that could be carried out in the field, other than that involving the use of acid sodium sulphate tablets, was embodied in the Water-Cart. In this apparatus water was pumped from the source, treated with aluminium sulphate with or without the addition of an alkali, filtered through a cloth-covered cylinder on which the aluminium hydroxide, produced by the hydrolysis of the aluminium sulphate, was deposited and which formed the real filtering medium. After filtration the water was treated with bleaching powder—chloride of lime—to produce sterilization. It was soon found that the amount of bleaching powder that was being added was often greatly in excess of that actually required to produce sterilization. Attempts were made to devise a simple method by which the amount of bleaching powder required to sterilize any water could be determined in the field. The first suggestion was made by Professor Sims Woodhead, and the actual details resulting in the fitting up of a case containing the necessary apparatus and chemicals with instructions for carrying out the test were worked out at the Royal Army Medical College under the direction of Sir William Horrocks (*See* Appendix, page 1149). With this test case, known in the Army as the "Case, Water Testing Sterilization," and the water-cart as the starting point, the whole of the great water purification scheme of the Army has been built up. That the methods adopted have been successful is seen from the fact that throughout the war there has been no epidemic of any water-borne disease.

The first advance upon the water-cart was the production of a type of water purification plant which sterilized water by a continuous process at the rate of 125 gallons per hour, using bleaching powder as the sterilizing chemical. This was a distinct improvement over the water-cart which only worked intermittently. From this small type a much better and larger plant was devised, giving a continuous output of 400 gallons per hour and in which the excess of chlorine that was left in the water after sterilization was completed, was removed by means of a solution of sodium bisulphite. This plant was fitted up on a 3-ton motor lorry and a large number were sent to France and known as Nos. 1 and 2 Water Tank Companies. These companies had a number of water purification plants which, in addition to being able to sterilize water, could also remove poisons from it. A large number of tank or carrying lorries were also attached to these companies for the purpose of transporting the purified water.

It was felt that these plants had several disadvantages. The output of water was relatively low and there was a considerable amount of work entailed in preparing the solutions used in the process. Attempts were made to overcome these defects and finally, by the introduction of the use of chlorine gas, a new type of water purification plant was devised which has been adopted, with minor alterations to meet special conditions, as the standard of the British Army. The principle of this plant has been applied to all types of water purification plants in use in the field.

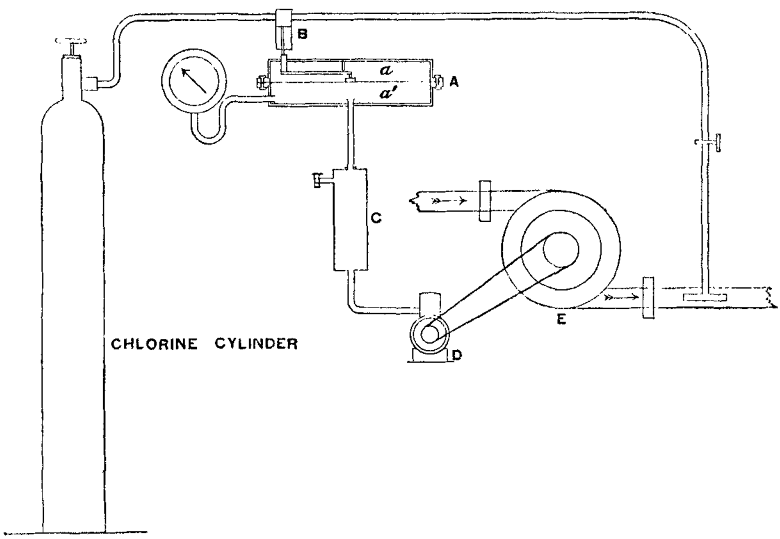
A considerable amount of work had been done in America on the question of sterilization of water by means of chlorine, and great difficulty had been experienced in devising a satisfactory method of administering this gas to water. In 1912 a patent was granted to Major Darnell, of the American Army, for an apparatus for the administration of chlorine gas to water for the purpose of sterilizing it.*

This apparatus, Fig. 1 (page 1130), consists of a cylinder of liquid chlorine connected to a pressure regulator A. This regulator controls the flow of chlorine from the cylinder by acting on a valve B by means of levers, the regulator itself being in turn controlled by the rate of

* American patent, No. 1007647, 31 Oct. 1912; Journal Amer. Public Health Assoc., Nov. 1911.

flow of the water that is being treated. The regulator consists of an iron case divided by a circular diaphragm, thus forming two similar compartments, *a* and *a'*. The diaphragm is connected at the top, by means of levers, to the easily adjusted valve B. The lower portion of the case, which is air-tight, is connected to a small compressor D through a reservoir C. This compressor is worked by means of a turbine E which is driven by the water that is being

FIG. 1.—*Chlorinator* (Darnell).




treated. As the water flows through the turbine, the compressor increases the pressure of the air in the lower portion of the regulator. This pressure will vary according to the rate at which the water is flowing through the turbine, and will thus act on the diaphragm and control the rate at which chlorine may pass through the valve B. Theoretically, the apparatus is automatically controlled, but difficulty was experienced in operating it successfully.

Leavett Jackson and the Electro Bleaching Gas Co. constructed apparatus to administer chlorine to water, but the chlorinating apparatus which has proved commercially successful is that made by Messrs. Wallace and Tiernan, of New York, who, working upon the lines of the Darnell apparatus, have produced two types of chlorinators which have proved very successful in operation. Other attempts have been made to produce apparatus for the purpose of administering chlorine gas to water, but up to the present those constructed by Wallace and Tiernan appear to be the best and most accurate.

The two types of apparatus manufactured by Wallace and Tiernan are the same in principle but differ in that, in the Direct-Feed type, chlorine gas is added directly to the water under treatment, while in the Solution-Feed type the gas is first dissolved in water and this solution added. Both types have as an object the delivery of a continuous supply of chlorine to water at a known indicated uniform rate, which is independent of any changes of pressure of the chlorine in the containing cylinder. The first instrument—a Direct-Feed type—was brought to England in August 1916 and placed at the disposal of the War Office by Messrs. United Water Softeners, Ltd.

An experimental plant was constructed and exhaustive tests were made upon the canal water at Brentford, Middlesex, with the object of determining if chlorine were an efficient sterilizing chemical and if the apparatus were satisfactory. Many of these tests extended over a continuous period of 72 hours and the results of one test are given in the Table (pages 1151–3). At the conclusion it was found that:—

(1) Chlorine is a most efficient chemical for sterilizing water.

(2) The apparatus is extremely satisfactory, easy to manipulate and accurate.

(3) Water so treated has a far less marked taste than water similarly treated with bleaching powder.

During the tests it was suggested that the use of sulphur dioxide gas to remove the excess of chlorine left in the water after completion of sterilization would render the process more efficient in that the purified water would be free from the slight taste imparted to it by chlorine, and would render the removal of this taste much easier than would the use of a solution of sodium bisulphite.

This method has been adopted as standard for all types of water purification plants in the Army, except very small ones which are too small to allow of this process to be economically used. The Direct-Feed type of Wallace and Tiernan chlorinator was adopted as standard.

*Direct-Feed Chlorinator* (Fig. 2, Plate 21, and Figs. 3 to 6).—The

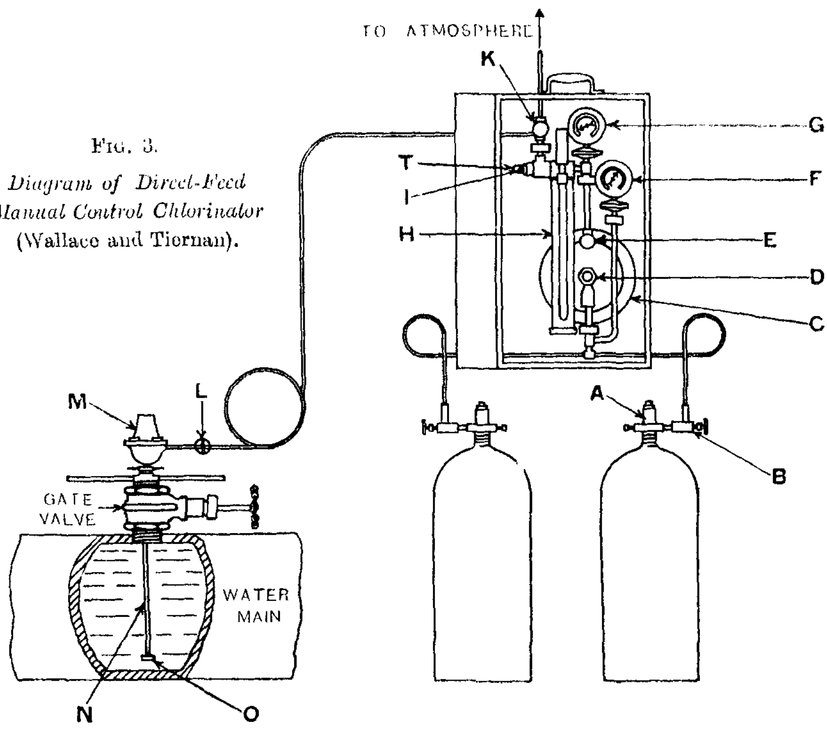



FIG. 3.
*Diagram of Direct-Feed Manual Control Chlorinator*
(Wallace and Tiernan).

apparatus is essentially one which meters chlorine gas and which at the same time delivers the gas at a constant pressure. Chlorine is stored in steel cylinders as a liquid and the pressure within such a cylinder will depend upon the temperature at which the cylinder happens to be. The pressure of liquid chlorine at 0° C. is 54 lb. per square inch and at 50° C. (122° F.) it is 216 lb. per square inch. The pressure registered within a cylinder of liquid chlorine is the

FIG. 4. - *Compensator* (C, *Fig.* 3) *in Section, separated. Chlorinator* (Wallace and Tiernan).

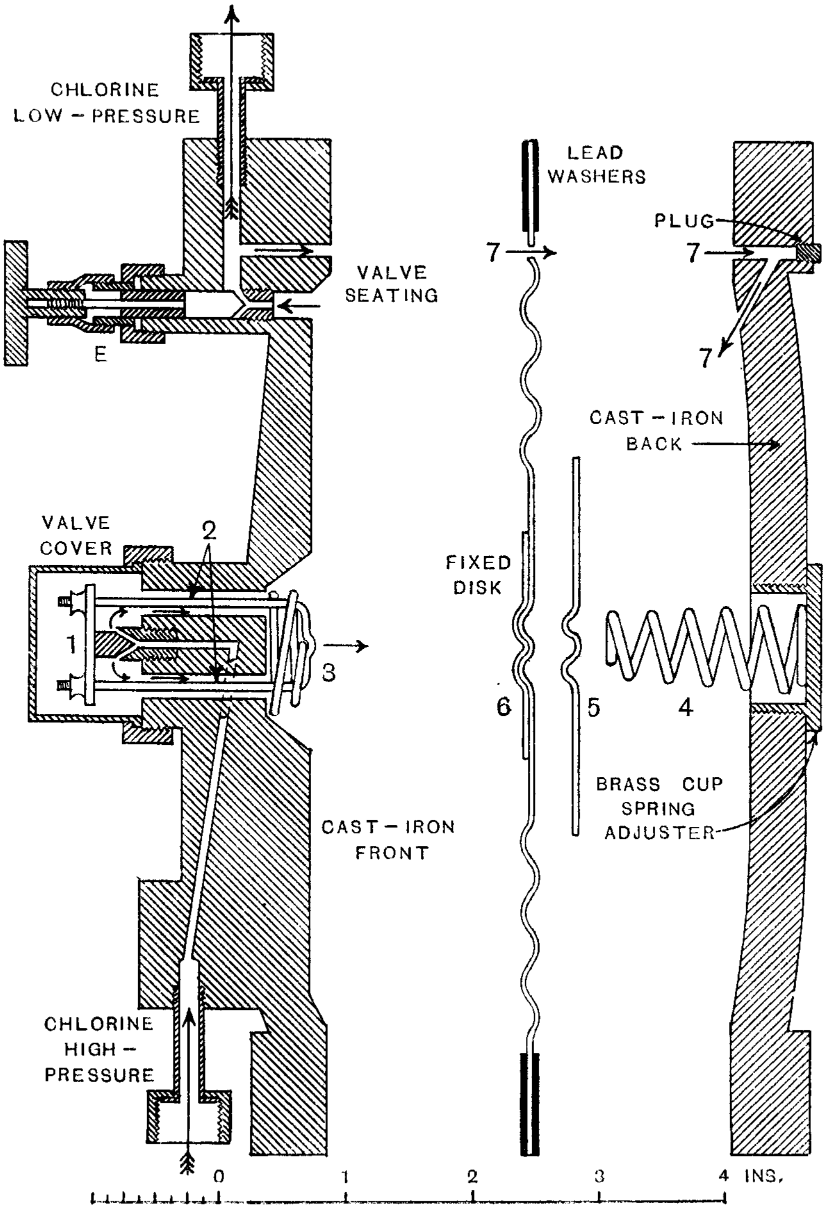


Fig. 5.—*Orifice* I, *and Manometer* H.

Scale: ½ approx.

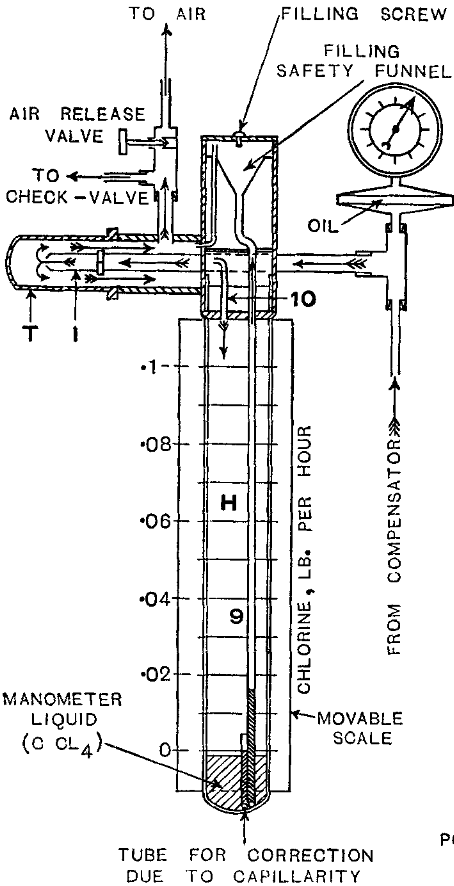
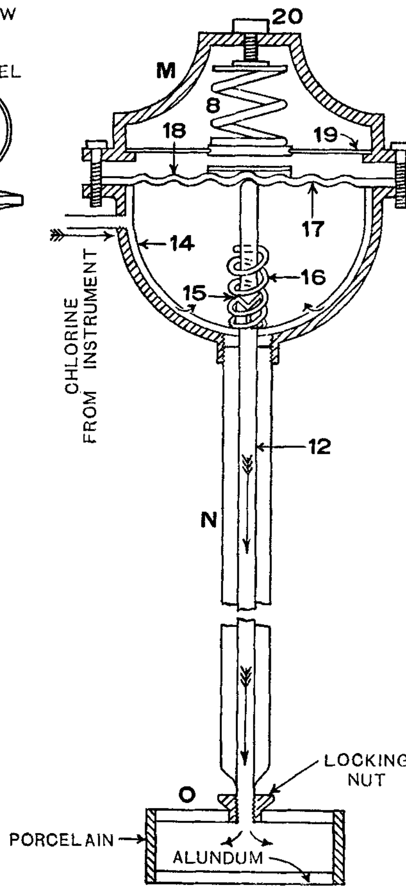



Fig. 6.—*Check-valve* M, *and Diffusor* O.

Scale: Half-size. (Separated and in part section.)




*Chlorinator* (Wallace and Tiernan).

pressure which the vapour of liquid chlorine, that is, chlorine gas exerts while in contact with liquid chlorine at the temperature of the cylinder and its contents. A rise in temperature will produce a rise in pressure and vice versa.

If gaseous chlorine is allowed to escape, by opening a valve on a cylinder of liquid chlorine, some of the liquid must evaporate to account for this escape. This will affect the pressure of the gas in the cylinder, for liquid chlorine is a bad conductor of heat and consequently most of the latent heat required to evaporate it will be obtained first from the liquid chlorine itself and not from the surrounding atmosphere, and as a result the temperature of the liquid chlorine inside the cylinder will fall and thus produce a fall in pressure. The density of chlorine will also increase with a fall of temperature, and consequently the volume of chlorine gas that may leave a cylinder is not a direct measure of its mass.

The Wallace and Tiernan Chlorinator, Fig. 2, Plate 21, is actually a reducing valve and meter combined and consists of three main portions:—

(1) The Compensator, in which alterations of pressure in the cylinder are compensated, Fig. 4.

(2) The Metering or flow-measuring apparatus combined in the Orifice, Scale, and Manometer, Fig. 5.

(3) The Check-Valve—or back-pressure valve—and Diffusor, Fig. 6.

*Compensator*: Explanation of working, Fig. 3.—Under normal conditions when the instrument is started, the valve on the cylinder A and the auxiliary tank-valve B, control-valve E, blow-off valve K, and auxiliary valve on check valve L, are shut. The auxiliary valve L fitted to check valve M and main tank-valve A are opened, the control-valve E being kept closed. The auxiliary tank-valve B is opened slowly. Chlorine now enters the compensator C through the small needle-valve (1, Fig. 4) and passes down the two holes (2) and fills the space between the front portion of the compensator and the silver diaphragm (6, Fig. 4). The pressure in this space increases and forces back the silver diaphragm (6) and the strengthening disk (5) against the spring (4) and at the same time allows the spring (3) to close the needle-valve (1).

The pressure of the chlorine in the cylinder is indicated by the tank pressure-gauge F, Fig. 3. If the control valve E is slowly opened, chlorine will pass through this valve and slowly build up a pressure which is registered on the back-pressure gauge G. This pressure will be exerted on the back of the silver diaphragm (6, Fig. 4) as there is a small hole (7) drilled through the apparatus for this purpose. During this operation the control-valve E is only opened sufficiently to cause the liquid in the manometer tube H (Fig. 5) to rise in the small inner tube (9) and remain in sight. If opened too much, the liquid in the manometer tube will be driven up into the space at the top, and it may get into the compensator or orifice cap I and T.

As chlorine passes through the control-valve E, the pressure on the front side of the diaphagm (6) will fall, consequently the pressure on the back side of this diaphragm—due to a spring (4) and the back pressure—will cause the diaphragm (6) to press on the needle-valve (1) and thus allow more chlorine to enter. As soon as the back and front pressures are equal, a state of equilibrium is maintained in the compensator. Any chlorine passing out of the compensator will tend to increase the pressure on the check-valve M (Fig. 6) and more chlorine will consequently pass through the needle-valve (1) due to the slight breathing movement of the silver diaphragm, the chlorine entering the compensator from the main cylinder at the same rate as it passes through the check-valve to the diffusor. Thus a steady flow of chlorine is maintained, the chlorine leaving the apparatus at a constant pressure set up by the check-valve M.

*Manometer and Orifice and Scale* (Fig. 5).—The outer glass tube of the manometer H is connected by means of the small tube (10) to the orifice I which is made of glass and which varies in size according to the amount of gas that the instrument is required to pass, and the small tube (9) to the orifice cap T. As chlorine flows from the compensator, it meets the orifice and is necessarily checked in its flow, and subsequently a pressure is set up before the gas passes through the orifice. The difference in the pressure of the chlorine before and after it has passed through the orifice is proportional to the flow of the gas, as in a Venturi water-meter. Since the back pressure set up by the check-valve is constant, the chlorine will be passing from the orifice at a steady pressure and will therefore be unaffected by any change of pressure to which the chlorine may be subjected. The pressure set up by the flow of the chlorine through the orifice is indicated by the height of the liquid in the manometer tube, and this height is read by means of an adjustable scale which has been graduated, experimentally, for the orifice in question, in pounds of chlorine per hour. Any desired quantity of chlorine can be allowed to pass from the instrument, within the range that the orifice can pass, by opening or closing the control-valve E, Fig. 3, on the compensator C.

*Check-Valve* (Fig. 6).—The check-valve consists of a silver-plated brass or copper stem N through which runs a silver tube (12). To the open end of this tube is attached the diffusor O, which consists of a porcelain ring into which two disks of alundum are cemented. The other end is attached to a perforated silver hemisphere (14) which fits inside the main portion of the valve, and is fitted with a needle-valve (15) which is kept open by a spring (16). Closing this hemisphere is a silver corrugated disk (17) with a similar strengthening disk of copper (18) on the top of it. Acting on this is a spring (8) to which is fitted an adjusting screw (20). This spring acts on a segmented disk (19) which in turn acts on the two diaphragms and closes the needle-valve. No chlorine can pass out of the check-valve until the pressure within is sufficient to overcome the pressure of the spring (8) and so lift the needle-valve. This pressure is the back pressure and is usually set at 25lb. per square inch.

By means of the apparatus the chlorine enters the compensator at any pressure and, after passing through it to the orifice, it is metered and leaves the apparatus at a constant pressure and is forced into the water through the diffusor which breaks up the gas into very small bubbles. The amount of chlorine passing through

4 H

the apparatus is regulated by means of the control-valve E, Fig. 3, and when once set will continue to deliver chlorine at the set rate until the cylinder is empty. For a temporary stoppage, it is only necessary to close the auxiliary tank-valve B and on restarting,

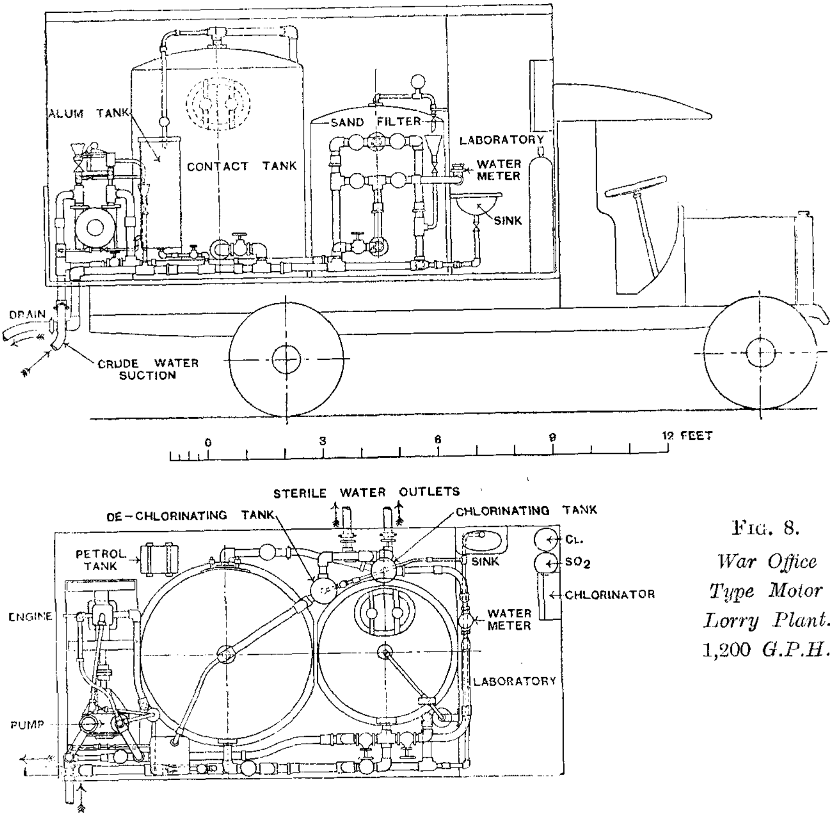



Fig. 8.
*War Office Type Motor Lorry Plant.*
1,200 *G.P.H.*

to open this valve. The apparatus can be emptied of chlorine by means of the blow-off valve K.

It is absolutely essential that moisture should be kept from getting inside the apparatus, as although dry chlorine has no effect, moist chlorine will rapidly corrode the metal parts of the apparatus. It is also necessary to keep the cylinder of chlorine at about the same temperature as the chlorinator, as at low temperatures chlorine under pressure liquefies very easily, and if the instrument is colder than the cylinder, liquid chlorine will collect in it and render the flow of chlorine unsteady.

The Solution-Feed type of apparatus, Fig. 7, Plate 21, differs from

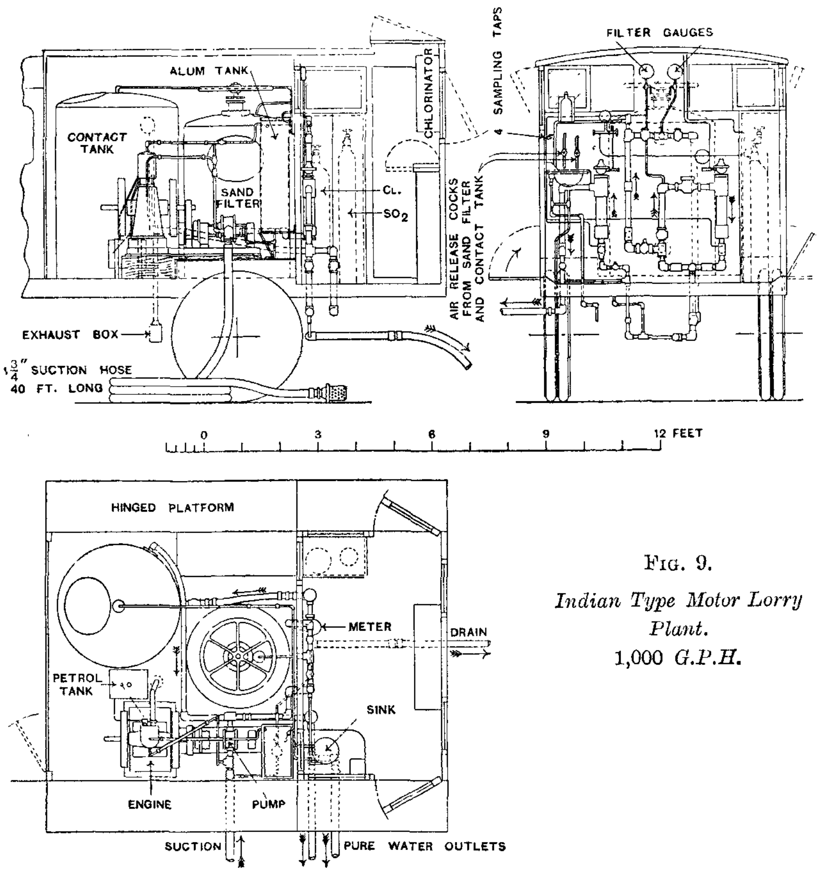



Fig. 9.

*Indian Type Motor Lorry Plant.*

1,000 *G.P.H.*

the Direct-Feed type in that the chlorine, after it leaves the compensator, passes to a bubble meter in which the bubbles of chlorine are seen and counted and are dissolved in water. The rate of flow of the chlorine is determined by the rate of the bubbles, and regulated by means of the control-valve on the compensator.

After the bubbles of chlorine have dissolved in the water that is led to the bubble meter and which is under constant agitation, it is injected into the water that has to be sterilized. This type of instrument has the advantage over the Direct-Feed type in that the actual chlorine that is being used is seen, and that it can be used to deliver smaller amounts of chlorine than the Direct-Feed type. It is, however, slightly more complicated and requires more care in fitting up, but it is if anything more accurate than the Direct-Feed.

The Direct-Feed type has been adopted throughout the water purification plants in use in the Army, and they have given every satisfaction. The makers guarantee an efficiency and accuracy of at least 96 per cent, and on several tests the accuracy has been almost 100 per cent.

The purification plants in the Army in which the chlorine-sulphur dioxide process has been adopted as standard can be divided into three classes:—

(1) Portable plants built on motor-lorries, Figs. 8 and 9, and Figs. 10–14, Plates 22–23.
(2) Portable plants built on barges, Fig. 15 (page 1142).
(3) Stationary or land plants, Fig. 16 (page 1143).

The first class is primarily for use with an army moving into occupied territory, in which the usual sources of water have been destroyed or rendered useless. The second serves to some extent the same purpose but on a larger scale, and the third is the standard type for supplying water to troops in the rear of operations and for replacing the water supply of towns.

The process of purification is the same for all three types of plant, and can be divided into five main operations:—

(1) Coagulation of suspended matter by means of aluminium sulphate solution, or, if necessary, with this chemical and an alkali.
(2) Sedimentation of the water so treated.
(3) Filtration of the water after coagulation and sedimentation.

(4) Sterilization, using chlorine gas.

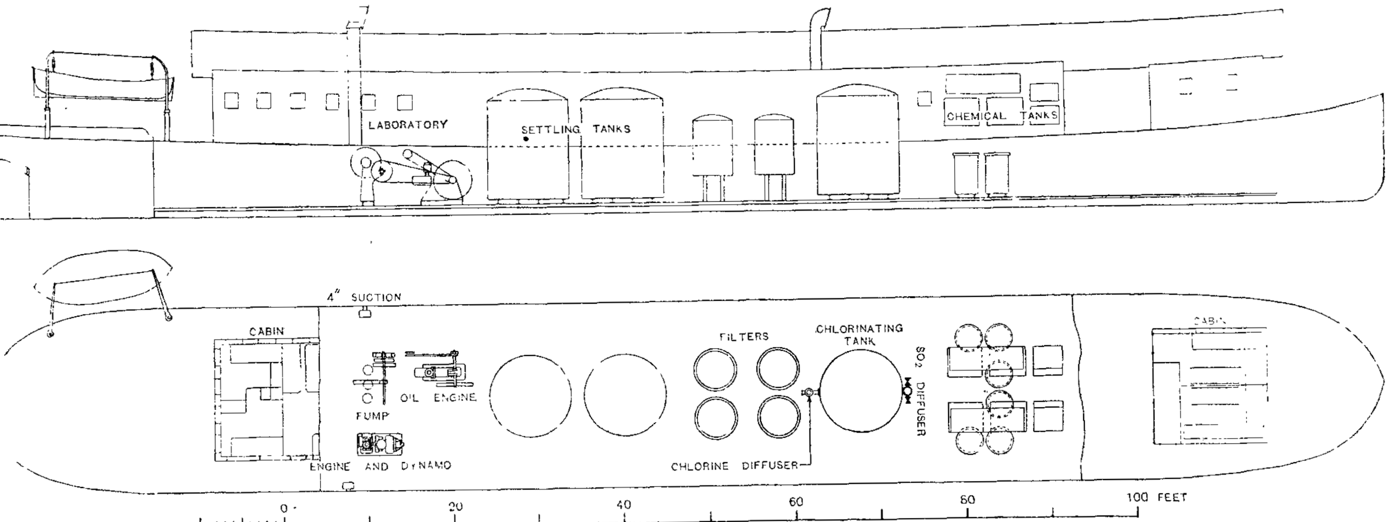
(5) Dechlorination, using sulphur dioxide gas.

Under some circumstances it may not be necessary to treat chemically or sediment the water before filtration, but whenever the crude water contains a large amount of fine material in suspension, or is coloured by iron or clays, a preliminary chemical treatment is essential.

The five operations are carried out in slightly different ways by the three types of plants, each adopting that which is most convenient. Coagulation and sedimentation are carried out by the motor portable plants in canvas dams, but in the other types pretreatment tanks form part of the plants. If it is necessary to pretreat the water, the required amount of aluminium sulphate, or alum, together with lime or soda if the water is very soft, is added to the water and well mixed. After standing for some time the water clears and the suspended matter falls to the bottom with the aluminium hydroxide which has been formed by the hydrolysis of the aluminium sulphate. The cleared water is then led to the filters in such a way that the sediment in the pretreatment tanks remains undisturbed. The filters, except those constructed by Ransome ver Mehr, consist of cylindrical iron tanks, filled with sharp clean sand resting on a bed of graded gravel, fitted with some arrangement for stirring the sand mechanically, and so constructed that water can be admitted from the top or the bottom.

Filtration always takes place through the sand from the top downwards. It is essential, however, that the filters should be completely filled with water from the bottom upwards, in order to remove all air from the sand, and to form a solid bed of it free from possible cracks and air-channels. When this has been done, the direction of the flow of the water is reversed and filtration commenced, the water passing in at the top of the filter and out at the bottom. The object of the mechanical stirring arrangement and the arrangement for sending the water up through the sand is to enable this to be backflushed or cleansed after it has been in use for some time, thus removing the matter which has been filtered

FIG. 15.—*General Arrangement of Filtration Plant on Barge. Capacity, 8,000 G.P.H. Filter Type "Ransome."*



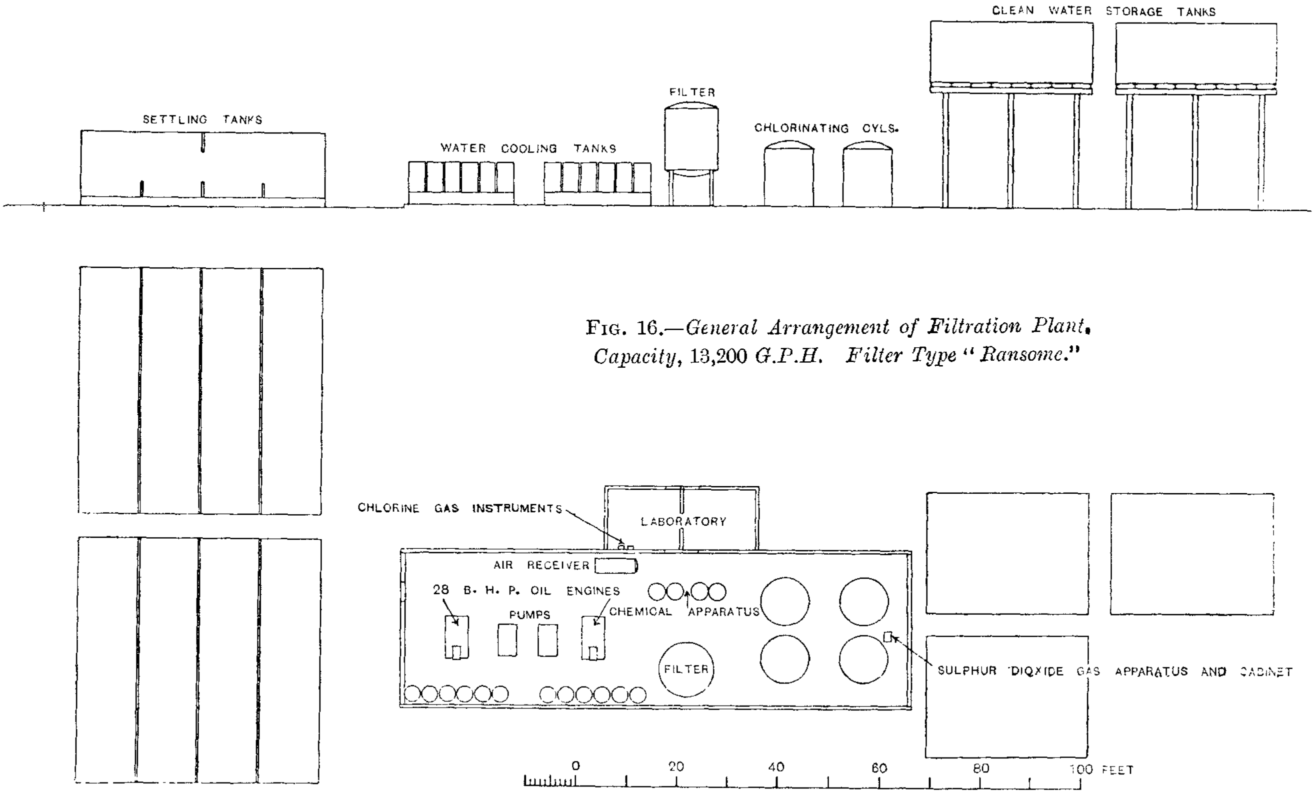



FIG. 16.—*General Arrangement of Filtration Plant, Capacity,* 13,200 *G.P.H. Filter Type "Ransome."*

out on the top of the sand, which gradually causes the filtration pressure to increase.

In the Ransome filter, used on some barge and stationary plants, a modification of the ordinary filter is used, a mechanical stirring arrangement being unnecessary as the surface of the sand is constantly shifting and being replaced by sand which has been automatically washed. In the earlier type of motor-lorry plant, in which weight was necessarily restricted, a mechanical stirring arrangement was not used, and backflushing of the filter had to be carried out with crude water. This made it necessary, on starting the filter, to allow the filtered water to pass to waste, as it had not been filtered right through the sand. In the other types of plants this was rendered unnecessary, as sterilized water is used to backflush the sand-filters.

A good sand-filter should remove all suspended matter and produce a clear water with a considerable reduction of the number of bacteria in it. It will work best if there is present on the surface of the sand a layer of aluminium hydroxide. If the water has been chemically treated, some of the aluminium hydroxide formed is carried on to the bed of the sand-filter from the settling tanks, but if it has not been so treated, then a solution of aluminium sulphate is injected into the water before it enters the sand-filter. This solution is hydrolysed by the water and the aluminium hydroxide deposited on the surface of the sand as filtration proceeds. The filter-bed thus formed clears the water to a very much greater extent than a plain untreated sand-filter could do and, at the same time, it will reduce the number of bacteria in the water very considerably.

After filtration has been going on for some time, the pressure on the filter-bed increases, and filtration becomes more difficult. A point is reached when the sand-filter must be backflushed to remove the layer of sedimentary matter which has collected on the top of the sand-filter. Before filtration can be commenced again the filtering surface has to be reformed with aluminium hydroxide. After filtration the water is then sterilized by means of chlorine. Some plants, especially those which have been converted to use chlorine gas, can be used for sterilization with bleaching powder in case the chlorine method should break down.

The amount of chlorine to be added is indicated by means of the test described in the Appendix (page 1149), the complete apparatus and chemicals for which are contained in a case supplied to the troops, and known as "Case, Water Testing Sterilization," unless the water has been examined bacteriologically. This indicated amount of chlorine is administered by the Wallace and Tiernan Chlorinator, which is adjusted to deliver the correct amount of chlorine for the particular rate of output of the plant. The apparatus is graduated in pounds of chlorine per hour, and this is converted into parts of chlorine per million of water by means of a conversion scale (page 1150). The adjustment of the flow of chlorine is carried out as described previously.

The filtered water is thus chlorinated and partly sterilized, but complete sterilization takes place after the water has been in contact with chlorine for not less than twenty minutes. The period of contact is obtained by allowing the chlorinated water to pass through a large tank or series of tanks. These tanks are fitted with baffles to prevent short circuiting of the water. During the period of contact some of the chlorine is absorbed, and at the completion of this time the water is completely sterilized as is shown by obtaining negative results by the MacConkey and Neutral Red Agar tests. The water, although filtered and free from bacteria, contains some chlorine, and as a consequence has a slight taste. This taste can be completely removed by the addition of sulphur dioxide, the chlorine reacting with this gas to produce hydrochloric and sulphuric acids, or chlorides and sulphates, which, at the very great dilution at which they are present, cannot be detected by taste.

The sulphur dioxide is added to the water by means of a simple apparatus which consists essentially of a check or back-pressure valve, to prevent the water under treatment entering the apparatus, and a fine adjustment valve for regulating the flow of the gas. A pressure-gauge is fitted to indicate the pressure of the sulphur dioxide in the cylinder. The amount of sulphur dioxide to be added is determined by a simple chemical test which is repeated from time to time and, if necessary, any alteration of the fine adjustment valve made. The test is made by adding a solution of potassium iodide and starch to a small quantity of the water after it has been treated with sulphur dioxide. A blue colour is produced by the chlorine, and the amount of sulphur dioxide that is being added is adjusted until only that colour is produced, which indicates that less than half a part of chlorine is present in a million parts of the treated water. This test is extremely delicate, for a definite blue colour is obtained with 0·2 part of chlorine per million.

The small amount of chlorine that is left in the water is for the purpose of preserving the sterility of it during the transit from the purification plants to the troops actually using it. If the water is required for use on the spot, the amount of chlorine left in can be reduced to an almost negligible quantity. On some of the larger plants a rather more elaborate dechlorinating instrument is used, differing only in detail to the above-mentioned type.

In field operations, the water which has been purified is either delivered to storage tanks, and from these to pipe-lines or, as is the case with the mobile purification plants, to tank-lorries or water-carts. The small amount of chlorine that is purposely left in the water generally disappears by the time it reaches the troops, and consequently no taste of this chemical can be detected. It has been found possible, under some circumstances, to deliver water direct to the petrol tins used for carrying water to the trenches, thus saving a great deal of transport and its attendant difficulties, a matter of considerable importance in warfare.

Experience gained in the late War has shown that water purification installations using chlorine as the sterilizing chemical are extremely efficient, simple, and cheap to operate, and that the water after treatment is without the characteristically objectionable taste which is associated with water that has been sterilized by means of chloride of lime. There is no question that, for installations of even a moderate size and even quite small ones that are in almost constant use, the chlorine-sulphur dioxide process is the best and most efficient one that can be adopted. Chlorine is cheap, it is easily transported and stored, and there is no loss or deterioration occasioned by even very long storage. The process entails very little labour for making solutions, and the manipulation is extremely simple and easily learnt.

For very small plants, and those which are not in frequent use, the initial cost of a chlorine-sulphur dioxide installation is comparatively high, and for this reason chlorine will never replace entirely chloride of lime as a sterilizing chemical for water. Chloride of lime, however, has one very serious disadvantage in that it is very easily decomposed by even a moderate temperature, and very great trouble was experienced in the early days of the War in providing a supply of sterilized water for the troops engaged in operations in the East. As soon as the chlorine-sulphur dioxide process was introduced, this difficulty was, to a very great extent, overcome, but the process could not be economically applied to small plants which gave an output of only a few gallons per hour.

As a result of experiments undertaken with the object of producing a sterilizing chemical which was not easily decomposed by heat a new substance was introduced. This chemical is known as bromine bleaching powder,* and is very similar in properties to chlorine bleaching powder, except that it is not decomposed at temperatures as high as 100° C. Bromine bleaching powder imparts a less objectionable taste to water than ordinary bleaching powder and is quite an efficient sterilizing chemical.

From this survey of the water supplies of the Army, it is evident that a supply of sterilized water can be maintained under almost any possible conditions by the use of one or other of the various types of water purification plants mentioned. So successful has the process been that new plants have been ordered for use in the East, Fig. 9 (page 1139). These are lighter and more compact than the ones used in France, and are even simpler to manipulate and embody many small improvements in design which have been

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* British Patent No. 14661/18.

found to be desirable as a result of experience gained on active service in the War.

This Paper would be quite incomplete if the invaluable work done on the subject of Water Purification for the Army by Colonel Sir William Horrocks, K.C.M.G., C.B., M.D., and his Advisory Board was not fully acknowledged and emphasized. The work done by this Advisory Board of the Army Medical Service contributed to an enormous extent to the magnificent standard of health of the Army during the War. The whole of the work on Water Purification was under the direct control and personal supervision of Sir William Horrocks, and this Paper only deals with a portion of this work, but it will serve to indicate what has been done to safeguard the water supply of the Army during the Great War.

The Author is indebted to Messrs. The United Water Softeners, Ltd., for their kindness in lending several of the blocks and photographs used for illustrating this Paper.

The Paper is illustrated by Plates 21–23, 9 Figs. in the letterpress, and is accompanied by an Appendix.

# APPENDIX.

## Description and Method of Using the "Case, Water Testing Sterilization," in connexion with Chlorine Gas.

### *Description of Contents.*

The contents of the case are as follows:—

Six white-enamelled cups, each holding $\frac{1}{3}$ pint of water when filled to the brim.

One black-enamelled cup with mark on the inside.

Two metal spoons, each holding 2 grammes when filled with bleaching powder level with the brim.

One stock bottle of zinc iodide and starch test solution and one dropping bottle. Three drops of the solution give a definite colour with water containing one part per million of free chlorine.

Six glass tubes or pipettes, each of such dimensions that a drop of standard bleaching powder solution delivered by it, when held in a vertical position, into a white cup filled with water gives a dilution of one part per million of free chlorine.

Four glass stirring rods, twelve pipe cleansers and two copies of instructions.

### *Method of Using.*

Crude water is generally used. The test is best carried out while the plant is being prepared for work. The test takes about half an hour to carry out.

1. A standard solution of bleaching powder is prepared in the black cup by putting into it one level spoonful of good bleaching powder, making it into a paste with a little water by stirring it with a glass stirrer and carefully breaking up all lumps. More water is added to the paste and the black cup filled with water to the mark on the inside. This is stirred vigorously and the glass stirrer left in the black cup. One of the pipettes is put into the solution, which is never clear as it contains lime in suspension.

2. The six white cups are filled with the water to be tested to within $\frac{1}{4}$ inch of the top.

3. Drops of the standard bleaching powder solution from the pipette are added to the water in the white cups so that they contain 1, 2, 3, 4, 5 and 6 drops respectively. Each cup is thoroughly stirred with a clean rod, and

this rod is left in one of the cups. The cups are allowed to stand for half an hour.

4. After half an hour, three drops of the zinc iodide and starch solution are added from the dropping bottle, and each cup is stirred with the rod that was left in one of the cups.

5. Some of the six white cups show no colour, while some will show a blue colour. The first cup which shows a blue colour, that is the one containing the smallest number of drops, is noted. If cups 1, 2 and 3 show no colour and 4, 5 and 6 show a blue colour, then cup number 4 is the one to be noted. The water will therefore require four parts of chlorine per million to sterilize it. If none of the cups show a blue colour, then the cups are washed out and the test performed again with 6, 7, 8, 9, 10, 11 and 12 drops of the bleaching powder solution in the cups.

6. Each drop of the bleaching powder solution in a white cup of water corresponds to one part per million of chlorine.

7. It is to be noted that only if the bleaching powder is fresh and good will this test accurately agree with the amounts of chlorine gas required for sterilization. It serves, however, as a guide for the amount of chlorine to be added to the water by means of the Wallace and Tiernan Chlorinator.

## *Conversion Table.*

SHOWING LB. OF CHLORINE PER HOUR.

| Parts per Million. | Gallons of water per hour. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **400** | **500** | **600** | **700** | **800** | **900** | **1,000** | **1,100** | **1,200** | **1,300** | **1,400** |
| 1 | 0·004 | 0·005 | 0·006 | 0·007 | 0·008 | 0·009 | 0·01 | 0·011 | 0·012 | 0·013 | 0·014 |
| 2 | 0·008 | 0·01 | 0·012 | 0·014 | 0·016 | 0·018 | 0·02 | 0·022 | 0·024 | 0·026 | 0·028 |
| 3 | 0·012 | 0·015 | 0·018 | 0·021 | 0·024 | 0·027 | 0·03 | 0·033 | 0·036 | 0·039 | 0·042 |
| 4 | 0·016 | 0·02 | 0·024 | 0·028 | 0·032 | 0·036 | 0·04 | 0·044 | 0·048 | 0·052 | 0·056 |
| 5 | 0·02 | 0·025 | 0·030 | 0·035 | 0·04 | 0·045 | 0·05 | 0·055 | 0·06 | 0·065 | 0·07 |
| 6 | 0·024 | 0·03 | 0·036 | 0·042 | 0·048 | 0·054 | 0·06 | 0·066 | 0·072 | 0·078 | 0·084 |
| 7 | 0·028 | 0·035 | 0·042 | 0·049 | 0·056 | 0·063 | 0·07 | 0·077 | 0·084 | 0·091 | 0·098 |
| 8 | 0·032 | 0·04 | 0·048 | 0·056 | 0·064 | 0·072 | 0·08 | 0·088 | 0·096 | 0·104 | 0·112 |
| 9 | 0·036 | 0·045 | 0·054 | 0·063 | 0·072 | 0·081 | 0·09 | 0·099 | 0·108 | 0·117 | 0·126 |
| 10 | 0·04 | 0·05 | 0·06 | 0·07 | 0·08 | 0·09 | 0·1 | 0·11 | 0·12 | 0·13 | 0·14 |

*Experimental Test on the Chlorination of Water by means of the Wallace Tiernan Chlorinator.* Brentford, 12th–15th Sept. 1916.

All chlorine was removed after sterilization by means of sulphur dioxide.

| Time of Test. | Rate of Flow. Galls. per hour. | Wallace Tiernan Gauges. | | | Chlorine—parts per million | | |
|---|---|---|---|---|---|---|---|
| | | Tank. | Back. | Mano-meter Level. | Injected. | A After 10 mts. | B After 30 mts. |
| 12/9/16 | | | | | | | |
| 2.30 p.m. | 540 | 74 | 19·5 | 0·8 | 4·7 | — | — |
| 3.40 „ | 770 | 70 | 19·5 | 0·57 | 3·6 | 3·0 | 2·7 |
| 4.30 „ | 720 | 72 | 19·5 | 0·56 | 3·5 | 3·5 | 3·3 |
| 6.0 „ | 600 | 75 | 20 | 0·55 | 3·5 | 3·2 | 3·2 |
| 8.30 „ | 720 | 75 | 19·5 | 0·5 | 3·4 | 3·2 | 3·2 |
| 10.30 „ | 640 | 75 | 19·5 | 0·525 | 3·5 | 3·3 | 3·3 |
| 13/9/16 | | | | | | | |
| 1.0 a.m. | 675 | 72·5 | 19·2 | 0·52 | 3·5 | 3·3 | 3·3 |
| 3.0 „ | 675 | 71 | 19·1 | 0·52 | 3·5 | 3·3 | 3·3 |
| 5.0 „ | 675 | 71 | 19·1 | 0·53 | 3·5 | 3·3 | 3·3 |
| 7.0 „ | 675 | 72 | 19·4 | 0·54 | 3·5 | 3·3 | 3·3 |
| 9.15 „ | 675 | 77 | 19·75 | 0·55 | 3·5 | 3·3 | 3·3 |
| 11.0 „ | 640 | 82 | 19·75 | 0·5 | 3·5 | 3·3 | 3·3 |
| 2.0 p.m. | 640 | 82 | 20 | 0·54 | 3·5 | 3·3 | 3·3 |
| 4.0 „ | 640 | 77 | 20 | 0·53 | 3·5 | 3·3 | 3·3 |
| 14/9/16 | | | | | | | |
| 5.30 p.m. | 720 | | | | | | |
| 6.0 „ | 720 | 63 | 20 | 0·75 | | | |
| 7.0 „ | 720 | 61 | 19 | 0·75 | 5·15 | 2·13 | 1·7 |
| 8.30 „ | 720 | 57·5 | 18·6 | 0·79 | 4·1 | 1·77 | 0·9 |
| 10.0 „ | 720 | 56 | 18·5 | 0·8 | 4·1 | 1·77 | 1·0 |
| 11.30 „ | 720 | 55 | 18·5 | 1·06 | 5·3 | 3·1 | 1·95 |
| 15/9/16 | | | | | | | |
| 1.0 a.m. | 720 | 52 | 18·5 | 1·07 | 5·8 | 3·9 | 1·95 |
| 3.0 „ | 720 | 50 | 18·5 | 1·07 | 5·9 | 3·8 | 3·2 |
| 5.30 „ | 720 | 49 | 18·3 | 1·08 | 6·2 | 2·1 | 2·1 |
| 7.0 „ | 720 | 48 | 18·1 | 1·1 | 6·2 | 2·2 | 1·6 |
| 9.0 „ | 720 | 52 | 18·75 | 1·15 | 6·2 | 2·6 | 2·1 |
| 11.0 „ | 720 | 65 | 19·1 | 0·55 | 4·7 | 4·4 | 3·4 |
| 1.0 p.m. | 720 | 68 | 19·1 | 0·55 | 4·8 | 3·8 | 1·77 |
| 2.30 „ | 720 | 70 | 19·2 | 0·55 | 4·4 | 3·8 | 1·7 |
| 3.30 „ | 675 | 70·5 | 19·5 | 0·35 | 2·4 | 2·0 | 1·5 |
| 4.30 „ | 640 | 70·5 | 19 | 0·17 | 1·4 | 1·2 | 1·2 |
| 5.30 „ | 640 | 70·5 | 19 | 0·15 | 1·2 | 1·1 | 1·1 |

*Remarks.*

13/9/16 (4.30 p.m.) Breakdown of pumping plant.
14/9/16 (5.0 p.m.) Started again after repairs.
„ (6.0 p.m.) Commenced chlorinating.
„ (10.30 p.m.) Chlorine increased.
15/9/16 (9.45 a.m.) Chlorine reduced.
„ (3.0 p.m.) Chlorine reduced.
„ (4.0 p.m.) Chlorine reduced.
„ (5.30 p.m.) Test stopped.

*Experimental Test on the Chlorination of Water.*—Continued.

| Time of MacConkey Test. | MacConkey Test—50 cm.³ incubated at Brentford. Date and Time of Inspection. | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14/9/16 11 a.m. | | 15/9/16 10 a.m. | | 16/9/16 2 p.m. | | 18/9/16 11 a.m. | | 19/9/16 3 p.m. | | 21/9/16 11 a.m. | | 22/9/16 11 a.m. | | 23/9/16 11 a.m. | |
| | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** |
| 4.30 p.m. | | + | | | | | | | | | | | | | | |
| 6.0 ,, | + | − | + | + | | | | | | | | | | | | |
| 9.0 ,, | | − | | + | | | | | | | | | | | | |
| 11.0 ,, | | − | | − | | − | | − | | − | | − | | − | | − |
| 13/9/16 | | | | | | | | | | | | | | | | |
| 1.30 a.m. | | − | | − | | − | | − | | − | | − | | − | | − |
| 3.0 ,, | | − | | − | | − | | − | | − | | − | | − | | − |
| 5.30 ,, | | − | | − | | + | | | | | | | | | | |
| 7.30 ,, | | − | | − | | − | | − | | − | | − | | − | | − |
| 9.45 ,, | | − | | − | | + | | | | | | | | | | |
| 11.30 ,, | − | − | − | − | − | − | + | − | | − | | − | | − | | − |
| 2.15 p.m. | − | − | − | − | − | − | + | − | + | + | | | | | | |
| 4.30 ,, | − | − | − | − | − | − | − | + | − | + | − | | − | | − | |

| | 16/9/16 2 p.m. | | 17/9/16 3.30 p.m. | | 18/9/16 11 a.m. | | 19/9/19 2 p.m. | | 21/9/19 11 a.m. | | 22/9/19 11 a.m. | | 23/9/19 11 a.m. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7.20 p.m. | − | | − | | + | | | | | | | | | |
| 8.45 ,, | − | | − | | − | | + | | | | | | | |
| 10.30 ,, | − | − | − | − | − | − | − | − | − | − | − | − | − | − |
| 11.45 ,, | − | | − | | − | | − | | − | | − | | − | |
| 15/9/16 | | | | | | | | | | | | | | |
| 1.0 a.m. | − | − | − | − | − | − | − | − | − | − | − | − | − | − |
| 3.0 ,, | − | | − | | − | | − | | − | | − | | − | |
| 5.0 ,, | − | − | − | − | − | − | − | − | − | − | − | − | − | − |
| 7.0 ,, | − | | − | | − | | − | | − | | − | | − | |
| 9.0 ,, | − | − | − | − | − | − | − | − | − | − | − | − | − | − |
| 11.0 ,, | | − | | − | | − | | − | | + | | | | |
| 1.0 p.m. | | − | | − | | − | | − | | − | | − | | − |
| 2.50 ,, | | − | | − | | − | | − | | − | | − | | − |
| 4.0 ,, | | − | | − | | − | | − | | − | | − | | − |
| 4.45 ,, | − | − | − | − | + | − | + | + | | | | | | |
| 5.30 ,, | | − | | + | | + | | | | | | | | |

*For* Remarks, *see next page.*

*Remarks.*—The following samples were taken, and sent to R.A.M. College:—

| | | | |
|---|---|---|---|
| 12/9/16 | (6.30 p.m.) | Two samples. | Both reported sterile. |
| „ | (11.0 p.m.) | „ „ | „ „ „ |
| 13/9/16 | (3.0 a.m.) | One sample. | Reported sterile. |
| „ | (12.0 noon) | „ „ | „ „ |
| „ | (3.30 p.m.) | Two samples. | One reported sterile, one non-sterile. |
| 14/9/16 | (12.0 midnight) | One sample. | Reported sterile. |
| 15/9/16 | (7.15 a.m.) | „ „ | „ „ |
| „ | (11.30 a.m.) | „ „ | „ „ |
| „ | (12.30 a.m.) | „ „ | „ „ |

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## *Discussion in London.*

The PRESIDENT said his first duty was to ask the members to pass a very hearty vote of thanks to the Author for his admirable Paper.

The Motion was carried with applause.

The PRESIDENT said the actual sterilization of water did not concern the mechanical engineer (except of course when he had to drink it), but he had to understand the principles on which that sterilization was effected, otherwise he could not design nor appreciate the machinery used for the purpose. The Author had given the principles, and had explained and illustrated the machines in his Paper, and he (the President) hoped there would be a good discussion.

Dr. SAMUEL RIDEAL said he was sorry he was the first speaker on the Paper, for the reason that the subject matter was more mechanical, as the President had said, than chemical. He had been a chemist and a bacteriologist all his life, and therefore did not feel quite competent to open the discussion. He very much regretted the absence of Sir William Horrocks, who knew more about the

Dr. Samuel Rideal.)
actual operations of chlorine sterilizers during the War probably than anyone else, and he had hoped he would have been able to open the discussion. The Author had said that the subject was novel, and had traced the early history back to the time of the Boer War. It was true that, during the Boer War, chlorine was not used for sterilizing purposes, but it had been used for sterilizing water long before that period, and bromine, which the Author also referred to in connexion with the bromine bleaching powder, had also been used for sterilizing water before that date. In fact, some of the earlier work was done shortly after the cholera epidemic in Altona, which was some fifteen years earlier, when experiments were conducted in using bleaching powder for sterilizing the effluent water from the emigrant station at Hamburg. The first practical use of chlorine for sterilizing water on a large scale was in connexion with the Maidstone epidemic, when Sir Sims Woodhead used bleaching powder for sterilizing the water mains.

He regretted that Sir Alexander Houston was not present that evening, as he had taken a great interest in the problem of utilizing chlorine and bleach for sterilizing water. In the Lincoln epidemic —which he did not think the Author had mentioned—in 1905, which was after the Boer War, chlorine was used for sterilizing the water supply by him, so that experience had been gained before the water problem became acute in connexion with the Army. He himself had seen in Philadelphia in 1912 Major Darnell's apparatus, which was one of the earliest forms of apparatus for using liquid chlorine as apart from bleaching powder for sterilizing. That was demonstrated before the International Congress for Hygiene and Demography which was held in Philadelphia in that year. The developments of the Darnell plant which had been shown that evening of course came rather late in the War, and one would have thought that the Americans, having had that practical experience in chlorine sterilization on a large scale for many years, would have been able to put forward their plant in a practical form for the use of the troops earlier than they actually did.

In the perfected form of the instrument that had been described by the Author, the advantages of chlorine over bleaching powder were obvious, although it must not be forgotten that there was a distinct difference between the behaviour of liquid chlorine and bleaching powder. Chlorine was a more effective germicide apparently in the acid condition, while bleaching powder was an alkaline body. It was known that the efficiency of chlorine under those two conditions was different. Chlorine in acid acted as an oxidizing agent and thus destroyed organic matter, whilst bleaching powder, being alkaline, was not so energetic until the chlorine from it had been liberated by means of an acid. Therefore when bleaching powder was added to an alkaline water there was less germicidal activity than when chlorine was added to the water.

Liquid bromine had been also used as well as liquid chlorine for water sterilizing purposes. It was used in the "Eighties" or "Nineties" by the German Army. Their method was a very simple one. They had the liquid bromine in a glass bulb and broke the dose of bromine which was required for sterilizing purposes into the amount of water required. Therefore the use of a corrosive liquid like chlorine was worked out in that way in the case of bromine, before the bromine bleaching powder described by the Author was suggested for water sterilizing purposes. The relative activities of bromine, chlorine, and iodine were known. What was known as the Rideal-Walker coefficient of chlorine was 24, whilst that for bromine was 62, and for iodine it was about 100. Those figures were very roughly proportional to the atomic weights of the three halogens, and at the same time expressed their relative germicidal values, taking carbolic acid as the unit.

One of the most important points that had to be carefully considered when using any of these methods for sterilizing water was, as the Author remarked, the removal of the after-taste of the water. Whether bleaching powder was used or chlorine, there was always that effect, and various methods had been devised for destroying the taste. The Author had selected sulphur dioxide as a means of neutralizing that after-taste of the chlorine. That had to be carried about in a cylinder as a compressed gas and used with the addition of a regulator very similar to the doser used for chlorine itself, and care had to be taken to control the excess of the sulphurous acid

(Dr. Samuel Rideal.)
in order to ensure the destruction of the taste, and therefore it might be necessary to add something to remove the excess of sulphurous acid itself. Iron had also been used as a " dechlor," but amongst the things which he thought in practice were simple and useful, and which did not give any after-taste or add any injurious or additional substance to the water were hydrogen peroxide—which was simply water plus oxygen and, therefore, added nothing to the water—and permanganate. Potassium permanganate or sodium permanganate was a common enough reagent and had been used for pinking wells in India for the last fifty years, and had a very excellent effect in removing the after-taste of chlorine. It had been tried by Sir Alexander Houston in connexion with the London water supply with very satisfactory results. The permanganate when dissolved could be added to the chlorinated water regularly and simply, and it was very easy with that chemical to see that a sufficient quantity had been added, because one could note from the colour when an excess was present or not. He thought those were useful points to remember, and congratulated the Author in putting on record the details of the plant which they had seen that evening.

Major-General Sir WILLIAM LIDDELL, K.C.M.G., said he could only say a few words as a user of the plant, and it might be of interest to state how the need for it arose. The authorities were faced with the problem in 1916 of providing water for a proposed force of about twenty divisions marching right through North-West Belgium. The water in that area, practically all from surface supplies, was probably as foul as could be found anywhere. It was extraordinary how bad the water supplies were, even in the big towns in that part of the country. It was necessary to provide for a rapid advance—which eventually, as a matter of fact, never took place. Thus we had, first of all, to depend on the water of the canals as the main sources of supply, although the water in them was grossly contaminated. The plant, or the early form of it, was therefore fixed on barges, which at the time was a novelty. Then motors had to be provided with the sterilizing plant to deal with water from surface wells and other sources remote from canals.

The capacity of the mobile sterilizing plant gradually evolved from 400 gallons to 1,200 gallons an hour by reason of the use of chlorine gas as a reagent. As the Author had said, there was an idea of providing a cavalry plant on horse-drawn vehicles as well; but this type was soon abandoned. That advance, as he said, never matured, but the mobile plants on barges and lorries proved extremely useful in every way on all parts of the Front. Their use was spread all through the Armies, and he thought that in many tight places the presence of water-sterilizing lorries had enabled the troops to maintain their positions and saved them from retirement.

Another point which he would like to mention was the forms in which the principles underlying the system of purification of water adopted in mobile plant was made use of for stationary plant. The River Yser was probably one of the most unpromising sources that could be imagined, or at least it was so in the neighbourhood of some of the intakes, but was the only large source available, and was made use of for the supply of a large section of the Front in 1917. A supply of between 200,000 to 300,000 gallons daily was required. At first a sand-filtration plant, which proved more or less a failure, was established, and was shortly succeeded by a system of sedimentation with alumino-ferric for about eight hours, in tanks holding about 50,000 gallons each, then by chlorination in tanks of similar dimensions by solution of bleaching powder added to the water as it was moved from one tank to another. That water was eventually pumped up 15 or 20 miles to the Front. It was a very simple method, and it required very careful watching by chemists, but proved thoroughly effective. The main interest in the system was that it dispensed practically with any filtration through sand at all.

Another form of the same simple type adopted in the later advance through Belgium in 1918 consisted of a small portable apparatus—really only two canvas tanks, each holding about 9,000 gallons, and a hand-pump or small motor-pump. One tank was a sedimentation tank, and in it the water was treated with alumino-ferric, being in contact with it for about eight hours.

(Major-General Sir William Liddell.)
The water was then pumped into the second tank and chlorinated as before with a bleaching-powder solution, and thence distributed to the troops. These small portable installations were in general use in Belgium towards the end of the War.

He (the speaker) thought it could be claimed that the water supply to the troops was extraordinarily good on the whole throughout the War. In the early stages of the War he thought he was right in saying that, whereas the French had something like 60,000 or 80,000 cases of enteric during the first eighteen months, the total British cases were something like 1,000. This comparative immunity was due to anti-typhoid inoculation being general, and to the careful treatment of the water supplied for drinking purposes.

Dr. Eric K. Rideal, M.B.E., F.I.C., said he was a chemist, but he had had a certain amount of experience with the various types of barges, not only of those described in the Paper, but also of the Bell system, which the War Office used in different parts of Belgium and France. He was practically the whole time in the Somme area, and did work both on the barges and on the portable water filters. There were always difficulties in dealing with water supplies during War time. First of all there was the usual type of difficulty which one sometimes got also in private work, namely, the question of people walking into the water supply. The French native troops, which came at different times into the area where he was situated, were rather attracted to the drinking water supplies for the purpose of washing. There were other difficulties, as, for instance, cohesion between the different parts of the troops—who was going to couple up the water supply to the pipe-line, and who was responsible for this, that, and the other. All those were naturally things that took place when some people were on a barge and other people were on land.

As far as the direct dosing with chlorine was concerned, there were two types of apparatus which could be used—the Wallace and Tiernan apparatus, which might be called the direct dosage, chlorine being passed straight into the water. Then there was the other type in which a minor volume of water was chlorinated, and the minor volume of water thus chlorinated was added to the main bulk. The fundamental difficulty was the question of the measurement of chlorine, which was really a most heartrending problem to anybody who had tried to do it.

There were three types of apparatus by which one could measure chlorine—the Venturi type meter, the Pulsing type meter, and the electric-flow meter. The electric-flow meter had not yet been applied to the measurement of chlorine, but it had been applied very successfully to the measurement of other gases, and there was no reason at all why it should not be also used for the purpose of chlorine measurement. All those types suffered from the disadvantage that one was dealing with very small quantities of chlorine (usually less than one litre per minute), and therefore the measurement gear had to be extraordinarily accurate. The Venturi meter could be divided into two types—the pin-orifice meter, and the long capillary tube. They were extraordinarily sensitive to temperature changes and also sensitive to little bits of iron coming off the cylinders, flies and other insects, and things like that sticking in the very fine orifice. The quantity of chlorine passing through was very small, and therefore the orifice type of meter was not a very good one. The Pulsing meter was preferable, owing to the fact that there were no very small contractions or jets in the gas flow. The electric resistance one could probably be elaborated into a very serviceable mechanical arrangement.

After having divided the chlorine meters into types and obtained a measurement of the gas passing into the water, the question naturally arose to the mechanically minded; how could the quantity of chlorine left in the water after a certain time be measured? The usual method was to take some of the water and do a tritration. There were some very interesting facts which were electro-chemical in the action of chlorine on water. He got out the oxidation potential of chlorine in both acid and alkaline water, and it was 1·9 volts in acid water and 0·86 in alkaline water. That meant that chlorine was very much stronger as an oxidation agent in acid water than in alkaline

(Dr. Eric K. Rideal.)

water. Chlorine in acid solution was nearly as strong as potassium permanganate. What was called the hydrogen ion concentration of water was a very important thing, and had a distinct bearing on the question of adding gaseous chlorine in lieu of alkaline bleaching powder and alkaline hypochlorites. One really required to measure in a water, not the available chlorine, because that did not convey very much information, but rather the oxidizing potential of the chlorine. That was a problem Mr. Evans and he were interested in many years ago, and they provided a mechanical apparatus for measuring the oxidizing potential of chlorine in water. It was simply a piece of platinum wire in a copper tube. A little of the water was passed through that apparatus, which acted as a little battery, and it was quite possible by a very simple device to read off the quantity of water flowing. That would give the quantity of chlorine in the water as measured in the terms of its oxidizing power, and it differed very considerably from the very alkaline water of the London basin to the comparatively acid waters which were found in certain parts.

The rapidity of action of chlorine depended on its oxidation potential, which was the important feature. In France one was much struck with the need of some very rapid method of getting that oxidation potential, owing to the fact that the water was always varying in chlorine absorption, and tests were frequently needed with potassium iodine starch, in order to see that the water was not ultimately going to kill everybody about the place. A little mechanical device was rigged up for adding the potassium iodide in starch. It took the form of a tube and siphon, and if the colour remained blue, one might be quite happy that things were going right, but the electrical method of measuring the quantity of chlorine was preferable to that.

The amount of chlorine with different waters was remarkably varied. On the Somme they had a great opportunity of studying the action of chlorine on impure water, which in the autumn season was polluted with a great deal of vegetable matter, and in the summer and other times with animal pollutions as well. The action of chlorine on vegetable and animal pollution was very different. The after-taste was extraordinary in animal pollution, and much less in vegetable pollution. The chlorine absorption was much higher with vegetable than with animal pollution. It was not quite clear what the peculiar taste was due to, but he thought it might be the presence of phenoloid bodies in the animal refuse, and of course a very small quantity of chlorphenol in the water would cause an extraordinary taste. The action of chlorine on micro-organisms was also most interesting; in fact, one type of B. coli could be changed into another in a short time by treatment with traces of chlorine. It all arose really out of the method which had been in use in the States for many years, and had been and still was being investigated in this country from all those different points of view.

Mr. William Paterson said that most engineers would share with him a certain feeling of diffidence in entering into a discussion on the subject of the sterilization of water supplies, for they felt that it was to the chemist and bacteriologist that they owed their knowledge of the action of the reagent. The Paper gave little scope for discussion, as it described only one particular type of apparatus used during the War, and therefore was not a subject upon which one would care to enter into a critical discussion, but the Author had referred in his general remarks to one or two points that he thought called for a reply. The general impression conveyed by the Paper was that the process of chlorination was first developed in America, and to some extent that was so, but he would have been better pleased had the Author referred to the first instance in which chlorine was used for the disinfection of water supplies, as at Lincoln in 1905.

On the first page the Author stated that "bleaching powder or chlorine was first used to sterilize the supply of drinking water in 1897 at Maidstone, where an epidemic of typhoid was raging." That was hardly the case. On that occasion hypochlorite of lime was used simply for flushing out the mains and ensuring their disinfection. The polluted source of supply was then cut off. Prof. Sims Woodhead was responsible for the good work done at

(Mr. William Paterson.)
Maidstone, and in his Paper on "Results of Sterilization Experiments on the Cambridge Water," read before the Cambridge Philosophical Society in 1910, he said: "I filled the whole of the water mains from the gravitation reservoir with 1 in 300 solution of chloride of lime or bleaching powder. From the complaints received by the water company from all sources I was satisfied that we had attained our object." It would be noted this was simply disinfection of the mains and not sterilization of the water supply.

No Paper on the chlorination of water supplies was complete without reference to the classic researches of Dr. Houston and Dr. McGowan, who in 1905, for the first time in history, maintained the sterilization of a polluted supply to 50,000 people. A full account of this work was given in the Fifth Report of the Royal Commission on Sewage Disposal, and he would strongly advise anybody interested in the subject to secure that Report. Their researches determined:—

(1) The amount of chlorine absorbed by waters of varying purity.
(2) The effect of sunlight on the action of chlorine-sterilized water.
(3) The effect of chlorinated water on slow sand-filter beds.
(4) Factors affecting taste troubles, etc.

It had been an invaluable guide since 1905 on all matters relating to the sterilization of water supplies with chlorine.

With regard to the question of the sterilization of water by chlorine gas, he regretted the Author made no reference at all to the first occasion when it was suggested that gaseous chlorine should be used for the sterilization of water supply. The idea did not originate in America, but came from Lieut. V. B. Nesfield, a British Officer in the Indian Medical Service. He (the speaker) had with him a copy of *Public Health* for July 1903, containing Nesfield's Paper on "A Chemical Method of Sterilizing Water without affecting its Potability," advocating the use of portable gaseous chlorine plants and dechlorinating with sodium sulphite, and giving the result of actual tests carried out with these reagents. Surely the Author might have made some reference to that first occasion on which it was suggested that gaseous chlorine be used, as a simple portable means for sterilizing water supplies for troops. This process was nine years later brought into practical working in America by Darnell and Ornstein. In his opinion Ornstein's 1913 patent indicated the first really practical method of applying chlorine gas for water-sterilization purposes. Although filed only a year after Darnell's, it represented a marked advance in the mechanical development of the process.

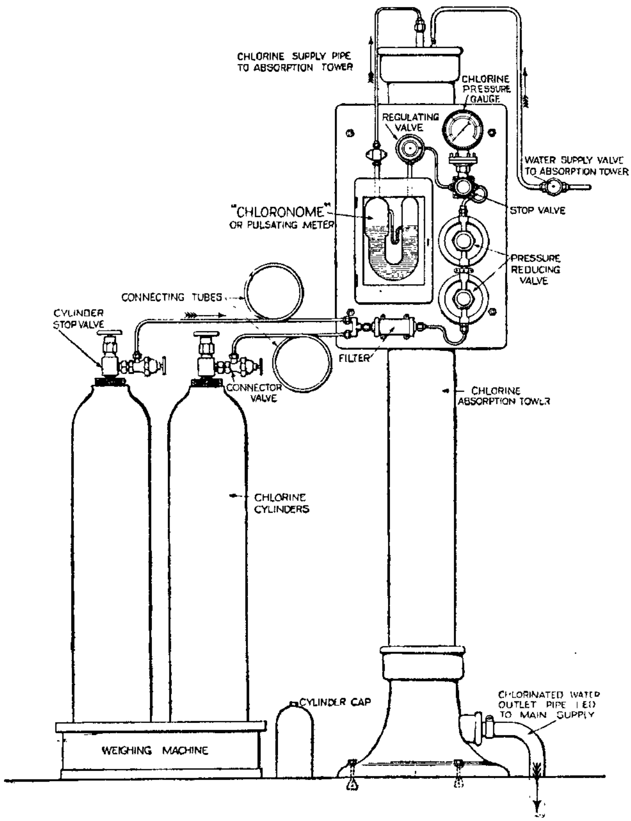
The Author stated that there was less taste with gaseous chlorine than with hypochlorite of lime, but the speaker's own experience had not led him to think so. He believed water accurately dosed with hypochlorite was no more liable to taste troubles than that treated with gaseous chlorine, and he understood others had a similar experience. The advantage of gaseous chlorine was the possibility of adding it more precisely than hypochlorite of lime. Taste, due to excess of free chlorine, could be removed by dechlorinating, but if the taste was due to the reaction of the chlorine with impurities in the water, no dechlorination would remove it. Sir Alexander Houston, in his Thirteenth Research Report for the Metropolitan Water Board, stated on page 37:—"When, however, a chlorinated water has developed the 'iodoform' taste, dechlorination is powerless to remove it." According to that authority the "iodoform" taste could be removed either by increasing the dose of chlorine sufficiently or by adding potassium permanganate, as well as chlorine, to the water.

The Author had referred to the active corrosion that was set up when water was brought into contact with chlorine. That was undoubtedly one of the greatest difficulties to be overcome in chlorinating plants. At the invitation of the President, he had brought an apparatus devised to overcome that difficulty, which he exhibited and explained, Fig. 17 (page 1164), pointing out the special feature that the instrument with its valves and mechanism was completely isolated from the water by a column of liquid unaffected by the gas or water, so that by no possibility could the moisture get into the mechanism and cause corrosion. The reducing valves maintained a constant pressure of 10 lb. per square inch on the regulating valve. This was adjusted so as to give the required flow

(Mr. William Paterson.)
of gas to effect the sterilization of the main supply under treatment. The rate of flow was indicated by the rate of pulsation of the sealing liquid in the U-tube meter. The plant demonstrated could treat

FIG. 17.

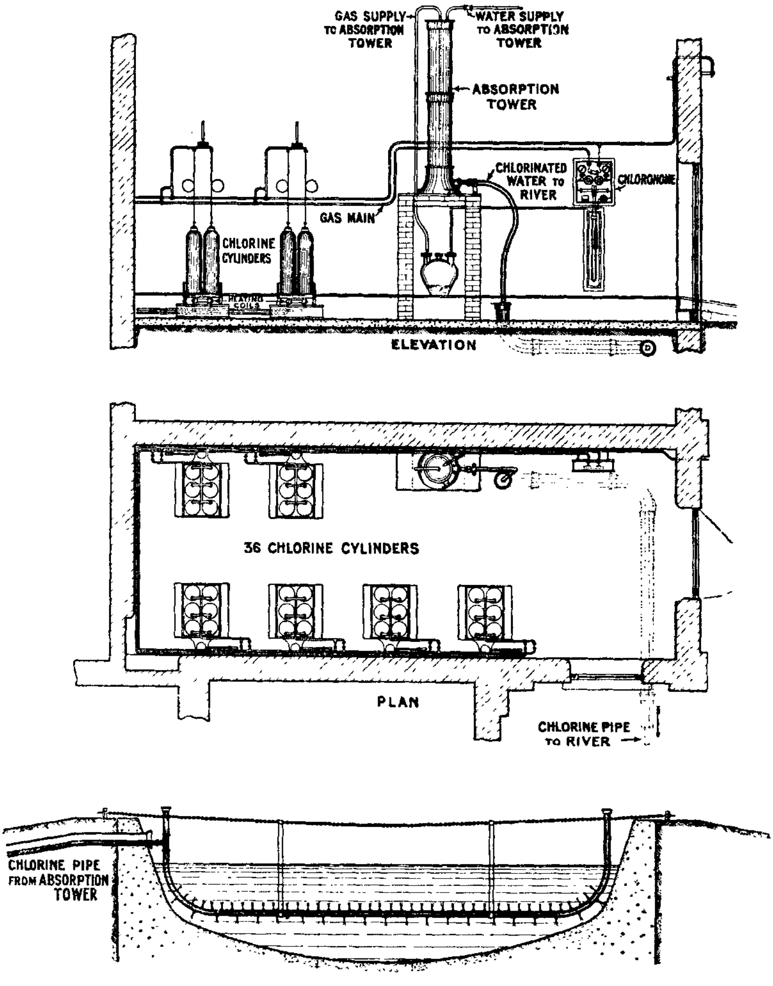
*"Chloronome" for Sterilizing Water by the Addition of Gaseous Chlorine. Capacity* 10 *lb. of Chlorine per day.* (Paterson.)




from 5,000 to 100,000 gallons of water per hour, and could be set at will to pulse at any speed from one in 6 seconds to one in 300 seconds, giving from 0·5 to 0·01 lb. of chlorine per hour. When once set, the precise rate of pulsation was maintained continuously.

Fig. 18.

*Arrangement of Gaseous Chlorine Plant, Sterilizing New River Water. Capacity 400 lb. of Chlorine per day.* (Paterson.)




CROSS SECTION THROUGH RIVER SHEWING DISTRIBUTING PIPE.

SCALE 0 1 2 3 4 5 6 7 8 9 10 FEET

(Mr. William Paterson.)

Fig. 18 illustrated a Chlorinating Plant of 40,000,000 gallons daily capacity which he had installed for the Metropolitan Water Board to treat the New River water supply. The apparatus was fitted in an existing storeroom where thirty-six cylinders mounted on six weighing-machines were connected to the regulating meter and board. The measured gas entered near the base of the elevated absorption tower, where it was absorbed by a minor stream of water which gravitated through a distributing pipe led across the New River. The distributing pipe was fitted with a large number of vulcanite nozzles which ensured the uniform distribution of the chlorinated water throughout the width of the stream. The capacity of this apparatus was 400 lb. of chlorine per day.

Mr. V. Hjort thought the Paper might have been entitled "The Sterilization of Water by Chlorine Gas for Military Purposes." The Author had had considerable experience, and a longer experience than most people associated with military work, in the handling of portable plant for use by the troops, and it was evident that he had concentrated more on that part of the work than on the general sterilization of water as, for instance, for municipal purposes. It was evident that both types of apparatus were found useful for the two classes of work, namely, stationary work and portable work. Probably the reason why the Americans did not bring over the type of chlorinating plant for the use of chlorine gas was that it was felt that the problem of designing a small portable unit, which was more wanted than any other type of plant for the troops in case of an advance, had never been tackled.

He would like to give a short historical explanation of the development of the portable sterilizing plant and show the early attempts which were made to solve the very difficult problem, as that would enable the members to understand that the War Office had a problem that was not easily solved, as it had not been attempted before. There was a certain amount of humour attached to the installation shown in Fig. 19, Plate 24. In 1914, experiments were carried out in the City of Paris on the treatment of water by bleaching powder, and a certain treatment for cancelling the excess chlorine; and on the basis of those experiments the little equipment shown was placed on a hired furniture removal lorry, as no lorry could be obtained from the War Office, and was shown to the War Office in 1915. The whole thing was a very temporary affair. Hand pumping was resorted to, and only a small output of 80 gallons an hour obtained, quite out of proportion to the enormous cost of the lorry and the cost of running it, but at any rate it was the first attempt in the right direction.

The next attempt was illustrated by the Author in the Paper. Two plants arranged on general service wagons were constructed, but they were never sent to the Front, as, whilst they were being designed, further experiments were carried out, and it was found that a much greater capacity could be obtained on a practically similar area. Fig. 20, Plate 24, showed what was brought out then, consisting of sterilizing plant using bleaching powder and with iron sulphate for dealing with the excess chlorine. The unit on the left of the illustration was designed for the urgent purpose, as called for by headquarters, of dealing with metallic poisoning which was reported to have taken place at a certain point on the Front, and instructions were given for experiments to be carried out. They were difficult experiments, because the passing of metallic poisoning by means of water had never been thought of. The matter was so pressing that the type of plant shown was developed, and it was so designed that it could be either used for sterilizing or used for taking poison out of the water. The officer in charge, who was in charge of the very earliest type of apparatus, was present that evening, Captain R. W. Stickings.

The next type of plant that was got out was the plant utilizing chlorine gas. Not only was it possible much more quickly to sterilize water, but it could be produced at a much higher rate. A 3-ton lorry, which up to then had been only capable of supplying water at 400 gallons an hour, was turned into a working unit of 1,200 gallons capacity, and, as a matter of fact, it was on record that that plant had been worked up to 2,500 gallons for 22 hours consecutively at a time when water was very urgently needed. So that it would be seen that progress was made not only in research but in output.

(Mr. V. Hjort.)

Fig. 21, Plate 24, showed the first chlorine-gas apparatus brought over from America. It was mounted temporarily, with the requisite pump, engine, filter and contact tank, on a lorry lent by the War Office for the purpose of the experiment, and this was returned as soon as the experiment was over. The whole of that equipment was got out in a hurry to put to a practical test the chlorine-gas apparatus, and to ascertain what contact was necessary in order to secure sterilization of the water. That was the first of the type ever made, and when compared with Fig. 11, Plate 22, it would be seen that, except for details of piping, these designs were identical. In due course the construction of plant for India and for the Italian and Belgian Fronts followed, and there was a development from 125 gallons an hour to 2,500 gallons. The efficiency of the plants had been officially acknowledged, and it might interest the members to know that it was on record that perfectly sterile and good water had been produced in seven minutes after the taking of a German trench. It could be imagined what that meant where water was practically as valuable in the case of an advance as ammunition and food. It was established that one big move would have been impossible without the use of quick methods of dealing with very bad water, and that was safely secured. It was a matter of satisfaction, he thought, that this country led the way and produced the first type of plant which was afterwards used by the Allies. The Americans, when they came over, brought an outfit very similar to the one that had been shown, except that they resorted to the older method of dechlorination by sodium hyposulphite.

As the Paper had been written mainly to deal with water treated for military purposes, he had not included in his notes anything dealing with the municipal water service, but in that connexion America was a long way ahead of any other country in the chlorination of water, and particularly so in the use of chlorine gas. The whole of the supply of greater New York was safeguarded by the installation of gas chlorinating apparatus at all possible points. The largest one was dealing with 500,000,000 gallons a day, where previously bleaching powder had been used, but as soon as the gas sterilizing apparatus was perfected, it was changed over.

Captain R. W. E. Stickings, O.B.E., said he was sorry that the chemists seemed to have monopolized the Meeting, because he had to plead guilty to being a chemist himself. As Mr. Hjort had said, he went to Brentford in the early days when the portable sterilizing lorries were in their infancy, and he mobilized the first unit and took it out to France. That unit was in working condition up to the time of the Armistice. During that time his company comprised thirty special lorries, some of which were for depoisoning water, and others for sterilizing purposes. The depoisoners had never been used as such, but were used as sterilizers. Altogether nearly 60,000,000 gallons of sterilized water was delivered to the troops by No. 1 Water-Tank Company (above). Various letters of congratulation were received from the staff officers of the Fourth Army in particular, with whom the detachment was working for most of the time. On one occasion they managed to get one of the sterilizers into position delivering water within 24 hours of the occupation of a village, during the 1918 advance. The weight of the lorries on the road was about 8 or 9 tons, and in a road that had been blown to pieces by shells and mines this was rather a difficult proposition to undertake. Those who had had lorries ditched knew how other people on the road regarded them.

He thought perhaps the introduction of the chlorine gas tended towards centralizing the Army water supplies. The cost of one of the compensators was a very big item when only dealing with small supplies, and the water engineers endeavoured to centralize the supplies as much as possible, so that a chlorine-gas chlorinator might be used to advantage. The water engineers and the water-tank companies worked together very well indeed; they were under the control of the Royal Engineers and received all their details from them. One of the things they tried to do was to chlorinate water at the source. Naturally that was an idea that would come into anybody's mind, namely, that if the supplies had to be centralized, the chlorination should be done at the source and the sterilized water distributed by the pipe-line system, and in that way the number of chlorinators required would be minimized. It was found in practice that this was a very difficult thing indeed in the field, because when there were 10 or 12 miles of pipe-line, it was not easy to keep the water sterile. He had once put in thirty parts per million of chlorine at a source, which made the water perfectly horrible, and on going to the end of the pipe-line, 3 miles away, and waiting for three days he found that no chlorine got through, and the effluent was not sterile; all the chlorine had been absorbed in the inside of the pipes.

The French had a chlorinating system somewhat different from the British, but it was very simple and satisfactory indeed, and personally he used it on a few stationary plants in France. They sterilized their water by means of *Eau de Jovel*, which was sodium hypochlorite. In making up solutions of ordinary "chloride of lime," the difficulty was that there was a tremendous excess of lime, which would not go into solution. On the other hand, *Eau de Jovel* was a perfectly clear liquid, was supplied commercially in France, and could be bought in shops as a sterilizing agent by civilians, so that a large supply of the solution could be commandeered. The water was simply pumped through a main, from which there was a by-pass which took off a little of the water through a sort of water-suction pump; this sucked in from the strong solution a certain amount (which amount could be regulated by means of a tap), and the movement of the water through the main brought the chlorinated by-pass water back again into the pipe, where it mixed with and sterilized the water in the mains. The French had those systems erected practically all over their Army area. He had come in contact with the French chemists in charge of the water supplies, and he thought their system was very excellent, but they had to deal with people who did not really care what they drank, and consequently did not care what they drank it from. That was one of the difficulties the British Company had to encounter. After they had chlorinated the water, the most urgent problem was how to keep it sterile until it was consumed. In order to do that, as far back as 1916 they dispensed with any idea of dechlorinating water; as a matter of fact, it was detrimental to do so. Unless one-half to three-quarters of the chlorine was left in the water, by the time it reached the people who were going to drink it, it was no longer sterile; consequently there was no dechlorination at all on the old type of plant.

Mr. WILLIAM H. PATCHELL (Member of Council) said several weeks ago, after travelling all night, he got out of the train in Detroit and took a bath, when he was forcibly reminded of the years gone by when he used to make skeleton leaves! He thought the room had been cleaned out with chloride of lime, but was told that they were chlorinating the water. Bearing in mind that the present Paper was to be read at the Institution, he tried to get particulars in Detroit of what they were doing. He met Mr Theodore Leisen, the engineer of the waterworks, who very kindly showed him the plant which had been used for chlorinating with gas there since 1915. The apparatus was not one of the automatic machines that had been shown by the Author, but was by Wallace and Tiernan, manually operated. The chlorine cylinders were put on large weighing machines, and the chlorine was bubbled into water at a steady pressure of 10 lb., which was run into the inflow of a large settling tank. The pumps drew the water from the far side of that settling tank and delivered it into the town mains. There were some 1,500 miles of mains, 65 miles of which were from 42 inches to 48 inches in diameter, so that there was a good chance of any sort of slight error averaging out. He did not go to the works until he had been in Detroit for ten days, and by that time he had quite lost any sense of taste or smell of the chlorine in the water. He asked the engineer if he had altered the quantity of the chlorine put into the water, and he said they had not, that they kept it quite steady. The death-rate in Detroit was low and would be lower still if it were not for the motor cars! The quantity of water handled in Detroit was 150,000,000 gallons a day, which was 150 gallons per head of the population, a higher figure than our average. That was probably due to prohibition!

He was in another waterworks, which were constructed for 750,000 gallons per day, where they were handling 13,000,000. The water was kept free from taint by chlorine gas. The water in both cases was taken from the Detroit River. It was

(Mr. William H. Patchell.)
more or less muddy, so they were at present arranging in Detroit to put down filter-tanks. At present they had none; they had merely the large settling tank. It was also interesting to note, in connexion with the Detroit Works, that they had laid wooden water-pipes within the last hundred years. He had dug up several wooden pipes in the Charing Cross area, but he did not think any had been laid in London for something like two hundred years. In New York he was spending a Sunday afternoon with a friend, a great admirer of Leonardo da Vinci, looking over volumes of drawings by that wonderful man, and amongst them he discovered a machine for boring out wooden water-pipes!

In justice to what had been said with regard to the Americans that evening, he had asked Mr. Leisen for a copy of Wallace and Tiernan's catalogue, from which perhaps he might be allowed to read a paragraph: "Notable among the first large-scale attempts to sterilize water by the process of chlorination is that undertaken under the direction of Dr. A. C. Houston (Fifth Report of Royal Commission on Sewage Disposal, Appendix IV), Director of Water Examinations of the Metropolitan Water Board of London, England, in 1905. At that time sodium hypochlorite was applied to the Lincoln (England) water supply, with gratifying results." This showed that even if the Author in his short note had not quite meted out even justice between the American and the Englishman, the Americans themselves had done so.

Mr. THOMAS BOUTS asked whether the Author could tell him how it was known that the water was sufficiently sterilized, and how much chlorine was required to sterilize a given amount of water.

Mr. A. W. MARSHALL said he would like to know what was meant by metallic poisoning. Was it derived from pipes or fittings?

Mr. W. J. A. BUTTERFIELD said a good deal had been heard about the sterilization of the water supply in France but very little about that in other spheres of the War, such as the Far East, where sterilization by chlorination did not get properly to work until the War was fairly well advanced. Up to within a few weeks of the fall of Kut it was altogether inadequate, and the large number of deaths from water-borne disease were due to the chlorination of the water supply not being carried out properly. During the War an officer in a line regiment happened to arrive at Basra in charge of men going up with the Relief of Kut expedition. He was seized upon by the medical officer, who happened to know him as an old schoolfellow who had become a trained chemist, and was forthwith put in charge of the sterilization of the water supply at Basra. He reported in a private letter that up to that time it had been entirely in the hands of Indian natives, and either it had been obviously inadequate or the water had been rendered undrinkable. He set to work with a barrel as an improvised churn, using chloride of lime, which was available; and a short time afterwards he used chlorine driven off from the chloride of lime by the addition of acid. He made up a solution of strong chlorinated water, which was standardized and then put into bottles and sent up by the river steamers, with instructions that one bottle would sterilize so many gallons of river water, the proportion varying according to the season of the year. Once that system got fairly to work there was no water-borne disease in that area. Later the improvised plant was improved upon. The account of the matter should be obtained direct from Captain Frank L. Bassett, B.Sc., F.I.C., who carried out the work, and who was now the chief chemist to the civil administration of Mesopotamia and had his quarters in Baghdad.

The Author had referred to brominated water. It would be undesirable to rely on bromine in future wars, unless we were sure that Germany would be neutral or on our side, because almost the only sources of bromine and bromine compounds in the world were in German territory.

Lieut-Col. A. E. Davidson, D.S.O., R.E. (Member of Council), said his experience with the types of plant, referred to in the Paper, had been confined to dealing with those patterns carried on motor-lorries in France. During the War there seemed to be an idea that, if there were any awkward looking object lying about at home, the first thing to do was to fit it up for mechanical transport. There were four companies dealing with the purification of water. The two early companies had bleaching-powder sets, and the two later companies chlorine-gas sets; and the latter were an enormous advance in increasing the output per set from 400 to 1,200 gallons per hour. As an indication of the saving effected, there were at one time on order from England four complete M.T. companies, and two of them were cancelled simply owing to the increase in the capacity. In fact, the capacity of the new plants was almost a drawback, because some of the places where they were required had a relatively small output, and it seemed rather a waste to use a 1,200-gallon plant to deal with a small supply.

The only other objection from the mechanical transport point of view was the excessive weight for the lorry. It was not only the weight, but the arrangement. Some of the very heavy parts came behind the back axle. He was glad to see that a lighter type had been evolved, which really made the plant much more portable for use with the Army, namely, the one described in Fig. 9 (page 1139). A number of the lorries carrying bleaching-powder sets were altered in France to chlorine-gas sets, and the people at the base workshops were continually sending urgent messages that it was very bad luck on the lorry to load it up to such an extent.

Captain J. Stanley Arthur, in reply, said that, with regard to Dr. Samuel Rideal's questions, he would like to point out that sulphur-dioxide dechlorination was not quite as Dr. Rideal had put it. In the Army, chlorine was always left in, for the purpose of being sure that the water was sterile, and therefore it was utterly unnecessary to add an excess of sulphur dioxide to remove all the chlorine. By an extremely simple chemical test, the amount of chlorine remaining could be determined accurately to 0·1 of a part per million parts of water, in less than half a minute. He did not think General Sir William Liddell's remarks needed any reply.

With regard to Dr. Eric Rideal's remarks as to the Venturi meter giving a considerable amount of trouble, from actual experience he thought the only trouble that had arisen in that work had been the small glass Venturi orifice. That trouble was expected, but it was not due to dirt, but to some curious condensation on the glass which could be removed quite easily by carbon tetrachloride, or even better by alcohol. Every lorry leaving for France was equipped with a spare orifice and a corresponding spare scale, and he thought that a man who had had any experience with those could exchange them in two or three minutes if necessary, without taking very great precautions. He wished also to point out that the plants were designed for active service, and it was not an easy matter to manipulate delicate electrical instruments in warfare. He was quite aware that it was easy to do such things with accuracy when there was a fixed definite point from which to work.

Mr. Paterson had accused him, and justly, he thought, of not dealing quite fairly with the chlorine question. He had to own frankly that he was in a very difficult position when he was asked to write the Paper ; he thought he might say that he almost refused to do it because it was quite unfair to other people engaged in the work. He himself did not come into the work until early in 1916, and other people had done a great deal of work before then. He came into it as a chemist and as an amateur engineer. He claimed nothing beyond the chemical side of it and the adaptation of his chemistry to engineering methods. With regard to the Paper itself, he had the difficult task of writing a chemical and bacteriological Paper for The Institution of Mechanical Engineers—not an enviable task—and he only hoped that his drawings, such as they were, would meet with approval. He had to make the Paper as short as possible. It was more or less a War Office matter, and it was written about twelve months ago and had been delayed ever since, partly because he was leaving the country.

He thought that, as a chemist, he might say that the water supply of Maidstone was really sterilized. When he said that it required, for the dirty canal water on which they had to work, an average of three parts per million of chlorine to sterilize it, he thought it would be agreed that there had been enough left in the pipes to sterilize that water for some time. With due regard to the English

(Capt. J. Stanley Arthur.)

work on the subject, he thought the Americans were considerably ahead of us; they had been doing the work for a long time, and were compelled to do it in the first place, because they had to draw their water from sources which were always polluted. That he believed was the explanation of the speed with which they got to work on the problem. At the time when he started work on the subject, there was no other chlorinator in existence which would do what was required. The chlorinator devised by Messrs. Wallace and Tiernan proved satisfactory, as had already been stated.

The problem in connexion with the taste of the water was a very curious one. General Sir William Liddell would remember that he (the speaker), when demonstrating the first machine at Abbeville, noticed a most objectionable taste in the water under treatment; it was like iodoform. At first it could not be traced, and he had the most wonderful theories with regard to the formation of substances having an iodoform taste by the reaction of chlorine with organic matter which was present, but he traced it next day and found it was due to the fact that they were washing ambulances a little higher up from his intake. He need hardly say that some of his theories were no longer tenable. But there was that possibility, and he had found that where the water had been extremely bad to work upon, where it was stagnant or sewage or very foul, it was not possible to get rid of the whole of the taste, but if one worked on water such as that of the Thames at Richmond, he was prepared to say that there was no taste in the water if sterilization was carried out properly, and the chlorine was removed by means of sulphur dioxide.

Mr. Hjort had put the question very plainly. Mr. Hjort was associated with the contractors who carried out the whole of the portable work for the War Office, and also carried out some of the other plant, stationary and on barges. Mr. Hjort placed at the disposal of the War Office a station, and the War Office worked in conjunction with his firm, suggestions being made by various officers and by the firm, and immediately carried out. The chlorinating tests were first of all carried out actually on a plant which was composed of a few old tanks and an old engine, and results were obtained from that, and he had put some of them in the Paper. It was then suggested that the plant was capable of being mounted on a lorry, and that was done and the War Office inspected it. He thought they were very frightened of chlorine gas; at all events, his instructions were to watch results very carefully. He did so, and in talking with General Sir William Horrocks on the subject, he suggested that it would be quite possible to increase the size of the plant without adding too much weight to the lorry, and he told him he thought it was quite possible to do that on the spot. It was done by three men, two Army Service Corps men and one R.A.M.C. man, and himself, and the whole thing was constructed on a lorry upon which a sterilization plant had been constructed, but which was not suited for field use. A new engine and pump were used and supplied by The United Water Softeners, Ltd., and it differed very much from the plant illustrated. Considerable hesitation was shown at the use of chlorine gas, and before he was allowed to start the work he was told he must be able to use bleaching-powder solution, and must be able to dechlorinate, not with sulphur-dioxide gas only, but also with sodium bisulphite solution. For some time he had been trying to inject bleaching-powder solution and sodium bisulphite solution into water under pressure and to measure the amount injected. It was not an easy problem. It was the first of what was called the pressure type. There were earlier types which were failures.

The plant that went to France differed in the respect that it was fitted for sterilization by chlorine gas and for dechlorination by sulphur dioxide gas, and at the same time sterilization by bleaching powder and dechlorination by sodium bisulphite, if it was required at any time. The plant was taken to France, and in less than a week the whole of the bleaching-powder and bisulphite solution apparatus was scrapped. He wished also to point out that the original plant built by The United Water Softeners Co. had on it two of those elaborate instruments he had shown, which cost considerably over £200. It seemed utterly unnecessary to add sulphur dioxide so accurately by one of those instruments, when it could be done by a simple hit-and-miss method which was under complete

(Capt. J. Stanley Arthur.)

control, and so the hit-and-miss method was adopted. It was done by a pressure-gauge and a back-pressure valve—later on a simple arrangement on the principle of a bicycle valve was used—and the sulphur dioxide was added by the rotation of the needle-valve, made by the British Oxygen Co. That had remained standard right through and was the standard to-day, and the total cost of it was very small indeed in comparison with a chlorinator. His original apparatus was improved upon by expert draughtsmen and designers, but the weight remained the same; in fact, it was slightly increased. The weight was mentioned as 8 tons, but it was really 8 tons 4 or 5 cwt., including a great deal of stores. The only reply he could make to Captain Stickings (page 1169) was to say that he (Captain Stickings) was the first chemist to start on the work.

With regard to metallic poisoning, it was referred to by chemists as poisoning which might be due to the presence of any metallic salt—copper sulphate, mercury chloride, potassium cyanide, arsenic compounds, or any chemical which could be dissolved in water and so render the water poisonous. Before he came into the work, it was part of the problem considered by Professor H. B. Baker and Sir William Horrocks, and machines were made to remove the whole of the poison and render the water perfectly fit to drink. It was expected that the Germans would put poison into the water, and that it would not come from the pipes.

With regard to the supply in the East, on his return from France, he was engaged in work as a research chemist and chemical engineer, and apparatus was designed for the East, but he could not say what was sent out.

Colonel Davidson had spoken of the size of the lorries (page 1174). The idea of increasing the size so much was to save transport and troops. For the India Office the weight and size had been reduced practically 50 per cent, and the output only reduced from 1,200 to 1,000 gallons an hour.

*Discussion in Manchester, Thursday, 25th November* 1920.

The Chairman (Mr. H. P. Hill), in opening the proceedings, said the members would find that, in the Paper, Captain Arthur gave a very interesting account of the way in which the water supplied to the troops during the war was sterilized, so that the health of all concerned was well maintained. Of course it was a truism to say so, but he did not suppose there had been any war in the history of mankind in which there was less mortality due to the diseases which arose from hygienic causes as distinct from fighting. The sterilization of water was one of the most important causes contributing to that result. But the interest of the subject did not lie entirely in the application of this process of sterilization by chlorine gas to water supplied to troops on active service; it also applied to the water consumed by the ordinary civilian population. Not every town nor every country was in so fortunate a position, with regard to water supply, as Manchester and this country as a whole were in. At many places in other countries, the supply was derived from sources which, if not absolutely polluted, were, at any rate, of so questionable a character that filtration did not entirely "fill the bill" in preserving the health of the inhabitants. For instance, it was well known that in America, such diseases as typhoid had in times past been more or less endemic, and it was said to be largely due to the water supplied. There was no doubt that the introduction of this process of sterilization by chlorine gas added a safeguard to the processes of filtration, whether they were chemical or whether they were merely by gravity beds. Where only water of unsatisfactory character was available, such treatment was bound to have a great effect upon the health of the people, and the results would be reflected in statistics as time went on.

He did not know whether Captain Arthur would be able to tell them the places in this country where the method had been adopted. He knew that it had been applied to the Thames supply of London, but to what extent he could not say. However, he believed it had been found very useful there during the War. Rotherham

(Mr. H. P. Hill.)

had installed it, but whether it had been actually brought into use he could not say. The system had possibilities; what the scope of those possibilities was, remained to be seen. It might have the effect of destroying vegetable organisms in water to such an extent as materially to reduce the deteriorating effect which some waters had on the pipes through which they were delivered to the inhabitants. If so, it could not help being valuable. But all this at present lay on the "knees of the gods." He mentioned these points to indicate the possible field that lay before this process, and to interest the members in it.

Captain ARTHUR then presented his Paper in abstract.

The CHAIRMAN said they had listened to a very instructive and interesting Paper on a subject which he did not think the members came into touch with very much in the ordinary course of events. If one wanted to sum up what the Author had told them in regard to research, it might be done by writing down the maxim, "Necessity is the Mother of Invention." Certainly, if the necessity had not been there, Captain Arthur would not have been able to tell them of the developments which had taken place and the progress which had been made in dealing with the emergency supply (should he call it) of large bodies of mobile troops. Of course, the Author had given them the point of view of the authors of the invention; perhaps some members present could give the other side by saying what they thought of the effluent that was turned out. He had heard it said that chlorinated water was not exactly an attractive kind of luxury. At least, the men at the Front did not seem to have always regarded it as such; they appreciated that it was the best that General Head-Quarters could give them, but that did not make it any the more palatable. If, therefore, anyone in civil life was thinking of applying chlorine to the sterilization of water, perhaps the Committee before whom the proposition came might not give it that cordial reception for which the promoter might hope, especially if that Committee included ex-service members.

He happened to be in Lincoln professionally about the time of the typhoid epidemic, and he remembered that chlorine was rather prevalent in the liquid they had to use in washing. But he thought that so far as the population of this country was concerned, they were happily circumstanced in matters of water supply. They were not driven to the expedients that the people in other countries were forced to use. Englishmen did not always appreciate the advantages that they enjoyed on that account; they were apt to grumble because some dirty water came out of a tap, but if they went across the Channel—to go no further—they might still meet with samples which would make them wish they were back home again.

The question of the treatment of water with chlorine in this country might occasionally arise, but he doubted whether it would do so often. Nevertheless, the Paper to which they had listened that evening could not but be instructive, and it would materially spur the imagination of those who had to deal with questions of this kind in foreign countries.

Mr. R. Forsyth asked whether it would not be advisable to use ozone, which was now obtainable in quantities sufficient to meet such a need as was dealt with in this case. If any peculiar advantage resulted from the use of chlorine, he would be glad to hear of it.

Mr. Ernest Reuss asked how, in the case of public services, the apparatus would be adjusted for the supply of chlorine, in sterilizing the water in the mains where the pressure varied from hour to hour.

Mr. C. Bentham said he would like to know whether, in making the experiments leading up to the perfecting of the plant, Captain Arthur always used pure chlorine gas, or did he attempt to mix chlorine gas with air or any other inert gas, so as to get a better mixture during the process?

Mr. T. Roland Wollaston said he had had a good deal of experience of dealing with water for industrial purposes, though not for drinking, and consequently, with the volumetric regulation of chemicals. He had never had to deal with reagents in a gaseous state, but had dealt with the measurement of small volumes of gas in other connexions, and knew the extreme difficulty of obtaining consistency and accuracy. He understood the Author to say that he obtained chlorine liquefied under pressure. It was obviously easier to measure a liquid than a gas. Would it not be possible to measure the chlorine volumetrically, while under pressure and in liquid condition, letting it be admitted as a gas afterwards? It appeared to him the mechanical difficulties in doing this would not be very great.

The Chairman said there was one point he would like the Author to deal with. They knew that the process was applied in an emergency, and questions of cost were not raised or considered. Now that they had returned to more peaceful times, he wondered whether the Author could give them approximately—he did not ask for an estimate—what the cost would be, say, per thousand gallons of water chlorinated by apparatus of this type, though not necessarily restricted to a travelling installation.

Mr. C. Bentham said he wished to put another question. Would the Author give them an idea of the relative weight between the gas used and the water treated? Was it dependent upon the amount of foreign matter in the water, or was it simply a fixed proportion between the weight of the water and the weight of the gas?

Mr. Daniel Adamson (Member of Council) said the Author might have mentioned another method by which chlorine could be applied to water; it was based upon an original patent taken out by Watt. The principle was one in which electric current was passed through salt water and so formed an electrolytic compound of chlorine (sodium hypochlorite) which had sterilizing effects and was also very useful for bleaching purposes. It was used in laundries, for example, with very satisfactory results. Where it interested them this evening was the direction in which his own firm were now using it—for the reduction of weeds in mill ponds and tanks connected with works. Weeds were a very troublesome factor in ponds used for condensing purposes, and caused a considerable amount of trouble and expense to the owner. His firm had a small plant working for that particular purpose, and he had brought to the Meeting a small sample which showed the effect of this electrolytic method upon the weed growing in the tank. It had been taken from the filters on the way of the water from the tank to the works, and was apparently the killed weed which, at this time of the year, grew very freely and necessitated a clearing of the tank, certainly once a year, to enable them to carry on. The advantage of this process for their purpose was that as users of electric power they were able to provide their own bleaching or sterilizing agent without the use of chloride of lime or chlorine, which were chemical compounds and would have to be purchased elsewhere. All that they had to purchase, apart from electric power, was the salt, which was not used in very great quantities, one ton worth about £4 lasting a year, during which time about 8 million gallons would be treated. They avoided the difficulties of using chloride of lime which was dirty, and unreliable unless under constant supervision, and the dangers of using chlorine gas; and the whole method lent itself to supervision by workmen of less skill than the Author had explained had to be brought to bear upon the apparatus described in the Paper. The electrolytic method was more easily controlled, much safer, and left no objectionable taste.

Captain J. STANLEY ARTHUR said ozone had been used as a sterilizing chemical for a considerable time and with a good deal of success. There was an installation working to-day in France. The greatest drawback to its commercial use was that it imparted a taste to the water which was most difficult to remove; he believed the only way to do this commercially was to allow the water which

(Captain J. Stanley Arthur.)
had been treated with ozone to trickle over sluices a number of times. Of course, for war purposes the use of ozone was absolutely out of the question ; it would entail electrical manufacture on the spot. Liquid ozone did not lend itself to transport and it was quite unsatisfactory for any possible field use.

Mr. Reuss (page 1181) had spoken about the alteration of the pressure of water in the mains affecting the amount of chlorine which went into it ; in other words, Mr. Reuss asked how one should regulate the amount of chlorine going into a varying supply of water. That evening he had only described the simplest type of chlorinating apparatus that was in use for measuring chlorine, and if any of the members were interested in this work he would refer them to The United Water Softeners, Ltd., of Imperial House, Kingsway, London. He had nothing whatever to do with that Company, but he would like to give the members an opportunity of getting information on this subject, and if they would refer to that Company no doubt a booklet dealing with the Wallace and Tiernan chlorinating apparatus containing diagrams and illustrations would be forwarded on request. Among those diagrams would be found one of an automatic control apparatus, in which the flow of the water passing through the chlorinating chamber controlled automatically the amount of chlorine passing into that water. It was called the Automatic Control type. The type described in the Paper was of the Manual Control type.

He imagined the question about measuring chlorine when diluted with inert gas was put because there was some little difficulty in reconciling the fact that a gas could enter water and be dissolved and give a uniform solution. Perhaps he ought to describe the diffuser through which the chlorine actually passed as it went into the water. This consisted of a cylindrical porcelain ring about the size of a watch, with two circular disks of alundum cemented together. The substance alundum was very permeable and allowed gas to pass through it in very tiny bubbles. In his experience the greater portion of the sterilization was carried out immediately those small bubbles of chlorine, having of course a larger surface area, passed into the water. He had tried experiments and found that to be the case. The chlorine at the instant of solution was in a very active state and appeared to be capable of rather more quickly sterilizing water than when already in solution—that is, when it was first dissolved in water and then added. The objection to the addition of a neutral gas to chlorine was fairly simple. It was not an easy matter to mix an inert gas with chlorine, and to be sure of the proportions. If he might take nitrogen as an example, one could not carry about liquid nitrogen; one might take compressed nitrogen, but it was adding considerable complication, and there was no advantage gained by so doing. The whole process depended on knowing that they were using pure commercial chlorine as delivered from manufacturers in the Cheshire district.

With regard to the question why chlorine was measured as a gas rather than as a liquid, perhaps he had not made it clear that the quantity of chlorine used was extremely small. For chlorinating the supply of a town, one-half of one part per million parts of water, that is to say 0·5 part of chlorine per million parts of the water to be treated, was the amount used.

Mr. Daniel Adamson inquired if these proportions were by weight?

Captain Arthur replied in the affirmative.

A Member further asked if the chlorine was added as a liquid or gas?

Captain Arthur replied that it was added as a gas, by weight.

Roughly speaking, two and a half ounces of chlorine (which was not very much) would occupy a volume of three quarters of a cubic foot—71 grams of chlorine having a volume of 22·4 litres at N.T.P. It was very much easier to measure a large volume subdivided than a small weight subdivided.

The Chairman had asked whether he could give details as to the cost. He was sorry he could not do so. Had he known

(Captain J. Stanley Arthur.)
that information was desired, he would have brought some figures with him. However, he could give some estimate. Chlorine, when purchased for the Army, cost 2½*d.* per lb., and he thought it worked out that the cost of chlorine as a sterilizing chemical, using three parts per million—he was speaking in round figures—was one penny for treating 13,000 gallons of water. It was found in France, that working on the ordinary water supply—not very bad water—a cylinder of chlorine treated about four million gallons of water. The cylinders varied somewhat, but the amount of chlorine used was extremely small. He could not give any figures as to the cost of pumping, which would vary with the type of apparatus used

There was a question regarding the relative weights of chlorine and water used. Roughly speaking, for town's water it would be 0·5 part in one million parts. For the water he was working on at Brentford—canal water and a sewage outfall—about three to four parts of chlorine per million were used. It was very small, and it could only be estimated easily by chemical methods. People had different degrees of taste. He thought the limit of taste for an ordinary person was 0·1 to 0·2 part of chlorine per million. Those who knew the taste and were fresh to it would detect less than that.

The electrolytic process had been used with success for the sterilization of water, and he knew of one or two installations which had been working. He thought it was necessary to keep the sodium hydroxide which was formed at the negative electrode away from the chlorine which was formed at the positive electrode—at the start at all events—and to keep the apparatus cold. A solution of sodium hypochlorite was really made, which was brought into contact with the water, but he believed it was an advantage to keep them separate to start with, to prevent decomposition of the unstable sodium hypochlorite. He was now speaking with some hesitation, because an expert was present who knew much more of the commercial process than he did, but he would hardly have thought it necessary to use the electrolytic process to get rid of the weeds. He did not know the type of weeds, but the ordinary algæ, and such like things growing in water, could be removed by other chemicals. Probably Mr. Adamson would find it much cheaper to use a method in which most of the material was available on the spot. The method was excellent, for the sterilization of water and chlorine, he knew, had quite a considerable action on growing material.

With regard to the question of chlorine in a town's water supply, he thought it was in the early part of 1918 that he went to Sir Alexander Houston of the Metropolitan Water Board and saw an installation at Hornsey where chlorine was being used to sterilize the flood water from the river, which formed part of the Metropolitan Water Board's supply; he spoke very well of it, and adopted the method as a safeguard against being overwhelmed on his filter beds by flood water. Some friends of his (Captain Arthur's) lived near the reservoir, and their water was drawn from these works. They knew that he was interested in water chlorination, and they suggested that a peculiar taste which the water they were using suddenly possessed was due to chlorine. He found the taste was not that of chlorine. He could not taste it, but they insisted that it was chlorine, so the water was analyzed, but no free chlorine was found. He imagined that the taste was due to some other action and not to chlorine at all, because it passed away quite rapidly, and he never heard any more complaints.

Some time ago he heard a man speak on this subject, and say that when he first tasted chlorinated water he felt violently sick. It was 0·3 part in a million parts. But after a few days he no longer knew that there was any chlorine in the water, and he complained that they were not sterilizing the water supply. He had got used to the taste of it and did not realize that the chlorine was there, which was generally the case with a small quantity of chlorine, as the palate became accustomed to it. He remembered one occasion when he was showing a water sterilizing machine at work to some officers of one of the Allies. The man in charge of the machine passed out a sample of water to taste, and by mistake he took it from the filtered water supply before any chlorine had been added to it. The officers said they could taste the chlorine in it, and were quite sure there was chlorine in it, but there was

(Captain J. Stanley Arthur.)

no possible trace of chlorine there at all. It had a flat taste due to being rather stagnant. When they were given the water that actually contained chlorine, it was sparkling; they thought it was excellent water, and made no objection to it.

If one took water which was not too stagnant, which was only full of ordinary dirt—that is to say, dirt from roads and streams, refuse carried in by rain-water—and it was treated with chlorine and sterilized, and after that, dechlorinated with sulphur-dioxide gas, he was perfectly certain that, providing the operation was carried out with a reasonable amount of skill, there would be no unpleasant taste noticeable. The skill was not very great. During the War, three to four weeks' training rendered the average man quite sufficiently skilled to carry out the process, and there was no real difficulty in it at all. It was different when sewage, sewage effluent, or the water from cesspools was to be sterilized. He had had to deal with water from stagnant pools, which had been stagnant for years, and which was filthy with both animal and vegetable refuse, from rubbish thrown into it, and then in such a case he did not think it was really possible to get rid of the flat taste which was there.

There was a chemical point which perhaps no one had actually brought forward. He rather expected the question to be asked, and he would like to answer it as though it had been put. What happened to the chlorine and the sulphur dioxide? They were present in such minute quantities that they were not tasted. The chlorine reacted with the sulphur dioxide and formed hydrochloric acid and sulphuric acid—two acids which were distinctly unpleasant, but in the very small quantity represented by the dilution they were untasted. Water, generally speaking, contained calcium and magnesium bicarbonates—that is, the water was "temporarily hard." By the action of the hydrochloric and sulphuric acids on this, calcium and magnesium chlorides and sulphates were produced and carbon dioxide liberated. The carbon dioxide converted the water into very weak soda water which sparkled—that is to say, rendered the water bright. The chemical substances produced were quite harmless, as they were of the nature of Epsom salts.

The CHAIRMAN, in moving a vote of thanks to Captain Arthur, remarked that he had turned what might have been a very technical Paper, and rather dry on that account, into a most interesting and lucid account by which he had brought home to the members the question of the water supply to troops in the late War.

Mr. J. PHILLIPS BEDSON, in seconding the motion, said the Paper was highly interesting in every way. It showed, as the Chairman had said, that necessity was the mother of invention. It had been given in a lucid manner, which could be understood by the non-technical side, and it had been listened to with very great pleasure. He was glad also to know that there was somebody present who had something to do with supplying the water-filters used before the War, and who had contributed to the discussion.

The Vote of Thanks was passed unanimously.

*Communications.*

Brevet-Major H. H. BATEMAN, R.E., wrote that he had had experience of chlorinating plants on four occasions, as under :—

(*a*) *At Haringhe* (*military*) *Waterworks in Belgium.*—Foul water, taken from the Yser, was treated with alum, and then passed through sand-filters or " Bell " filters of small capacity (relatively). Water from the sand-filters, after passing a rectangular measuring notch, was led through a wooden flume 12 inches in section, to the contact tank. The chlorine diffuser was let into the 12-inch wooden flume, and was 30 feet from the actual chlorinator. The apparatus gave extremely good accurate results. As pointed out by the Author, it was necessary to keep the chlorinator at a certain temperature to avoid condensation of the gas and irregular working.

This plant was for 12,000–20,000 gallons per hour. Frequent tests by the medical authorities showed that the sterilization was complete, and that the resulting sterilized water could be practically freed from any trace of chlorine, even without the use of $SO_2$. Sulphur dioxide was not used in this case, as the medical authorities insisted on the water taken from the pipe-line being treated with bleaching powder, in the effort to avoid contamination from dirty vessels, so the taste of chlorine was unavoidable.

(*b*) *At Rosbrugge* a 6,000 g.p.h. mechanical filtration plant (Bell filters), taking water from the same sources as (*a*), which worked equally well.

(*c*) *At Zuytpeene* (*France*) a 6,000 g.p.h. Mather and Platt mechanical filtration plant. This took its water from a very foul old chateau moat, which, although cleaned prior to the installation being made, still contained the accumulated filth of ages. The water was successfully purified there; but, although free from bacteria, was always unpalatable. An additional alum sedimentation tank would perhaps have improved matters; the alum in this case was fed into the suction of the pump which pushed the water through the filters; and its time of action was of course limited.

(*d*) *Ypres Town Waterworks.*—Contaminated water from Dickebush and Zillebeke Lakes was led to Ypres Prison and subjected to alum sedimentation (24 hours) in 100,000 gallon sailcloth tanks which were put in the old, shell-pierced, open reservoirs. The settled water was taken over a weir to the suction-pump, and the diffuser placed in the suction-pipe of the pumps, which pushed the water forward. There was no contact tank: passage through 7-stage centrifugal pumps and 2 miles of pipe-line were considered sufficient. The water dealt with here was 12,000 g.p.h. The operation of the plant commenced in the winter 1917–18, and great difficulty was experienced in obtaining equal distribution of gas, in spite of all precautions. The German advance put an end to experiments which would doubtless have been successful.

The Author laid rather much stress on the fact of these plants being *standard* for all large water-supply installations in France. At the end of the War the writer's (E and M) Company was working eighty-two pumping plants. Of these, three only were provided with gas chlorinators. The average yield of the plants so provided was greater than 1,000 g.p.h., i.e., than the output of the largest lorry installation so provided. It was considered that it was only worth while installing these chlorinators in lorries and very permanent stationary plants. The remainder of the drinking water installations, however large, could be dealt with quite well by bleaching powder.

Captain Alec C. Jarvis wrote that he was particularly interested in Captain Arthur's Paper, because he had had the honour to have carried out the mobile barge plants and the stationary land plants mentioned on page 1140, and illustrated on pages 1142–3, and had had the pleasure of seeing them at work in Mesopotamia. The accompanying photo, Fig. 22, Plate 25, was taken of one of the barges at work on the Tigris. These vessels were quite an appreciable size, being over 160 feet long. Much of interest could be written of the scheme as a whole; numbering as it did some twenty-four complete floating and land units and considerable auxiliary plant.

Not the least of the features of general interest was the voyage out to the East of the first four vessels; later floating plants were shipped knocked down, the barges being specially constructed for re-erection, but the first four were built into large converted dumb barges of Belgian or Dutch type. Each of them, manned by a small crew of N.C.O.'s and men of the Inland Water Transport Branch of the Royal Engineers, ballasted with coal in bags and in tow of a deep sea tug, had adventurous voyages, but in spite of submarines and bad weather they all eventually reached their destination; all credit to the handful of brave fellows who manned them.

On one of the voyages, owing to stress of weather, the tug's limited coal supply gave out before a port could be made, and in a heavy sea the ballast in the barge was opened up and coal passed to the tug to enable her to make port. On another, a barge that had become strained and leaky owing to bad weather was only saved by the N.C.O. mechanic starting up the oil-engine and main pumps, and keeping them going until port was reached. In anticipation of such a contingency, the writer had arranged for the necessary pipe-connexions and fuel supply to enable the plant pump to be used as an emergency bilge-pump. The plants sent to Mesopotamia did not suffice by any means to provide a universal

(Captain Alec. C. Jarvis.)
supply of filtered water, and many depots, camps, etc., were furnished with water treated by more rough-and-ready methods; for instance, many small supplies in the vicinity of Basra were pumped from the river and hand-dosed in tanks with alumina and chlorine, and settled.

Bleach was used and good work was done with it. A laboratory was set up by the R.A.M.C., where the bleach was tested and daily made up into standard quantities in bottles; the chemist officer in charge then visited the supplies in a motor-boat, accompanied by an orderly and the bottles of strong bleach mixture, and dosed the tanks with the required quantities. The writer well remembered, while in that land of heat, dirt, and disease, meeting a friend of his one morning, who was at the time in charge of such work, and he laughingly referred to it as his "milk-round"; only a few days afterwards he made the great sacrifice. The filter barges sent to France had the honour of being "Mentioned in Dispatches," as well as suffering casualties to their number. Chlorine gas for sterilization was used throughout the Mesopotamian series of plants, with bleaching powder as a standby; nevertheless it was emphasized by the writer in his official book written for the guidance of the officers and men in charge of the plants that the greatest care must always be taken to ensure the best possible water bacteriologically with the ordinary coagulation, sedimentation and filtration facilities, as the exigencies of warfare might at any time cause a cessation in the supply of gas and bleach.

It was true, as the Author stated, that filtration could not wholly remove the bacteria, but in the writer's opinion one did not chlorinate a water to sterilize it, but to ensure that no bacteria of a pathogenic character survived in the water as delivered for use. The term "Sterilization" was misleading—very few samples of water treated by chlorination in practice were sterile, nor need they be—so long as there were none of the ubiquitous and indicative B. Coli in 100 $cm^3$ the water was absolutely safe, and with chlorine this result could be reliably achieved without employing doses sufficiently great or periods of contact sufficiently long to kill the more resistant spores of harmless water bacteria.

There could be no doubt that liquefied chlorine gas was far preferable to bleach in every way, but the writer could not agree with the Author that the residual taste present after treatment with bleach was absent with liquid chlorine; this point had been investigated in America, and it seemed to be established that the residual taste was practically the same in both cases, other conditions being equal. What doubtless did happen, especially under war conditions, was that the superior control and the definite strength of the gas enabled much greater nicety to be used in the treatment, and therefore residual chlorine could be reduced to a minimum. Chlorine gas in cylinders was quite safe and easy to handle; the writer sent hundreds of cylinders to Mesopotamia without receiving any complaint, and tons of it were sent all over America, yet there were in Europe to-day shipping companies who refused to carry it. If the gas escaped, it was not pleasant, as our late foes could testify; it was one of the first gases we used in trench warfare, yet familiarity bred contempt. The writer recollected, when testing some instruments in very cold weather, that the chlorine cylinder was set on a glowing coal brazier to "warm up a bit" before connecting up.

The Wallace and Tiernan apparatus was used exclusively by the writer; it was thoroughly examined and dissected, and was found undoubtedly superior to any that had been brought to his notice. The description of the working of the "Compensator" given in page 1136 of the Paper was, in the writer's opinion, not quite clear, and did not bring out what the exact function of the Compensator was, namely, to maintain a constant pressure-drop across the valve E.

With regard to the difficulty in deciding what quantity of chlorine to add to a water to effect the desired result, without having recourse to trials controlled by bacteriological examinations, the method given in the Appendix (page 1149), while extremely valuable, could not be said to be universally reliable. The presence of chlorine in a water after half an hour's contact was no guarantee that the water contained no B. Coli.

As an illustration of the unreliability of working only upon free chlorine estimations after contact, the following figures were

(Captain Alec. C. Jarvis.)
given from one of the tests made in England with a filter-barge upon a river water :—

TESTS BY CAPTAIN J. N. SUDGEN, LATE R.E., B.Sc.

*Chlorine Gas in Parts per Million.*

| (a) Chlorine Injected. | (b) Chlorine immediately after Injection. | (c) Chlorine after Contact. | (a–b) Immediate Absorption. | (b–c) Contact Absorption. | B. Coli. |
|---|---|---|---|---|---|
| 5·0 | 2·45 | 1·05 | 2·55 | 1·40 | Absent. |
| 3·75 | 2·0 | 0·8 | 1·75 | 1·20 | ,, |
| 2·5 | 1·6 | 0·55 | 0·9 | 1·05 | ,, |
| 1·75 | 1·0 | 0·65 | 0·75 | 0·35 | ,, |
| 1·25 | 0·70 | 0·65 | 0·55 | 0·05 | Present. |

It would be noted that B. Coli was present in the last case where the excess chlorine after contact was 0·65 and absent in the previous two cases, where the excesses were 0·65 and 0·55 respectively; the contact absorption, however, was only 0·05 in the non-sterile sample, whereas it was 0·35 and 1·05 in the other two. The amount of chlorine instantaneously absorbed was remarkable.

In the writer's opinion, it was in the figures for contact or time absorption that one could perhaps look for the promise of a speedy and reliable test for the control of chlorination under practical working conditions. It was found, for instance, in two different cases of filtration and chlorination of grossly polluted river waters that, if the amount of chlorine added was such as to permit during the period of contact an absorption of 0.5 part per million, then the treated water contained no B. Coli in 100 $cm^3$.

The writer would very much like to see exhaustive research carried out to determine the value of the above method of deciding the chlorine dose without bacteriological examination. The quantitative chlorine estimation was quite simple and could be carried out by any intelligent filter-plant attendant.

There was a slight inaccuracy on page 1141 of the Paper, regarding sedimentation with the floating stationary plants; the water after the addition of the coagulating chemicals did not stand for some time, the whole process, including the sedimentation, being continuous in the usual modern manner.

The writer would like to associate himself thoroughly with the Author's remarks regarding Colonel Sir William Horrocks. The writer's work came under Sir William's official inspection, and he (the writer) would always remember the Colonel's devoted work and his unfailing kindness and courtesy to all, down to the humblest sapper, who came into contact with him.

Major C. C. B. MORRIS, M.C., R.A.S.C., wrote that No. 1 Water Tank Company, which went to France in the early part of 1916, was the first systematized attempt to deal with the supply of water by mechanical transport at the Front. The establishment of the Company was as follows, as far as the water equipment was concerned:—

1 30-cwt. Lorry for Chemicals.
111 1-ton Water Tank-Lorries, each containing 150 gallons.
20 3-ton Lorries, each containing 500 gallons.
15 Sterilizing Plants on 3-ton Lorries.
9 Poison-eliminating Plants on 3-ton Lorries.

The above establishment was increased before the Somme offensive in 1916 by the addition of 144 3-ton extemporized tank-lorries, each being fitted with tanks holding 550 gallons.

The sterilizing plants were the old type referred to by the Author, their chief disadvantage being that the rate of delivery was very slow. In other ways the results were entirely satisfactory. The Company, in addition to the A.S.C. officers, had four chemist officers attached, who took charge of all work in connexion with the sterilization of the water. Certain of the de-poisoning plants were fitted up with laboratories, and a large amount of work was done by the chemists in testing the drinking water that was being utilized by the troops in the 4th Army area, to which Army the Water Tank Company was attached on the Somme.

When the Company first arrived in France, owing to its being the first of its kind, and to nobody having had any experience with this type of transport, numerous difficulties were encountered; for example, it was not realized that the greater portion of the water delivered to the troops would be supplied direct into the tank-carrying lorries from water points under the control of the R.E.'s, without being passed through the sterilizing plants at all, the water being merely chlorinated by the chemists after it was placed in the tanks. This necessitated all the lorries being fitted with their own pumps, the small lorries being fitted with Dando hand-pumps and the large lorries with petrol-driven trench pumps. Official trials took place before the Somme offensive on the 24th May, at Rainneville, and plans were worked out for the supply of 20,000 gallons per day to each of two Divisions. The water was supplied to the tank-lorries by the sterilizers and from a water point about 300 yards off the road, this latter condition being frequently met with under actual service conditions. The method employed in the latter case was to place the small petrol-driven pumps adjacent to the supply of water which was off the road, and to pump the water through canvas hose into large canvas dams erected on the roadside. Additional petrol-pumps were placed adjacent to these canvas dams and quickly filled up the lorries as they came alongside. These trials were witnessed by large numbers of the corps and divisional staffs, who reported favourably on the results. After the trials the lorries were widely distributed on the whole of the 4th Army front, the work being of a dual nature, namely, water sterilizing by the sterilizing machines and water carrying by the tank-lorries. Frequently the water sterilized was delivered direct into water-carts or other receptacles, whilst on the other hand much water was carried by the tank-lorries, which was obtained from other sources than the sterilizing machines, that is, the stand-pipes erected by the Engineer services and fed by pipe-line installations. In many instances the water-tank lorries saved a critical situation during the Somme battle, by carrying water from the water-points in the rear into the concentration area, where the Engineer pipe-line services had been hit by shells, or otherwise put out of action. This occurred at such places as Fricourt, Montauban, Longueval, and Becourt. On other occasions the sterilizers were able to establish a water point from a dirty stream or marsh, where it would have not been feasible for the Engineers to put in a pipe-line or well-supply of good quality; for example, at Etineham, Allonville and Poulainville, Meault and Derancourt. It was soon found that the sterilizers often could not approach near enough to the water source to get to work, so that auxiliary pumping sets were installed in such places, which pumped up the water into a canvas dam of about 2,000 gallons capacity, the latter being fixed up wherever required. These canvas tanks were of great use all through the campaign, and were an invaluable asset to the sterilizing machines.

An actual instance of the conditions under which the lorries worked might be of interest. Within twenty-four hours of the first advance on the Somme, canvas dams had been erected in Fricourt, which was in the old German lines, and were kept filled by the tank-lorries obtaining their water both from sterilizers and from the R.E. water-points, this being the only drinking water adjacent to that area. One of the greatest difficulties that the Company had to contend with was the condition and congested state of the roads. It was here that the small 1-ton lorries proved invaluable, as they could cover ground where it would have been extremely difficult or impossible for 3-ton lorries to have been used. At this particular water-point, in order to keep up the supply of water, the section of lorries detailed for this work at Fricourt were working continuously for three days and three nights. In addition to supplying sterilized water during the Somme battle, the large tank-lorries carried water for horses, locomotives, and baths.

During the severe frost in February, 1917, all the sterilizers had to cease work because the water froze in the piping even whilst running. Considerable trouble was experienced with tank-lorries also which froze almost solid, if left stationary and full of water.

Mr. R. Edgar Taylor wrote that as the Author made no reference to the steam-plants which were in use by our Army, the writer drew his attention to the fact that a number were made and despatched to the various fronts by Messrs. John Kirkaldy, Ltd., similar to the one shown in Fig. 23, Plate 25. In addition, two sets of quadruple-effect distilling plants, capable of producing 100 tons of pure distilled water every twenty-four hours, were

(Mr. R. Edgar Taylor.)
made and despatched to Egypt. One set was badly shelled by the Turks, when being erected at Gallipoli, but the other was erected completely and proved quite satisfactory. A similar set was erected at the Immingham Docks for Admiralty purposes, and gave every satisfaction.

The AUTHOR wrote, in reply to the communications, that Captain Jarvis referred (page 1192) to the misleading usage of the term sterilization. Throughout the Paper the accepted meaning had been adopted, as explained. Water which did not contain B. Coli in 100 $cm^3$ was termed sterile. With regard to the figures of chlorine absorption, obtained by Captain Sugden, they were known to the Author and only served to confirm the results of many experiments carried out soon after this work was commenced. No mention of this was made, for the reason that the Paper only aimed at giving a description of the process and the apparatus used. Experience in the field showed, however, that for all practical purposes the chlorine estimation by the "Case, Water Testing Sterilization" was sufficient.

Major Morris (page 1195) had not stated the composition of No. 1 Water Tank Company quite correctly. This company and also No. 2 Company had each nineteen sterilizing plants and eleven poison-eliminating plants. The establishment of No. 1 Company was incomplete as regards one sterilizing plant until the original Chlorine Gas Sterilizing Plants were sent out. Nos. 3 and 4 Water Tank Companies were composed of fifteen sterilizing plants and four mobile laboratories. No poison-elimination plants were used. During the severe frost mentioned, the chlorine gas sterilization plants were in some cases kept at work, the R.A.M.C. officers in charge wrapping, very thickly, all exposed parts with straw and sacking. The nominal output of these plants was rated at 1,200 gallons per hour, but in actual service a greater output was often maintained. They had been known to deliver twice this quantity for twenty-two consecutive hours per day for many days together.

A few distilling plants were sent out to Egypt, but they were not under the control of the R.A.M.C., but of the R.E. Sedimentation, filtration, and chlorination—either by bleaching powder or chlorine gas—were the principal methods in use for the sterilization of water.

*Chlorinator*
*(Wallace-Tiernan).*

**Fig. 2.** *Direct-Feed Manual Control.*

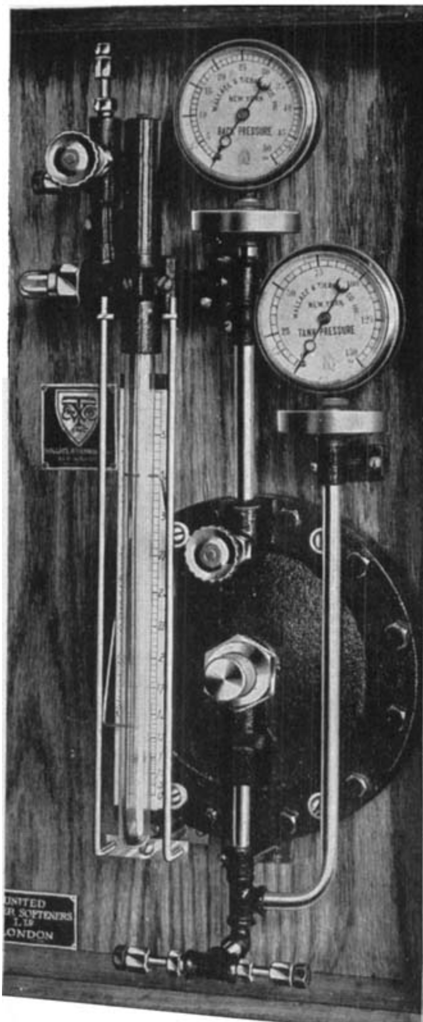
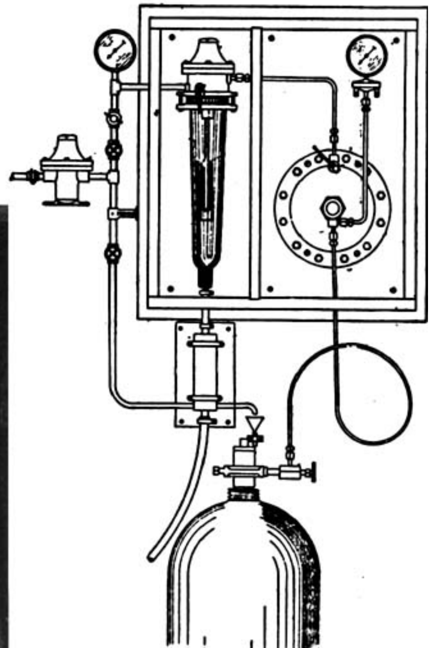



**Fig. 7.** *Solution-Feed Pulsating Meter.*



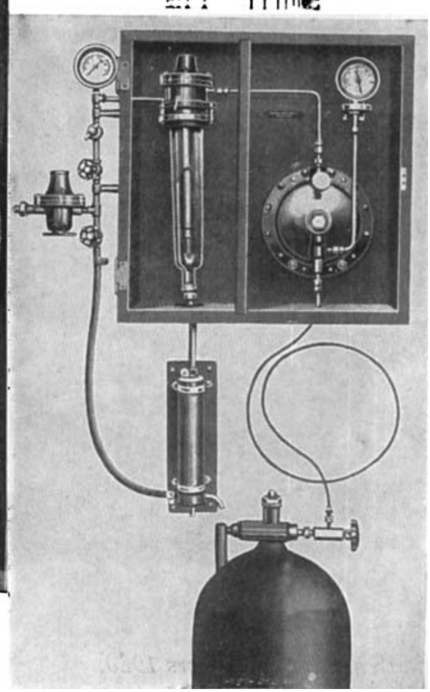


Fig. 10. *Original Bleaching Powder Type, 125 gallons per hour.*

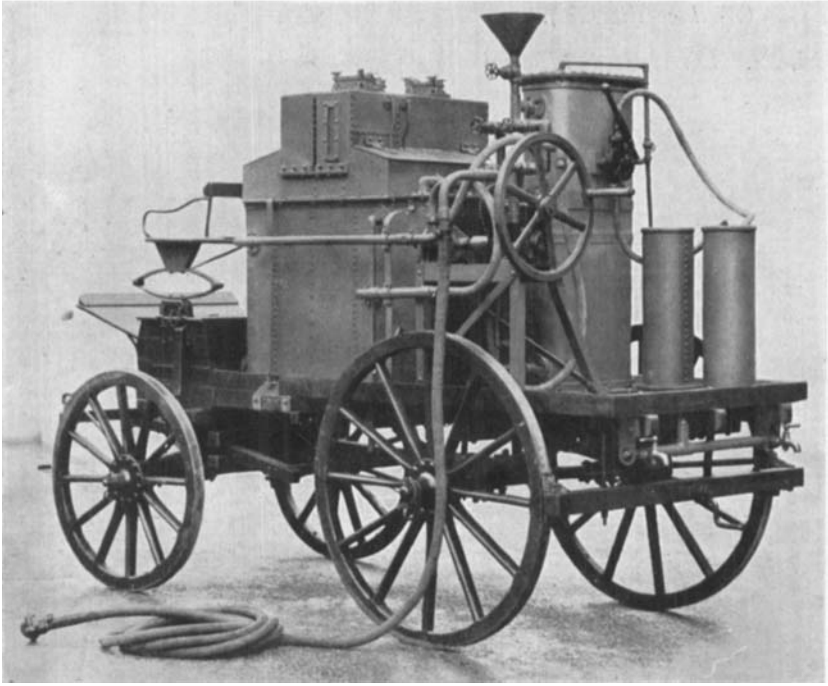
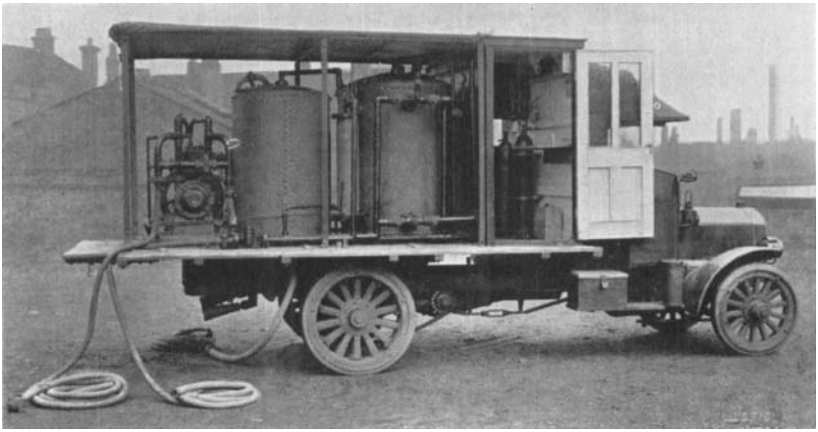
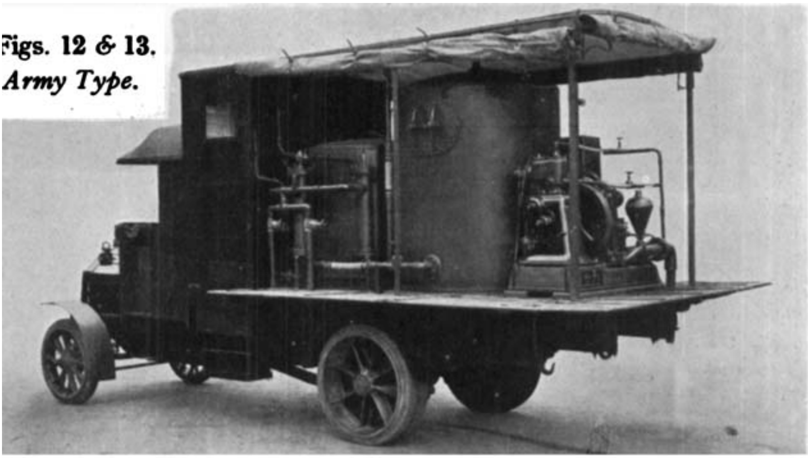


Fig. 11. *Original Machine actually constructed by the Author.*



**Figs. 12 & 13.**
***Army Type.***



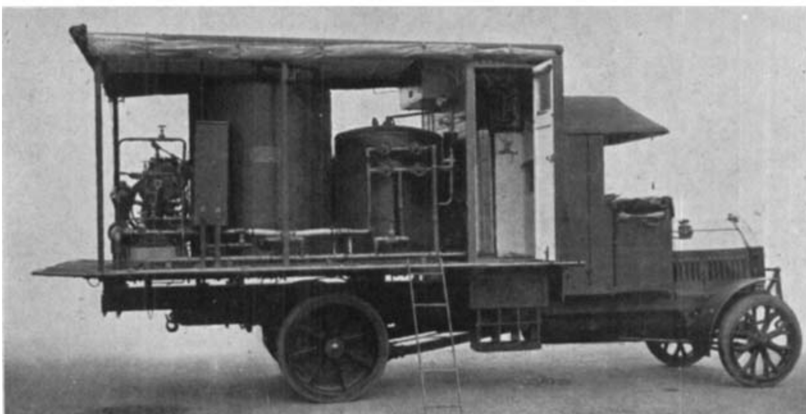
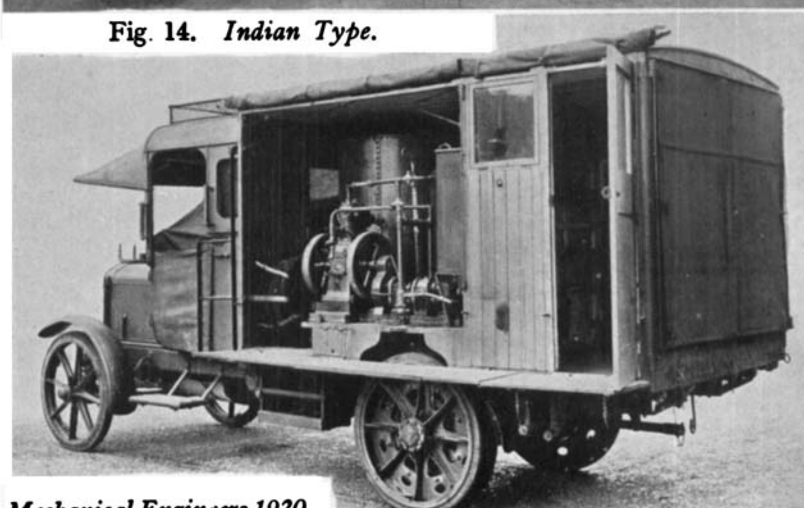


**Fig. 14.** ***Indian Type.***



 STERILIZATION OF WATER BY CHLORINE GAS.

*(Mr. V. Hjort's remarks.)*

Fig. 19. *First Hand Pumping Equipment, temporarily mounted.*

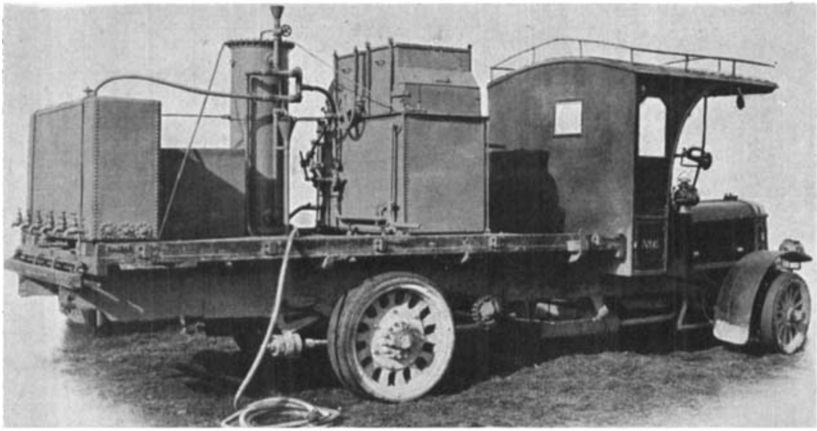


Fig. 20. *Plant for sterilizing or for taking poison out of water.*

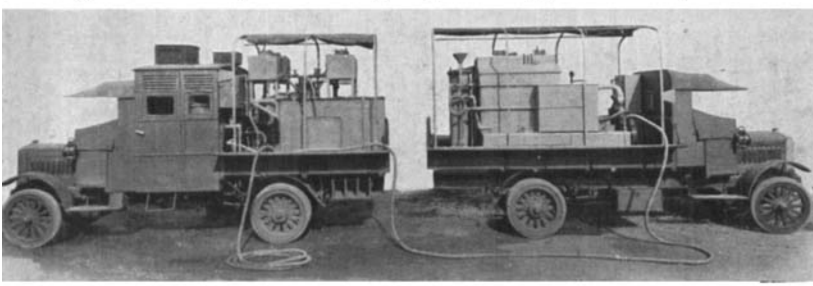
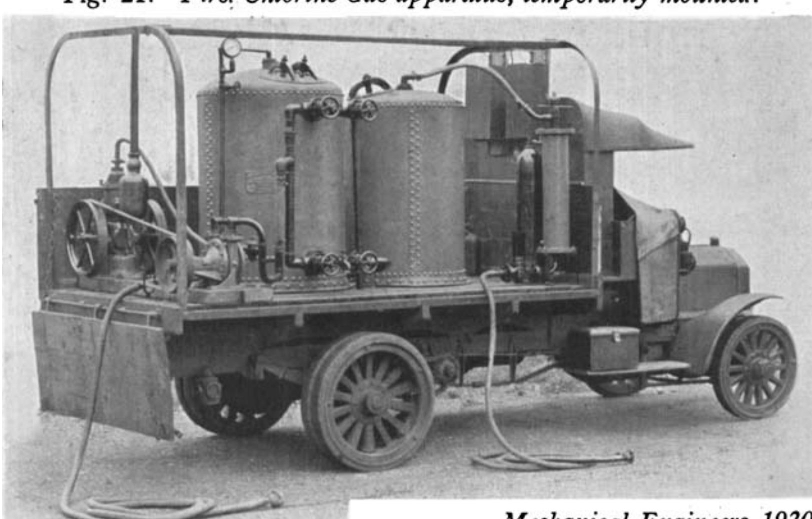


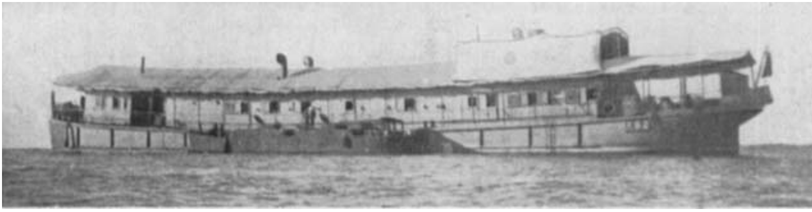
Fig. 21. *First Chlorine Gas apparatus, temporarily mounted.*



# STERILIZATION OF WATER BY CHLORINE GAS. *Plate 25.*

*(Captain A. C. Jarvis' communication).*

Fig. 22. *Filtration Barge on the Tigris.*



***(Mr. R. Edgar Taylor's communication).***

**Fig. 23.** ***Steam Sterilizing and Distilling Plant.***

***To Sterilize 150 G. P. H.***
***or Distil 15 G. P. H.***
***from Muddy or Impure Fresh Water.***
***Total weight 27 cwt.***