WATER PURIFICATION

AND

SEWAGE DISPOSAL

BY

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With 21 *Illustrations in the Text*

NEW YORK

D. VAN NOSTRAND CO.

TWENTY-FIVE PARK PLACE

1913

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PREFACE
TO THE ENGLISH TRANSLATION

SINCE the recognition of their significance in the promotion of the public health, methods of water purification and sewage disposal have earned a steadily increasing importance. Consequently, these branches of industry have enjoyed the most zealous attention of the scientist and of the engineer.

I have endeavoured in the present monograph to give a survey, short perhaps, but as complete as possible, of the present position in regard to Water Purification and Sewage Disposal.

Owing to the wide range of this subject particular processes could only be treated shortly in the space at disposal.

One chapter, which is very fully treated in the present volume, though slightly elsewhere, is the disposal of industrial sewage. Many of the processes of purification are of quite recent date, and fresh experience is being obtained daily and reported upon in the most diverse publications. I have endeavoured to collect such information.

In the translation some small changes and additions have been made in the chapters on sand filtration, the removal of manganese, and Travis and Emscher wells.

The extensive literature supplied in the German original, which served as the basis in the composition of the book, has not been printed in the English translation, as it treats in the main of German literature.

THE AUTHOR.

FRANKFORT-ON-MAINE,
October, 1912.

TRANSLATOR'S PREFACE

ENGLAND, as the author points out, is the classic country for sewage disposal. As a consequence, the translation of a book on the subject of water purification and sewage disposal from the German point of view, might at first sight seem unnecessary. It is to be hoped, however, that a study of the present volume will prove that view to be incorrect. The careful attention which has been paid by the German authorities during the past few decades to the provision of suitable water supplies and the adequate disposal of sewage, renders the present critical survey of modern methods at once interesting and useful to the English reader. Especially should this be true of the chapter on the disposal of industrial sewage.

I have to express my thanks to the author, Dr. Tillmans, for a revision of the present text, and to Messrs. Hubers and Mond. I desire also to record my indebtedness to my friends Mr. J. W. Yates, M.Sc., and Mr. A. Shacklady, B.Sc., for valuable guidance and assistance in the correction of the proofs.

HUGH S. TAYLOR.

LIVERPOOL,
October, 1912.

TABLE OF CONTENTS

WATER PURIFICATION.

GROUND-WATER, SPRING-WATER, SURFACE-WATER.

SEWAGE DISPOSAL.

TABLE OF EQUIVALENTS IN WEIGHTS AND MEASURES.

1 metre = 10 decimetres = 100 centimetres = 1000 millimetres = 1·093 yards = 3·28 feet = 39·37 ins.

1 cubic metre = 1000 litres = 1·308 cubic yards = 35·3 cubic feet = 220 gallons.

1 kilogram = 2·2046 lbs. 1000 kilograms = approximately 1 ton. 1 gram = 15·43 grains.

LIST OF ILLUSTRATIONS

WATER PURIFICATION

THE water present on the earth is engaged in a continuous circulatory process.

It evaporates from the oceans, seas, rivers, etc., and passes into the atmosphere as water-vapour. In the higher strata it condenses to form clouds, and then returns to the earth's surface as rain, snow, hail, and dew.

A part of this water evaporates immediately, another part flows away to the nearest surface reservoirs. A third part, on the contrary, penetrates into the earth's crust, and sinks deeper and deeper until it reaches an impermeable stratum, whereupon it collects and fills the pores and hollows of the overlying ground. This water is called ground-water. Volger considers ground-water as a product of the condensation of ground-vapours, and Mezger assumes that it is the vapours rising from the depths which condense. According to Novak it mainly results from the water of the oceans penetrating into the interior of the earth. Although ground-water may receive considerable additions from one or other of these sources, still it must originate in greater part in the first-mentioned manner, through infiltration. From the impermeable layer it passes along very slowly to the nearest lower-lying waters.

Spring-water is a mountain ground-water which, owing to this movement, makes its appearance in a cleft of the mountain.

In contradistinction to ground-water, all water which remains in contact with the outer air is designated as surface-water. Surface-water is therefore the water of seas, rivers, ponds, cisterns, dams, etc.

Water is obviously a necessity to man. In the first place, it is used for drinking purposes. Moreover, it is found to be an indispensable auxiliary in almost every possible pursuit.

Frequently it must be submitted to certain treatment before use. The application proposed serves as a method of differentiation. One can distinguish, therefore, two processes : purification of water for drinking purposes, and for technical purposes.

A. Purification of Water for Drinking Purposes.

Water used for human consumption must be free from suspended matter. It must be colourless, odourless, agreeable to the taste, and must not have too high a temperature. It should be of such a nature that it may be partaken of with pleasure. Further, and of chief importance, it must contain no disease germs.

Surface-water and ground-water are both used for water supply. Ground-water, taken from certain depths, is free from bacteria; for, during its passage through the soil, it is freed from germs, which remain attached to the particles of sand in the ground. Surface-water, because it is easily polluted, is always more or less rich in bacteria.

The germs of contagious diseases, typhoid, diarrhœa, cholera, and certain groups of the so-called ptomaines, are the most important disease germs disseminated through water and claiming consideration. Pus germs also are found. It is only in the rarest cases possible to demonstrate the existence of disease germs in infected water, since they only occasionally succeed in entering, and also between the date of their reception by the person and the development of the sickness a period of time always elapses (e.g. with typhoid, one to three weeks). If, therefore, developing diseases give rise to an investigation, it is usually too late to trace the origin to water. Quite apart from this, also, the proof of the existence of disease germs amidst the many other harmless bacteria is a matter of considerable difficulty.

Proof of the absence of disease germs is not sufficient, and is no guarantee of the harmlessness of a water to health. Sanitary opinion is based, however, upon the assumption that the strata of earth at slight depths are already free from any such germs, and that therefore a discovery of bacteria in water proves that it has come into contact with the outside world, that it has received surface influxes. In the dissemination of typhoid and other contagious diseases, the possibility that even secretions of such men or animals as harbour disease germs in themselves have been admitted to the water cannot be excluded. The more influxes of surface-water, the greater is the probability of contamination in a ground-water. From these considerations it follows that a river-water is much more dangerous than the water from a suitably situated reservoir.

If a natural water containing bacteria be used for drinking purposes it must first be rendered innocuous to health. This can be done by methods of filtration or of bacteria destruction. But the harmfulness of a surface-water to health is not its only fault. Many surface-waters, such as river-waters, have also the disadvantage of an unappetising odour and taste, or a disagreeable temperature. Then, even the sanitary improvement of water by the destruction of bacteria or by filtration will only remove the gravest danger—the danger to health—but will not make of the inferior water a good one. It must furthermore be borne in mind, that when such measures of purification are demanded, failure must be expected either of the plant itself or failure due to excessive demands on the available material, of which the best-known example is the notorious water-main in the Ruhr district.[1] As regards filtration, it must be remarked that removal of all the bacteria is not effected. Filtration only brings about a reduction of the number of germs. Since, however, for the origination of a contagious disease a definite amount of disease germs is always necessary, reduction of the germs, if it is at all considerable, signifies a considerable sanitary improvement in the water.

Ground-water from sufficient depths is therefore superior, for all the above-mentioned reasons, to surface-water, even if the latter be very carefully treated. But the former also may be doubtful for drinking purposes. There are two ways in which disease germs may reach a ground-water and make it unsafe as a water supply. The first manner in which it may be polluted, and the one coming into consideration in the greatest number of cases, is contamination from above. Through fissures in the

[1] This water-main drew water from the River Ruhr. During the year 1911 the level of the river sank so considerably that the end of the pipe lay above the surface and no water could be drawn off.—*Translator.*

ground, through leaking wells, and through a permeated ground-water, external streams may be incorporated without sufficient previous filtration. The second method of pollution with disease germs is through the so-called subterranean streams from strata in the earth rendered contagious by human refuse. This method of pollution has been frequently affirmed and disputed. There come into consideration here filled-up waste sewers, drains, depots for fæces, etc., which, owing to underground hollows, for example, rat-runs and the like, are connected with wells, and through which the ground-water flows into the wells. Even without direct hollows or runs existing, a certain amount of danger is assumed, owing to insufficiency of filtration. If the ground-water, in its passage from the suspected area to the place where it is drawn, flows through at least 10 metres of ground free from objectionable features, that is regarded, in general, as adequate filtration.

Occasionally drinking-water must be purified for quite other reasons than the hygienic reasons previously discussed. In such cases it is a question of removing substances, including salts, which give the water an unappetising appearance, or make it unsuitable as a drinking-water or for domestic use. There may be present substances which impart to the water a certain corrosive action on the walls of the pipes through which it is led or the vessels in which it is stored.

Methods of water purification may be divided into two classes, those on a large scale, which serve for central water supply, and those for the purification of water on a small scale, which are applicable on a journey, in housekeeping, and in industry.

I. PURIFICATION OF WATER FOR DRINKING PURPOSES ON A LARGE SCALE.

The purification of drinking-water on a large scale, in order to obtain a healthy and unobjectionable water, is effected either by filtration or sterilisation. In the first case the bacteria are mechanically removed, in the second case they are killed.

(i) Filtration Processes.

The greater part of the suspended matter can be removed in settling reservoirs, or by leading the water through clarifying basins in which the very small velocity of the water enables the greater part of the suspensions to settle to the bottom.

Sedimentation basins for the purification of drinking-water are constructed and managed according to the same principles as those for the purification of effluent waters. On this account the question may be relegated from here to the chapter on the conduct of sewage purification.

The most finely divided suspensions, the bacteria, are not removed from the water in this way ; for that purpose filtration is required.

(*a*) *Slow Sand Filtration.*

For the sand filtration of drinking-water we have to thank the Englishman *James Simpson*, who, in the year 1829, constructed the first filter of this type. In 1839 the London Waterworks introduced the first of such filters for the purification of drinking-water. In the year 1853 Simpson sand filters were also constructed in Berlin, and shortly afterwards in many other towns. The inventor only had in view the removal of suspended matter and the clarification of the water by means of sand filtration. That it would remove the bacteria he could not have anticipated, as at that time such micro-organisms were still unknown. We know to-day, however, that the main importance of sand filtration lies in the elimination of bacteria.

In case the water does not contain too large a quantity of suspended matter, a preliminary clarification is unnecessary, and the water flows immediately on to the filters.

The filters (see ~~Fig. 1~~) consist of large, generally rectangular surfaces, surrounded by a wall. They are filled with gravel and sand. At the bottom there is a layer of stones 60 to 150 millimetres in diameter. Above this rests a layer of gravel which serves to support the superimposed sand, being coarser below than above. The layers of gravel are generally set down with the first about the size of nuts (30 to 60 mm.), then one about the size of beans (20 to 30 mm.), one the size of peas (10 to 20 mm.), and a layer about the size of millet (3 to 5 mm.). Over this there rests the layer of sand upon which the raw water is placed to a certain depth. The sand and gravel layers can be set down together in varying amounts. The average height of water, sand, and gravel is about ~~0·60 metre~~ (2 feet) each. The filtered water flows away underneath, and passes thence into the reservoirs for purified water. To supply a town with filtered water a large number of such sand-filters are needed.

The plans of artificial sand filters must be so arranged that each individual filter can be separately filled, emptied and cleansed,

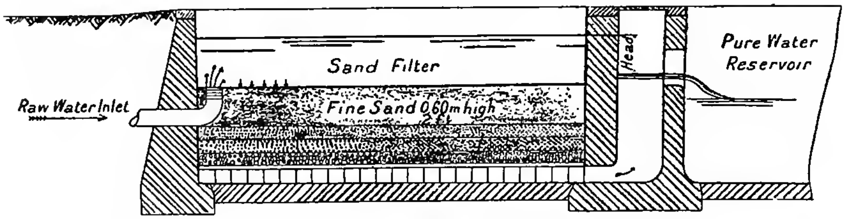

FIG. 1. DIAGRAMMATIC REPRESENTATION OF A SAND FILTER.

and that the purified water from each filter can be drawn upon independently. Only in this way is complete control of each separate filter possible. The water filters the more quickly through the sand the larger the size of the grains. Coarser sand does not yield, however, such pure, germ-free water as does the finer sand. With this finer sand the surface of the filter layer clogs up more quickly than with the coarser, which latter is easier to clean.

Further, similarity of form in the sand is important. The more dissimilar the particles of sand are, the more erratically the filter works. In the cleaning of the filter the fine sand is in part washed away; sand must therefore be added from time to time to the filter, according to the length of time it is in use, if it is not to become continually coarser. Whilst the form of the filter must be adapted to the disposition of the available space, its size varies considerably. The size of a filter, according to König, varies in a series of large towns from 607 to 7600 square metres, and is on the average about 2000 to 3000 square metres. The water should be maintained in the filters as far as possible at the same height. The entry of the water to the filter takes place continuously from above, and the entrance of course lies opposite to the discharge-pipe. Frequently the inflow of water is automatically regulated by means of valves, to bring about as uniform an inflow as possible. A uniform discharge of water, also, is of no less importance. In consequence of the gradually increasing clogging of the filter the velocity of discharge would always become less if the head of water were not increased. This head of water is the difference of water-level in the filter and in the pure-water reservoir. To increase the head it is best to diminish the water pressure in the pure-water reservoir, since, as already mentioned above, it is not advantageous to alter the amount of water in the filter.

In the Berlin Waterworks the head amounts to 60 or 65 millimetres, in Altona to 1422 millimetres, in Kiel to 1000 millimetres.

In order to permit the air enclosed in the filter to pass out, so that it is not constrained to escape to the top, thus causing a breaking-up of the filter-bed, tubes for the removal of the air are let into the side-walls.

Filters are either covered or uncovered, both systems having their advantages and disadvantages.

Open filters have the disadvantage that during frosty weather cleaning is made very difficult, owing to the freezing of the moist sand. This objection disappears with covered filters. On the other hand, covered filters are far more costly.

A further disadvantage of the covered filter is that with it the sediment layer is formed more slowly and more imperfectly, and the covered filters, consequently, do not yield a sufficiently germ-free water so quickly. This is readily explained, as the sediment layer is composed in part of organisms containing chlorophyll, and consequently needing light, which organisms cannot increase, or can only do so more slowly than is the case with open filters exposed to the full light.

In practice the filters are arranged thus. They are filled with water from below to just above the surface of the sand ; then the impure water is allowed to flow in from above, and to remain at rest for a period of time during which the formation of the sediment layer is accelerated. The filtrate is allowed to flow away until the germ content has reached a certain limit, generally 100 or less per cubic centimetre (1600 per cubic inch). Then the pipe to the pure-water reservoir is connected.

After a certain time, when the sediment layer has become too strong, the filter works itself dead, and no more water passes through. It must then be purified. For this purpose a layer of sludge, generally about one inch thick, is first of all scraped off. The sand lying underneath likewise contains a lot of dirt, which is, however, of the greatest importance for the filter layer about to be constructed. After removal of the layer of sludge, therefore, the sand is loosened to a depth of about 8 inches, and the filter is then allowed to remain unused for a day, to permit the access of fresh air. The so-called journey (running time) of a filter is likewise very varied. From eleven different waterworks, according to König, it amounts on an average to 25·5 days, during which the amount of water filtered per square metre averaged 69·3 cubic metres.

From time to time the sand must also be replaced by fresh or washed sand. It is removed down to the layer of gravel, new sand filled in, and this is covered with a layer of the lower portion of used sand, which has a sticky nature and accelerates the formation of the sediment layer. Washed sand is only to be recommended in place of fresh sand in cases where the fresh material is dearer than the washed, since by washing more or less of the fine useful portion of the sand is removed. For this reason a sand which has been washed many times must be replaced by fresh sand. The washing of the sand takes place automatically in drums, or boxes, in which the sand comes many times into contact with fresh water. There are numerous different systems of sand washing.

The more slowly filtration takes place, the purer, as a general rule, is the filtrate. The velocity of filtration, which varies largely in different waterworks, amounts on an average to about 100 millimetres (4 inches) per hour.

Very soon after the introduction of sand filtration it was recognised that the sediment layer would be difficult to control. This layer consists for the most part of organic suspended matter, displaying either living organisms or dead substances, while there is also present, in smaller degree, inorganic matter like clay, oxide of iron, etc. The most varied organisms are to be found in the composition of a sediment layer.

C. Piefke demands a maximum filtration velocity of 100 millimetres per hour, while other investigators could establish no variation in the bacteriological and chemical composition of the water with considerably greater velocities.

C. Piefke found, further, that with an increase in the pressure of filtration the bacteria content of the pure water rises, more so, of course, the more bacteria the raw water contains. He also proved by investigation that a filter freed from the sediment layer yields water of small bacteria content more quickly than fresh sand. This is explained by assuming that the suspended matter penetrates into the sand a little, and this sand layer, containing suspended matter, takes part in the work of filtration. Of great importance is the answer to the question, whether the bacteria in the pure water have passed through the filter during the filtration of the raw water, and therefore are derived from the raw water, or whether they are washed away from the sediment layer or from the sand. By their investigations on this question, Fränkel and Piefke came to the conclusion that the quantity of micro-organisms passing over into the filtrate is proportional to the bacteria content of the raw water.

For towns which have to deal with very poor raw water, like Hamburg, Altona, Königsberg, Warsaw, and others, double filtration, proposed by Götze, is to be recommended. The most diverse hygienists express themselves very approvingly concerning this method. By double filtration, the raw water already passed once through a sand filter is sent again through a filter well clogged with sludge. Götze showed that with double filtration a raw water with a germ content of 28,000 was purified to one of 780 bacteria per cubic centimetre in the preliminary filtration, and to 31 per cubic centimetre in the final filtrate. The preliminary filtration of Puëch-Chabal is largely employed. In this system the water is purified by a series of coarse preliminary filters. The fine filter then employed has only to further diminish the already considerably reduced quantity of bacteria, so that the water can be regarded as free, bacteriologically, from objection.

The cost of sand filtration, exclusive of interest and repayment of loans, amounts on an average to 0·7d. to 2·5d. per 1000 gallons (König).

The filtered water is submitted to a continuous bacteriological control. The constant estimation of the number of bacteria is an excellent means of settling whether the filter is working well. A crack arising in the sand, or any other abnormality, reveals itself immediately in a rise of the number of bacteria. The official rule runs that pure water should not contain above 100 germs per cubic centimetre.

(*b*) *Percolating or Dry Sand Filters.*

In France, recently, the so-called percolating sand filters have come into use for water purification. They are based on the theory that oxygen plays a part in the removal of bacteria, especially of the pathogenic kind. The ordinary filter can contain no oxygen, since it is always covered by water. On this account the percolating sand filter is employed similarly to the percolating filters in bacterial sewage purification, except that it is composed of fine material (sand).

Miquel and Mouchet, in laboratory investigations, were unable, after using this method, to prove the presence of typhoid bacilli added to the raw water.

This method was tested by Baudet, in Chateaudun (France), working on a large scale. The results seem very favourable. The number of bacteria fell from between 293 and 1498 in raw water, to 6 bacteria per cubic centimetre in pure water. Especially remarkable is the consideration that in the pure water bacterium coli was never found.

This filter likewise requires several months to build up, and the velocity of filtration cannot be raised indefinitely; still, the percolating sand filters seem to be considerably more productive than the slow sand filter.

Baudet maintains that with a clear but bacteriologically impure water, results are obtained with percolating sand filters which are better and less troublesome than those obtained by any other method.

The introduction of the filter for barracks has been recommended by the French Army administration. In Germany the filters have not yet, to my knowledge, come into use. Further, there has been, up to the present, no German investigation of the method.

(*c*) *Mechanical Filters.*

The considerable cost of sand filters in relation to their productivity, and the great space necessary for a sand-filter installation, shows clearly the advisability of replacing the sand filter in technical work by other apparatus which takes up less room and permits a greater velocity of filtration. From these considerations the mechanical filter originated. Since the natural, workable layer is first formed after a long interval of filtration, chemicals are generally added to the water, especially with the newer filters of this type, in order to produce an artificial plankton and an artificial filter layer. With the mechanical filters of newer pattern, aluminium sulphate is almost always used for this purpose, as it reacts with the alkaline earths present in the water according to the following equation :

$$Al_2(SO_4)_3 + 3\,Ca(HCO_3)_2 = Al_2(OH)_6 + 3\,CaSO_4 + 6\,CO_2.$$

Most of the flocculent, gelatinous aluminium hydroxide sinks to the bottom, and the suspended matter travels along with it. The flakes still remaining in the water form a sediment layer on the filter. The velocity of filtration exceeds that of the sand filter, generally being 60 or 70 times more rapid.

There is a large number of different systems of the mechanical-filter type.

Older patterns are, for example, the Anderson revolving purifier, the Warren Filter, the Kröhnke Filter.

Filters of newer construction are, amongst others, the Jewell Export Mechanical Filter, the Halvor Breda Filter, the Bell Filter, Reeves Filter, Candy Filter, Puëch Filter, Sucro Filter.

These filters are not only employed for removing bacteria from drinking-water, they frequently find application in technical work.

As a type of this filter the Jewell Export Filter, which has been studied closely from different points of view, may be described more carefully.

The Jewell Export Mechanical Filter.—The Jewell Filter, represented in Figure 2, consists of the steel cylinder containing the filter-bed, which is encased in a second cylinder of somewhat larger diameter, so that between the two there is an annular space which is closed underneath. In this annular space, through the valve situated on the left-hand side, the raw water, which has been previously treated in sedimentation tanks, and also with aluminium sulphate, passes into the filter, in order to flow over the edge of the inner cylinder on to the filter-bed. After it has streamed through the filter-bed, composed of sand, it passes at the bottom through sieve heads in a system of outlet tubes which, in their turn, fit into a diametrically placed collector, and to which they are all rectangularly placed. From the collector the water passes through the regulator (Weston Controller), shown in the front of the diagram on the right side, into the pure-water basin to be found underneath. This regulator serves to keep filtration constant. The importance of a constant velocity of filtration has already been brought into prominence in the case of sand filters. With mechanical filters this importance is increased owing to the employment of chemical coagulants associated with it, and which can only be added in these cases in precisely estimated amounts. By means of a float working on a throttle-valve (shown on the left in the diagram) the inflow is

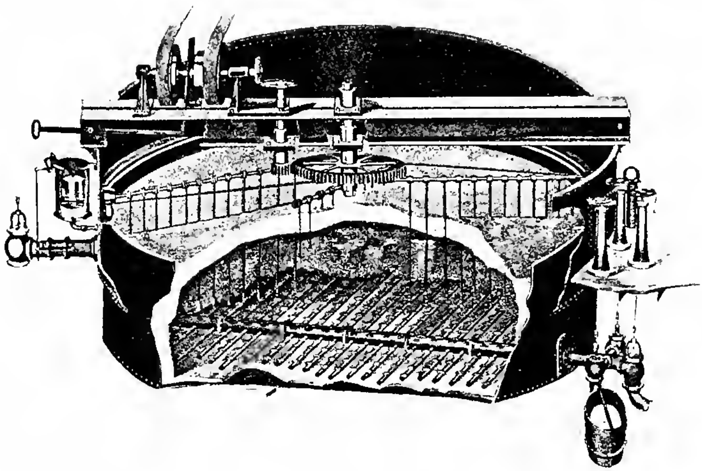

FIG. 2. THE JEWELL EXPORT MECHANICAL FILTER.

also regulated, and the water in the filter kept at a constant height.

To clean the filter the water takes the reverse direction. It is allowed to stream in under the pressure of a pump or a high reservoir, through the cleaning-valve situated at the extreme right in the diagram. It is then allowed to flow through the collector, exit tubes, and filter-bed in the reverse direction from bottom to top, to pass over the rim of the inner cylinder into the annular space, out of which it streams into the effluent tube, through a valve not visible in the diagram. At the same time the stirring arrangement shown in the diagram is set in motion, which thereby gets the whole of the filter-bed into a floating condition, so that each separate particle of sand is washed by the water and is consequently thoroughly purified. In the cleaning process it is necessary, of course, that the cleansing water be distributed uniformly over the whole surface of the filter-bed, so that no stagnant corners or angles result. This important need is met in the Jewell Filter by keeping the throats of the strainers in the outlet tubes very narrow, so that the pressure and velocity of the cleansing water at these points are very large.

After the first cleaning there comes a further cleansing process, in which the first water filtered is allowed to flow through the third of the three valves shown on the right of the diagram, in order to remove the muddy water still present in the filter. The cleaning and the subsequent operation take up about ten minutes, and are effected as a rule once daily. The starting of the filter is always performed mechanically without any manual labour on the filter-bed.

Jewell Filters have come into use largely for the water supply of municipalities. I mention the towns of Alexandria, Trieste, Helsingfors (Finland), Annecy (France). Critical examinations on the basis of the tests previously put forward generally prove favourable.

Bitter and Gottschlich have obtained very favourable results with the Jewell Export Filter in Alexandria.

Hilgermann has likewise made investigations with the Jewell Export Filter, and come to fewer favourable results. He holds, according to his experiments, that the Jewell Export Filter, like every other mechanical filter, is, in bacteriological respects, absolutely inferior to the sand filter.

K. Schreiber has searchingly investigated the Jewell Filter, in a series of experiments with an experimental plant at the Berlin Waterworks, and comes to the conclusion that it is quite as good as the sand filter in bacteriological respects, in the removal of the turbidity and colour of the raw water, as well as in the method of washing, which takes place quite mechanically, without danger of contamination from the hands and clothes of the workmen. According to Schreiber, the method may, however, be far superior to the sand-filtration method.

The amount of aluminium sulphate added is of great importance. Schreiber comes to the conclusion that with an addition of 33·6 g. of aluminium sulphate per cubic metre (5 oz. per 1000 gallons), with a time of sedimentation lasting 1 hour 28 minutes, and at a velocity of filtration of 4 metres (13 feet) per hour, 94·3 per cent of the bacteria in the raw water are removed by the Jewell Export Filter.

The increase of sulphates occasioned by the addition of the chemicals is confined within such narrow limits that a deterioration of the water for drinking and domestic purposes does not come into the question in practice.

The increase of aluminium salts, apart from the consideration that this disappears completely with well-ordered management, is so small that hygienically it may be neglected. At all times in those places where in the water-supply plant there is no horizontal space at disposal for expansion, the Jewell Export Filter can be applied with advantage, as, for example, in cases of water supply in besieged strongholds in time of war.

Further, Friedberger has also carried out searching investigations with the Jewell Filter, with the water of the town of Königsberg. He comes to fewer favourable conclusions than Schreiber. With water rich in bacteria, mechanical filtration does not guarantee so complete a reduction of the bacteria that one could be satisfied with mechanical filtration alone.

A quite new work of Gottschlich and Bitter gives an account of over four years' practical experience of Jewell Filter management for the town of Alexandria. The plant worked excellently during this time as regards removal of bacteria and turbidity, as well as the trustworthiness of the method.

(*d*) *Artificial recovery of Ground-water from Surface-water* (*Intermittent filtration*).

For the reasons discussed on page 2 ground-water is to be preferred to purified surface-water. As a consequence, municipalities which are in a position to do so are always attempting to supply themselves more and more with ground-water for drinking purposes. In order to obtain such water in sufficient quantity, many towns find it necessary to go a considerable distance from the town. Considerable expense thereby results in conveying, and also in superintending the water conduits, etc. Owing to the expense of bringing water from a distance, it has been attempted many times to increase artificially the ground-water in the neighbourhood of towns.

The recovery of artificial ground-water was originated scientifically by Thiem.

So-called natural sand or bank filtration comes into consideration here. It consists in the sinking of wells on the banks of a lake or river. The water in these wells is then pumped away, and its level thereby considerably lowered. As a consequence water enters the wells from the lake or the river through the sand or gravel strata, which act as the filtering medium.

In its progress through the ground the water is freed from bacteria in a manner similar to ground-water. Bank filtration results in the suspended matter being gradually drawn through the sand. As opposed to artificial sand filtration in which filtration is vertical, bank filtration is horizontal, and this is really the cause of the observed passage of suspended matter through the filtering layer.

The investigations of Scheelhaase with Maine River water showed that with wells at a distance of 25 metres from the river-bank, while the bacteria were of course removed, the water had become like ground-water in no other respects, since the temperature was not sufficiently adjusted, nor was its odour nor taste improved.

Intermittent filtration in a vertical direction has later been investigated in various ways. According to Richert there are the following methods: The surface-water is conducted to an irrigation field, where it is allowed to drain away. This method ought to have been tested on an experimental scale. It has proved of little use, as it is untrustworthy and difficult to control.

It is better to lead the surface-water to an intermittent filtration basin or well, which has been sunk to the ground-water level, or to a basin which lies over the ground-water.

Success in producing a workable ground-water depends on the possibility of leading the stream sufficiently far in a horizontal direction, and on the water having time, apart from the removal of bacteria, to become a useful ground-water in respect of the temperature, colour, taste, and smell. In this direction, Scheelhaase, in Frankfort-on-Maine, has lately published important and interesting researches.

River Maine water purified by means of a sand filter was allowed to flow to a double-branch irrigation bed laid out 3 metres deep, 50 metres long, and constructed of gravel and dräns. The infiltrate, finely distributed by this treatment, had to trickle in a vertical direction, to the natural ground-water level, through a layer of ground 13 to 14 metres deep, consisting of fine sand and gravel. Then it joined with the natural ground-water, and flowed along with it to the nearest pumping-station following the incline of the ground. The result of the investigation was that at 100 metres from the place irrigated, a distance which the infiltrate flowed through in 190 days, Maine water, which is very dirty river-water, had been transformed as regards its bacteriological nature, its temperature, smell, taste, and colour, into a water equally as good as ground-water.

J. Braikowitz reports on the nature of artificial ground-water in different towns : " In Offenbach-on-Maine the water of the old waterworks is brought to the neighbourhood of the new works, which draws upon a well of water free from any objection. In Brunswick the condenser water from steam engines in the waterworks is made to percolate through the ground, whereby the ground-water obtained only experiences a rise in temperature of 0·4° C. In the Ruhr Waterworks the river-water is led through ditches, or through a broken-up portion of the choked-up river-bed, to the layer of rubble-stone underneath. The Ruhrtalsperren Co. seeks to increase the lower waters of the Ruhr, and also to augment the ground-water, by constructing dams."

According to Richert the ground-waterworks of the town of Schweinfurt is a beautiful example of natural filtration.

Since the year 1875 the town of Chemnitz has employed intermittent filtration with the best results, in which, above a series of wells sunk in a ground-water area, an irrigation field for intermittent filtration was dug out to the ground-water level. The water introduced into the open ditches of the irrigation field unites directly with the ground-water, and flows along with it to the wells.

In a similar manner the town of Gothenburg produces artificial ground-water.

(*e*) *The Importance of Water Filtration in Public Health Administration, and Critical Opinions on the value of Sand and Mechanical Filtration.*

The purification of surface-water for drinking purposes by means of filtration has become a question of great importance as affecting the health of towns and their economic improvement.

According to Hilgermann, cholera and typhoid diseases especially have decreased in those places where sand filtration has been introduced and properly conducted. In those places where epidemics have appeared in spite of filtration, they have been caused by faulty arrangement of the sand filter or faulty management of the undertaking. During the cholera epidemic in Hamburg, in the year 1892, sand filtration worked splendidly, since, for example, the town of Altona, which used filtered Elbe water, was quite free from the epidemic although the filters received for their work Elbe water, rendered contagious by all the Hamburg discharges.

According to Vincey, as recently as 1905 a number of townships around Paris employed raw Seine water. After the introduction of sand filters mortality in typhoid cases fell about 42 per cent, cases of typhoid about 48 per cent.

Hilgermann, in his work already mentioned, critically compared the newer American mechanical filters with the sand filter.

European workers who have experimented in recent years with American mechanical filters have in general come to favourable conclusions. American professional men who have had the opportunity of studying the mechanical filter on the spot for ten years are not especially favourable.

According to Hilgermann, the main difficulty with the American mechanical filters which work by addition of aluminium sulphate, is that it is not possible, with the varying composition of the raw water, to add the right amount of chemicals. This causes faulty sedimentation and faulty formation of the filter layer.

On the basis of his researches with the Jewell Filter, Hilgermann comes to the following conclusions on the working of the mechanical filter :—

1. With raw water containing a small number of bacteria the American mechanical filter yields good results.

2. The efficiency of the whole method of filtration depends upon the sedimentation.

3. The addition of aluminium sulphate at any time is dependent upon the amount of the substances suspended in the raw water.

4. With poor raw water the mechanical filter fails if the addition

of chemicals cannot be immediately increased with the increase of suspended matter in the raw water.

5. There is no principle for such a regulation. The increase must be settled by experiment.

6. As regards the removal of turbidity due to clay and also the removal of colour, and in respect of the hygienic method of cleaning, the mechanical filter is superior to the sand filter.

Closer examination shows that as regards cost, sand and mechanical filtration are approximately alike. Of course, the cost of setting up the mechanical filter a second time is far smaller than with the sand filter, owing to its small dimensions and to the small space it requires. Still, the wear and tear of these machines is much greater than is the case with sand filters ; hence one has to allow for a greater depreciation. Further, the constant consumption of chemicals raises the cost of management considerably.

(ii) Methods of Water Sterilisation.

The removal of bacteria from water can take place by filtration and by sterilisation, i.e. the destruction of the bacteria. For this purpose a number of chemicals have been employed, e.g. ferric chloride, chrome iron alum, lime, hydrogen peroxide, calcium permanganate, chloride of lime, bromine, copper chloride, organic acids, ozone, etc. Of these very many must be rejected, since they either do not work with certainty in general, or they need a long time for the development of their sterilising action, or they alter the appearance, smell, and taste of the water too much. The only methods of any practical value are those in which ozone and chlorine (as chloride of lime or sodium hypochlorite) are used.

(*a*) *The Ozone Method.*

Ozone, the so-called active oxygen, which is formed from the oxygen of the air by the silent discharge of high-tension electric current, has proved to be a good medium for sterilising water. When dissolved in water it kills the greater part of the bacteria and then escapes again from the water, without influencing taste or smell in the slightest degree, since it decomposes to ordinary oxygen. For the sterilisation of drinking-water a number of ozone plants of varying design have been proposed; for example,

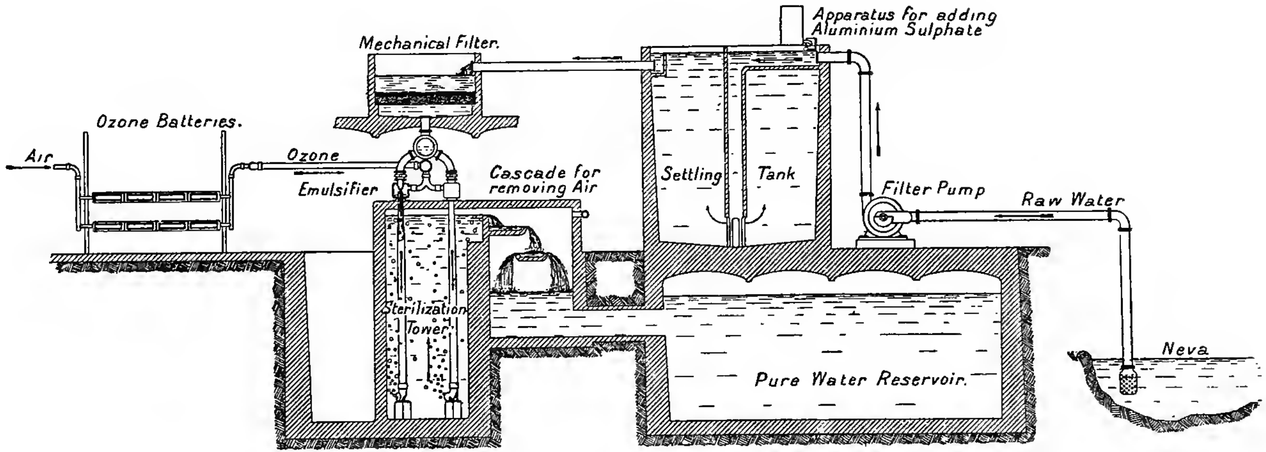

FIG. 3.

DIAGRAMMATIC REPRESENTATION OF THE OZONE WATERWORKS AT ST. PETERSBURG.

the system of Siemens and Halske,[1] Trindall, Abraham Marmier, Otto and Vosmaer. Quite a number of towns now purify their water by means of ozone, e.g. Paderborn-i.-W., St. Petersburg, Hermannstadt, Nizza, St. Mans, near Paris, and others.

As an example of an ozone plant, that of the metropolis, St. Petersburg, may be more closely described here as one of the newest according to the system of Siemens and Halske. As can be seen from Figure 3, the raw water is taken direct from the

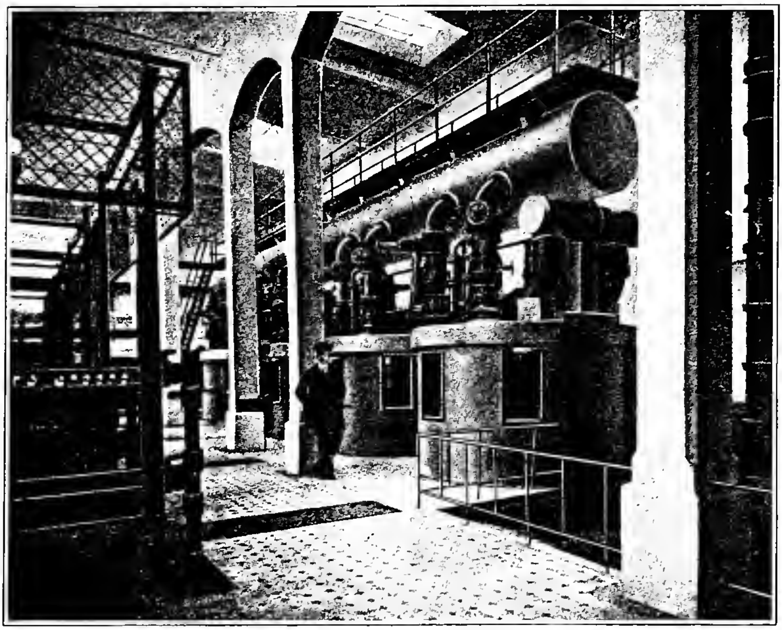

FIG. 4. OZONE WATERWORKS OF ST. PETERSBURG.

Neva by means of a pump, and pumped to the sedimentation reservoirs for purification. Before entering the purification reservoir the water is treated with aluminium sulphate. It is then filtered through thirty-eight mechanical filters. These filters are on the Howatson system, which is similar in many respects to the previously described Jewell Filter. To the filtration plant

[1] Recently the Berlin Ozone Company has incorporated the firms of Siemens and Halske and the General Electric Co., and has taken over all the patents of Siemens and Halske.

there is attached the actual ozone plant, which consists of two parts, the ozone batteries and the steriliser.

In Figure 4, on the left, the ozone batteries, consisting of 128 pieces of apparatus, are shown, and on the right the five sterilisers can be seen, one of which serves as a reserve. The individual apparatus are Siemens and Halske ozone cylinder elements, as shown in Figure 5. In this apparatus the oxygen of the air is converted into ozone by means of high-tension discharges. The

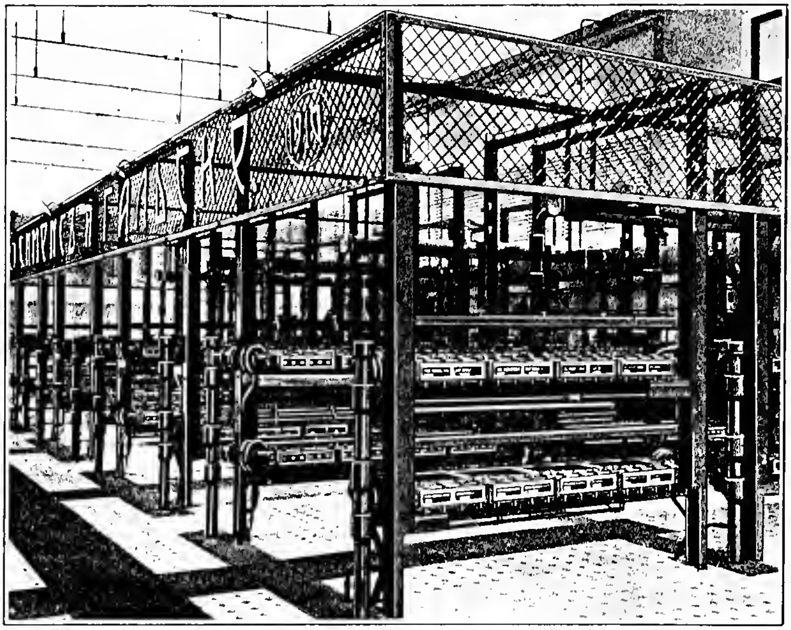

FIG. 5. OZONE WATERWORKS, ST. PETERSBURG. OZONE BATTERIES.

concentration of ozone amounts to 2·5 grams in 1 cubic metre (1 grain per cubic foot) of ozonised air. The air, before entering the apparatus, is dried in a cooling machine. The movement of the air through the ozone batteries and pipes takes place by the aid of the so-called emulsifiers (Otto's system). These emulsifiers are injectors or water-jet air-pumps, which, by means of a water pressure of about 4 metres (160 in.), sucks the ozonised air out of the ozone batteries, and brings it mixed with water into the steriliser. The absorption of the ozone and the consequent sterilisation of the water takes place partly in the emulsifiers placed near the sterilisers, and partly in the agitators, from the bottom of which the ozonised air rises to the top in a very fine state of division, and therefore in very intimate contact with the water. From the emulsifiers and sterilisers the water passes over a cascade for removing the air to a pipe which leads it to the pure-water reservoir. From there it is pumped away into the town's mains.

It is a necessary preliminary for the satisfactory working of an ozone plant that the water to be sterilised contain no suspended matter, and not too large an amount of organic matter, or ferrous oxide. In such cases the ozone is in great part consumed in the oxidation of the dissolved substances, or of the iron. The unsatisfactory working of a plant in Schierstein was attributed to the presence of a considerable amount of iron in the drinking-water.

The researches undertaken by Erlwein, Ohlmüller, and Prall on the "Auftrage des Kaiserlichen Gesundheitsamtes" (Commission of the Imperial Sanitary Board), and by Proskauer and Schuder, of the "Königl. Institut für Infektionskrankheiten" (Royal Institute for Infectious Diseases), with the water of the Spree, and with water to which large quantities of pathogenic bacteria (typhoid, diarrhœa, cholera) had been added, are in agreement in proving that the bacteria are almost entirely destroyed, and that the pathogenic variety were in all cases destroyed without exception.

The Pasteur Institute also obtained favourable results in its investigations on ozone processes.

Halbertsma and Dolezalek prove that the opinion that no daily control is necessary in ozone processes as contrasted with sand filtration is wrong.

Karl Schreiber, in the "Auftrage der Königl. Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung" (Commission of the Royal Test-Institution for Water supply and Sewage disposal), as a consequence of the unfavourable observations of Halbertsma and Dolezalek, undertook a searching examination of the ozone works in Paderborn, in which he established that the ozone process satisfied all demands.

G. W. Chlopin and K. E. Dobrowolski report that in St. Petersburg the bacteria are not completely killed off, but are decreased on an average about 98·8 per cent. Intestinal bacteria should be absolutely destroyed. The water should also undergo an improvement in taste and colour. The chemical composition does not alter essentially, and the ozone dissolved in the water disappears after ten minutes.

S. Rideal reports on his experience in the works at Paris. After ozonisation all bacteria, except the more resistible spores, were destroyed. The temperature of the water was not raised.

According to Gärtner the bacteriological action is as good with ozonisation as with sand filtration, and it is also more certain.

Sauna made experiments in which ozone was used in quantities averaging about 4 milligrams per litre (1·75 grains per cubic foot. ' It gave the following results: Nitric acid is completely destroyed; 15 to 43 per cent of organic matter is oxidised. The efficiency of ozone on the organic matter increases according as the water is more oxidisable. Ozone also oxidises ammonia present in water. Sulphates, carbonates, and chlorides are not altered. Nitrates and free oxygen show an increase. Within a few minutes the last traces of ozone disappear. Hydrogen peroxide is not formed By using suitable amounts of ozone, complete sterilisation of the water takes place. Ozone acts most effectively on pathogenic bacteria.

The sterilising effect of ozone depends, according to Schreiber, on four factors, viz.—

1. On the nature of the water.
2. On the amount of water passing through the plant.
3. On the concentration of the ozonised air.
4. On the amount of the ozonised air used.

For the right working and control of ozone plants, Schreiber recommends that a hygienist and an official experienced in electrical management should undertake a test of the four factors mentioned, and that they should then work out regulations for running the process in accordance with the test. The finished plan should be tested, as regards its sterilising action, with water in which bacterium coli and similar bacteria have been disseminated. The maintenance of the working regulations must be controlled from time to time by an electrical engineer.

The cost of sterilising water in Paderborn ranges, according to Schreiber, from 0·43d. to 1·5d. per 1000 gallons without preliminary filtration, and with filtration from 0·66d. to 1·94d. per 1000 gallons.

At the Parisian works, according to Rideal, 1·31 kilowatts current were necessary to sterilise 100 cubic metres of water. The total cost, exclusive of the repayment of loans and payment of interest, amounted to 0·33d. per 1000 gallons.

In the St. Petersburg undertaking the cost of working is 0·87d. to 1·0d., of which only half is due to ozonisation.

The cost of sand filtration, according to Schreiber, amounts in comparable cases from 1·05d. to 1·87d. per 1000 gallons.

(*b*) *The Disinfection of Drinking-Water with free Chlorine.*

In the year 1894 it was shown by *Traube* that, by treatment with very small amounts of free chlorine, the bacteria in water could be destroyed. Later investigations by other authors showed that for certain destruction of the bacteria the amounts of chloride of lime must be greater. The process remained thus for a long time, but was eventually taken up again in practice several years ago. Recently, however, the method has been extensively applied, especially in America.

The Duyk Ferric Chloride Process, Howatson System (Thumm and Schiele).

In this process the raw water, either during or immediately after the sedimentation of the undissolved particles, is treated with a solution containing chloride of lime, and then with one of ferric chloride. The mixture is led on to a mechanical filter (Howatson system) without further sedimentation, or with an intermediate disposition of sedimentation arrangements; the filtered water is then ready for use.

By the addition of the chemicals the following reactions take place:

$$6\,CaOCl_2 + Fe_2Cl_6 = 6\,CaCl_2 + Fe_2O_3 + 3\,Cl_2O.$$
$$3\,Cl_2O = 3\,Cl_2 + 3\,O.$$

The resulting chlorine and oxygen act as disinfectants, whilst the voluminous ferric hydroxide and the calcium carbonate, resulting from the decomposition of the calcium chloride, draw the suspended matter along with them to the bottom on settling.

In Middelkerke, in Belgium, the method is in practical application; there, and later in Paris, it has been tested. The conclusions are favourable. The destruction of the bacteria must have been extensive.

Thumm and Schiele, who inspected the Middelkerke undertaking, and base their view on the impressions obtained and the accounts received, express themselves as generally favourable. In the ferric chloride process it may be important to consider that the chlorine disappears of itself after some time, and that the water treated does not then contain any harmful chlorine compounds.

(*c*) *Sterilisation with Chloride of Lime or Sodium Hypochlorite.*

This method, according to Imhoff and Saville, has been introduced in considerably more than one hundred American towns. The method is especially suitable in those places where the water is physically good, but has the disadvantage of containing either permanent or transitory disease germs.

The chloride of lime is generally added to the water in the proportion of 1 part to 350,000 parts of water (which means 1 part of active chlorine per 1,000,000 parts of water).

The free chlorine acts upon the bacteria, more especially on those which communicate disease.

The cost of the process is very moderate, being only 0·027d. per 1000 gallons, therefore only a twentieth the cost of other purification processes.

The method is not applicable where much suspended matter, or even organic matter, or iron, is present in the water, for then the free chlorine is consumed in the oxidation of these substances.

On account of the small amount of bleach added, it should not be necessary to displace the chloride of lime from the water subsequently ; the water, also, should not possess any appreciable taste or smell.

Quite recently a series of reports upon the method have come from English and American towns.

G. A. Johnson, who has taken up the process again in America, declares that sodium hypochlorite can be used as well as bleach. The following are mentioned as advantages of the process : the rapidity with which the bacteria, especially pathogenic bacteria, are quickly destroyed ; the ease with which the addition of chemicals can be adapted to any change in the water ; the absence of any harmful reaction product in the water ; the rapidity of the reaction.

The bleach treatment is useless in the following points: bacteria spores are not destroyed; the bacteria embedded in the suspended solid particles remain unaffected.

C. Walker reports on the chloride of lime water-purification process called the De Chlor process, which was tested for six months on an experimental scale. The De Chlor system removes the excess of chlorine by means of a preparation (charcoal) insoluble in water, added to the filter in granular form. The number of bacteria fell, after passing through the filter, to between 234 and 421 per cubic centimetre; the purified water contains on an average 32 germs per cubic centimetre. Bacterium coli was found in 1 cubic centimetre of raw water, in 10 cubic centimetres of the first filtrate, and in the pure water was no longer found in 100 cubic centimetres.

According to Craven, 0·3 to 0·4 milligram of chloride of lime is added to every litre (20 to 25 grains per 1000 gallons) of Ohama water, which is previously treated in clarifying basins. The number of bacteria is thereby reduced by about 97 per cent. Bacterium coli could only be found in isolated cases. In Minneapolis from 1·54 to 3·04 milligrams is added to a litre of water. The number of bacteria in the raw water sank from between 250 and 8000 to between 7 and 1200. Bacterium coli was not found in the water so treated.

In the opinion of the author it is of advantage to use the method for a time with a certain amount of scepticism, as suspicion almost prescribes that to be certain of the destruction of all the bacteria such an excess of bleach is necessary, that it is noticeable in smell and taste, or vice versa, that if there is no smell and taste in the purified water the bacteria are not destroyed with certainty.

Add to this also that it is not yet established that the continued use of small quantities of bleach, even should they be imperceptible by the senses, is not a matter for serious misgivings.

For this reason this method cannot be recommended for general imitation. It might possibly be of service in certain circumstances, if there were temporary dangers with the drinking-water, as in times of epidemic, or it might perhaps be used with success in time of war.

(*d*) *Sterilisation of Drinking-Water by means of Ultra-Violet Light.*

It is well known that if white light be analysed into its components by means of a prism, beyond the extreme violet end of the spectrum there can be indicated certain rays which cannot be perceived as light rays, and are therefore invisible, but to which there belong powerful chemical activities, e.g. towards a photographic plate.

That these ultra-violet rays also possessed the power of killing bacteria has long been known. Downes and Blunt, two English investigators, observed this in the year 1877, and the power of sunlight to kill bacteria is attributed to these ultra-violet rays. Ultra-violet rays are to-day generated by means of the quartz mercury-vapour lamp. An electric current is sent through mercury vapour which is enclosed in an evacuated quartz-tube; the mercury vapour thereby glows and sends out ultra-violet rays which have the property of passing through quartz though they are retained by glass.

The real discoverers of the sterilisation of drinking-water by means of ultra-violet rays are the French workers, Courmont and Nogier. In their experiments a lamp was fastened in the axis of a cylinder of 60 centimetres diameter, so that the walls were not more than 30 centimetres distant from the source of the light. Only clear water, without turbidity or colour, is sterilisable in this manner. The lamp is purposely immersed in the water. In the first place the sterilising action is better when the lamp is immersed, as the water is in closer contact with the source of the rays, and all the rays are used up on every side. It seems, however, to be also necessary to immerse the lamp in order to cool it, and to prevent it varying on account of heat changes. It was formerly thought that the action of the ultra-violet rays rested on the formation of hydrogen peroxide or ozone. That is not the case; such compounds could never be shown to be present. The taste, smell, temperature, and chemical properties of the water are in no way altered by the rays, and protracted experiments on animals have further demonstrated the complete harmlessness of the water so treated.

The sterilising action, as communicated by Courmont and Nogier, is good, and not inferior to that in the water-purification methods previously mentioned. Also as regards economy, the process, according to the accounts of Courmont and Nogier, can bear comparison with the above purification methods.

From experiments conducted by two members of the Königl. Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung (Royal Institute for the Testing of Water Supply and Sewage Disposal) the results are not so favourable as those of Courmont and Nogier in all points. Grimm and Weldert carried out their researches with the mercury-vapour lamp of the Quartz Lamp Co., Ltd., Hanau-on-Maine. They collect the results of their work as follows :—

"(1) With the apparatus tested clear water, containing few bacteria, can be sterilised at the rate of 0·55 cubic metres (120 gallons) per hour under the conditions described above. Clear water, very rich in bacteria, can, on the other hand, only be rendered sterile at the rate of 0·45 cubic metre per hour, in which case it does not make any difference whether the bacteria are water bacteria or, with pathogenic bacteria, coli bacteria. (2) Turbidity of the water, even to a small extent, makes disinfection uncertain. With a high degree of turbidity the destruction of bacteria by the lamp is impossible, at all events within the limits which come into practical consideration. (3) Likewise the yellow colour of water due to colloids, such as bog-water shows, acts as a very great hindrance. Indeed, with only a slight amount of coloration, the hindrance is so great that it is practically impossible to accomplish disinfection by this method. (4) The water is not altered in any physico-chemical respects by its passage through the experimental apparatus, with the exception of an increase in temperature of a few tenths of a degree. With prolonged action of the rays, further increases of temperature result, as well as symptoms of chemical decomposition. (5) The expenses of water purification by means of ultra-violet light, reckoned on the basis of the researches, are, comparatively speaking, very high, and cannot bear comparison with the cost of the methods of water purification employed at the present time on a large scale."

Erlwein reports on the experience of the firm of Siemens and Halske in this respect. The energy required is greater than in sterilisation with ozone. With regard to the other factors, a comparative estimate of the cost of working, under the conditions operative in a central waterworks undertaking, is wanting in the case of the ultra-violet light method, and especially the most important, viz. a more exact knowledge of the deterioration and cost of repairs of the still very expensive quartz lamps.

Buywid is of the opinion that the ultra-violet light method is more promising than the ozone method.

To the knowledge of the author the method has not been to the present applied on a large scale. Mercury-vapour quartz lamps are supplied by different firms, e.g. The Ultra-Violet Firm, 22 Rue Chanchat, Paris; Westinghouse, Cooper, Hewitt and Co., 131 Wilhelmstrasse, Bèrlin, the Quartz Lamp Co., Ltd., Hanau-on-Maine.

Taking into consideration the fact that the water is not in any way changed as regards its nature, and that extended researches with animals have shown that water acted upon by the rays even for a long time is not harmful, the method should have a future if the cost can be reduced.

In addition to their researches on the ultra-violet light method, Grimm and Weldert collected together the costs of the principal water-purification methods. Nos. 1 to 4 of the following table are the averages of estimates of various undertakings on a large scale. No. 5 is reckoned on the basis of the experiments of Grimm and Weldert.

List of the various Processes.	Cost per 1000 gallons of purified water.
(1) Slow Sand Filters.	
Cost of working	0·61d.
Total cost	5·2d.
(2) Mechanical Filters.	
Cost of working	2·8d.
Total cost	5·8d.
(3) Ozone Plants.	
Cost of working	2·8d.
Total cost	8.2d.
(4) Chloride of Lime Plants.	
Cost of working (Johnson)	0·07d.
Total Cost (Johnson, Imhoff, and Saville)	0·34d.
(5) Ultra-violet light plant.	
Cost of working:	
100% Bacteriological Effect	14s. 6d.
99 to 99·9% " "	5s. to 7s. 3d.

(*e*) *Disinfection of Water-Mains and Wells.*

If an epidemic reigns in a town, and there are grounds for believing that the contagion is to be attributed to drinking-water, the disinfection of the water-mains is to be recommended, especially in those cases in which a fresh drinking-water, free from any objection, must be led into the infected main. Flügge and Bischoff, during a typhoid epidemic in Beuthen (Upper Schleswig), employed for this purpose a 0·2 per cent solution of sulphuric acid. The acidified water remained standing in the main many hours. The strength of the sulphuric acid in the water is controlled at the stop-cocks. In an epidemic of typhoid fever in Gelsenkirchen, in the year 1901, the mains were likewise disinfected with sulphuric acid.

With wells which in general are suitably situated and lie in surroundings free from objection, but which seem to be infected from above, it is possible, according to a proposal of M. Neiszer, to introduce compressed steam (5 atmospheres); the whole contents of the well are thereby brought to the boiling-point.

The same method, or disinfection with "Carbolic-Sulphuric acid" (Fränkel), which is subsequently pumped away, can be applied in the preliminary works of a central water supply for disinfecting borings, so as to be able to take away samples bacteriologically free from objection.

(iii) **Purification of Water in directions other than that of Health.**

As already mentioned, substances occasionally appear in water which, without being detrimental to health, still cause great trouble, since, as with iron and manganese, they may discolour the water, or, as with free carbonic acid, may attack the walls of pipes and reservoirs.

(*a*) *Removal of Iron.*

Ground-waters of the diluvial and alluvial strata of the North German Lowland often contain iron in greater or lesser quantities, as ferrous carbonate or the ferrous salt of humic acid. When freshly drawn the water is generally clear, but becomes turbid after some time owing to the separation of a brown precipitate, since the oxygen of the air converts the ferrous salt into insoluble ferric hydroxide with evolution of carbon dioxide.

Although this turbidity due to iron is objectionable not so much from the point of view of health as from that of appearance, still it frequently causes trouble. The flocculent hydroxide, settling in the pipes and reservoirs, renders their frequent cleansing necessary. Further, the presence of iron in water favours the appearance of numerous micro-organisms which store up iron, especially the iron bacteria, which decompose and evolve odours of sulphuretted hydrogen and other decomposition products, and gives to the water a specific metallic taste.

Such water is not suitable for most technical purposes.

A few tenths of a milligram of iron in a litre of water may make an iron-removal plant necessary, since iron bacteria thrive best in waters weak in iron.

The methods of removing the iron are based on three physico-chemical actions.

First, by contact of dissolved ferrous iron with air, oxygen converts the ferrous compound into insoluble ferric compounds. Consequently the water may be aerated, and subsequently filtered.

Secondly, since carbonic acid keeps the iron in solution, the precipitation of the iron may be effected by neutralisation of the carbonic acid with lime.

Finally, if the iron is present in the water in colloidal form (organically combined), a coagulant, such as aluminium sulphate or ferric chloride, is employed.

The last method is often used in America, whilst in Germany all processes for the removal of iron are based upon aeration and filtration.

The method of effecting this aeration and filtration varies considerably with different systems.

Aeration is effected by allowing water to fall through the air, cascades (Elbing), by means of raining devices using perforated troughs (Wismar), in coke-towers (Piefke), over wood (Berlin), over clinkers (Delitzsch), over glazed brick (Sternberg), and in other ways.

Similarly, the method of filtration varies. In general, sand and gravel have proved the best media for filtration. The size of the grains of sand is an important factor in the formation of the filter layer, and in the complete retention of the ferric hydrate particles.

The method of cleaning the filter and aerator is also different in the various systems.

In the following review of the most important methods for removing iron are also included those which are used mainly for industrial purposes, since they are based on the same principles and are conducted in precisely the same way as are the larger undertakings for central water supply. The removal of iron from single wells, on the other hand, will be specially treated on page 49.

The most important systems for the removal of iron are characterised as follows (Schwers) :—

1. Piefke system : One of the oldest and best systems. The water containing iron is brought to the coke-tower, a cylindrical upright vessel, filled with pieces of coke the size of a man's fist. The water flows slowly over the coke and passes into a settling-tank situated underneath, whence it flows on to a sand filter, which is arranged on the usual lines. The coke-tower is cleaned by flushing in the reverse direction. It should only be necessary to refill the tower once or twice each year. These Piefke towers are largely used, and have proved excellent.

2. Oesten system : A raining arrangement (2 m. rainfall), with roses, and filtration through gravel the size of wheat-grains.

3. Kurth system : Violent rainfall and gravel filtration, worked by the stroke of a piston ; for small plants.

4. Bieske system : Analogous to the previous one.

5. Thiem system : Raining arrangement with perforated trays.

6. Reichling system : Raining arrangement with centrifuge or sieve, closed filtration upwards, under pressure, through layers of sand, gravel, and wood-wool ; used in industry.

7. Koerting system : Similar to the previous one.

8. Pfeiffer system : Simple aeration and sand filtration.

9. Wingen system : Waterfalls, sand filtration.

10. Taacks system : Waterfalls, sand filtration.

11. Kröhnke system : Coke-tower, rotating cylindrical filter that is alternately filled with sand and water.

12. Lanz system : Filtration through natural sandstone.

13. Fischer system : Filtration through porous artificial stone (Wormser Kunststein).

14. Agga system : Filtration through pipes of artificial stone in the sand filter, purification by a reverse stream of water.

15. Reisert system : Filtration in the open air through gravel, with or without previous aeration over coke ; cleansing by a reverse stream of water.

16. Bollmann system : Gravel filtration under pressure without previous aeration, purification by a stream of water in the reverse direction.

17. Breda system : Filtration under pressure through "Tonkoks" (clay-coke) and gravel of various sizes, after preliminary aeration in a mixer ; purification by a reverse stream of water.

18. Helm system : Filtration through brown iron-ore slag in which aeration takes place by means of occluded oxygen ; purification by reversing the water current.

19. Bühring system : Filtration, as in the previous case, through bone charcoal ; purification with dilute hydrochloric acid ; for domestic purposes.

20. Büttner system (von der Linde and Hesz) : Filtration under pressure through wood shavings, impregnated with tin oxide without any special aeration ; purification by reversal of stream.

21. Bock system : Filtration analogous to the previous one, through wood-wool.

22. Sellenscheidt system : Raining arrangement, filtration through plant-fibre ; used especially in breweries.

23. Dehne system : Aeration by raining with an injector, addition of milk of lime, filtration under pressure through felt discs ; used in industrial concerns.

24. Jewell system : Rapid sand filtration with or without addition of milk of lime and sulphate of alumina, unaccompanied by any aeration. This system was introduced in Posen, in 1909, producing 30,000 cubic metres per day. No chemicals are added ; the water is freed from iron by simple filtration.

25. "Voran" system : Frankfort-on-Maine. Aeration in the closed system by compression through nozzles, in the open system by sprinkling over a cataract-like erection of coke, bricks, etc. An open and a closed "Voran" plant are pictured in Figures 6 and 7. The figures are intelligible without further explanation.

Plants for the removal of iron are built both open and closed. Closed systems offer greater protection, naturally, against infection of the water by bacteria ; still, according to Schwers, plants with open apparatus have proved as good as the closed from the bacteriological point of view. In recent years a vehement dispute has been in progress with reference to the greater or lesser suitability of the open and closed systems. Both systems have been equally praised and criticised. On the whole they may be regarded as of equal value.

The efficiency of iron-removal plants depends upon the height of the aerator and filter, the velocity during aeration and filtration, and other technical points.

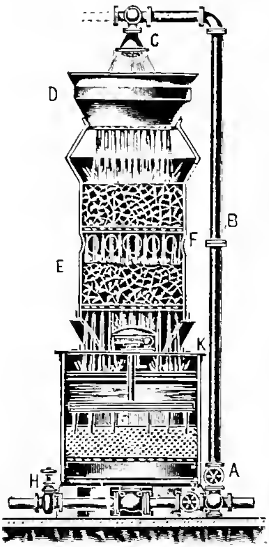

Fig. 6. Open Plant for the removal of Iron. "Voran" System.

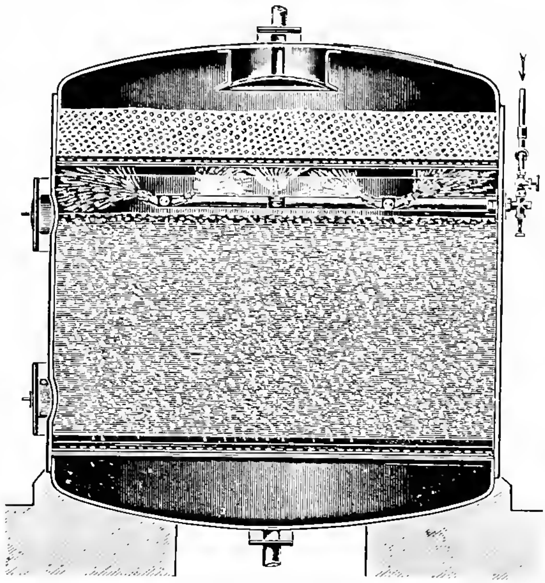

Fig. 7. Closed Plant for the removal of Iron. "Voran" System.

The height of the aerator is generally about 3 to 7 metres; the velocity of filtration in open systems seldom amounts to more than 1 metre, in closed systems it is often 10 metres (per hour).

The pressure is generally produced by the difference in level between the surface of water in the filter and in the pure-water reservoir.

Good iron-removal plants yield a water which at most still contains 0·1 milligram iron per litre.

The cost of removing iron from water amounts in a series of German towns from 0·04 to 0·4d. per 1000 gallons.

(*b*) *Removal of Manganese.*

As a result of the water calamity in Breslau in the year 1906, general attention has been turned to the occurrence of manganese salts in water. Although only present in small amounts, they deposit a weak scum which makes the water insipid, stains linen and paper, pollutes the reservoirs in breweries, injures the complete action of yeast, etc. Certain micro-organisms absorb it to a still greater degree than iron. Manganese almost always accompanies iron, but the amount is generally so small that its presence in the majority of cases does not approach practical importance at all.

Proskauer was the first to point out the occurrence of manganese salts in water.

Manganese is removed by aeration, like iron, but it separates out with greater difficulty, since, during aeration, mangani-manganous compounds result, which are soluble to a considerable extent in water.

The calamity in Breslau originated in consequence of the existing geological conditions. Iron and manganese sulphides, in the humous layers situated over the ground-water, were converted to sulphates by oxidation and then passed into the ground-water owing to a flood which inundated the whole tract of country.

For the removal of manganese, and also of iron, Permutit has recently been recommended. Permutit is an artificially prepared product (aluminium silicates), principally employed in the softening of water (see page 60).

Permutits have the property of withdrawing from water, lime, magnesia, iron, and manganese, in exchange for sodium, if the water be allowed to flow over them. Lührig and Becker, Gaus and Noll, have carried out experiments on the removal of manganese by means of calcium permutit. The manganese is thereby exchanged for calcium. Whilst Lührig and Becker obtained good results in laboratory experiments, a trial on a large scale proved a failure. The water took from the permutit substances which imparted to it an alkaline reaction, causing a precipitation of manganese as oxyhydrate. This precipitate choked up the filter. Noll found on an experimental scale that manganese was quantitatively removed from water by calcium permutit, so long as the content of the permutit in manganese was less than 2 per cent. The cost of removing manganese with calcium permutit is estimated by Noll to be 0·09d. per 1000 gallons.

Quite recently the Permutit Filter Company, Berlin, have recommended a new method for removing manganese and iron by means of permutit. According to Kriegsheim, the method is as follows: From a suitable permutit, e.g. sodium permutit, a manganese permutit is prepared by treatment with a solution of manganese chloride. This manganese permutit is then treated with potassium permanganate. The permanganic acid is thereby easily combined with the manganese oxide of the permutit to form highly oxidised manganese compounds. If a water containing manganese be now filtered through a permutit filter so treated, these higher oxides of manganese can very rapidly effect complete removal of the manganese, even with rapid velocity of filtration. The action is based upon the fact that the oxygen necessary for the oxidation process is presented to the manganese separating out during the filtration of the water in the solid condition and easily split off from the highly oxidised manganese oxides. The oxidation causes the precipitation of the manganese in the water in an insoluble form. Should the action diminish, the filter can be regenerated by means of a 2 to 3 per cent solution of permanganate. The cost of this process should be very small.

As already mentioned, the process is not only recommended for removal of manganese, but also for the removal of iron. The principle is the same in the latter case also.

(c) *Removal of free Carbon Dioxide.*

If water contains much free carbon dioxide, it exercises a very deleterious action on the various materials required in waterworks. Thus it was observed, for example, at Frankfort-on-Maine, that a newly constructed deep reservoir made of reinforced concrete was strongly corroded by the water. Similarly the iron pipes were vigorously attacked.

Whilst the action of the water on these materials is more a matter of economy than of hygiene, the corrosion of lead pipes, which are used in most cases for the conveyance of water inside houses, is in the highest degree serious from the point of view of health, since lead passes into the drinking-water as a result and is, even in the smallest quantities, inimical to health.

In practice three methods are used for the removal of free carbonic acid.

1. The water is allowed to flow through limestone (Heyer-Scheelhaase). The free carbonic acid is thereby converted into calcium bicarbonate according to the following equation :

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2.$$

By this method, therefore, hardness due to carbonates is increased. Where the water is of itself very soft this increase in hardness is not harmful, and may even be desirable. If, however, the water is already fairly hard, the increase in hardness might be a disadvantage. Besides, the removal of carbon dioxide by means of limestone is not accomplished in such cases, or only incompletely. The method is in use on a large scale in Frankfort-on-Maine for the removal of the free carbonic acid from Stadtwald water of 1·5° hardness, and containing 30 milligrams CO_2 per litre. It had caused great trouble in the new deep reservoirs of Sachsenhaus, and also in the mains. The hardness of the water, when freed from acid, amounts to about 5°

As the Frankfort plant for removing carbonic acid has proved excellent, it may be shortly described as follows (see Fig. 8) :—

In the years 1906–7 the plant for removing carbon dioxide was erected at a cost of 78,000 marks (about £3900) in the Chamber A of the deep reservoirs of the Sachsenhaus plant.

Seven of the ten passages of the chamber were employed for the neutralising process. The first serves as an inlet chamber, the second and third as sand filters, and the four following as limestone scrubbers.

From the inlet chamber the water is distributed through perforations in the partition-wall on to the sand filter, which only serves to retain the particles of ferric oxide carried along out of the pressure tubes. The velocity of filtration amounts to 80 m. in 24 hours. The filtered water passes through openings to the base of dividing-wall, and with the help of distributors passes under the limestone scrubber. The limestone scrubber is composed of a layer of flints at the bottom, over which rests a layer of gravel, and then four layers of limestone in different states of division, namely, about the size of walnuts, beans, peas, and coarse sand. Each of the first three layers is 3 inches high, the height of the fourth being 2 feet. The velocity of water in the scrubber reaches 40 metres (130 feet) in 24 hours. The water, when neutralised, flows partly through an opening in the partition-wall between sections 7 and 8 to the last three sections of Chamber A, and partly through a special pipe to Chambers B, C, and D of the reservoir. About every three months the sand filter has to be cleaned, by being washed through with water in the reverse direction from the bottom upwards.

With about 5,000,000 gallons of water neutralised daily, approximately 1½ tons of limestone are dissolved by the water and carried away.

2. Caustic soda, or sodium carbonate, is added to the water in calculated amount, according to the estimation of carbonic acid (Heyer). The free carbonic acid is converted to the bi-carbonate.

$$CO_2 + H_2O + Na_2CO_3 \rightarrow 2\ NaHCO_3.$$

This method was introduced by Heyer to neutralise the drinking-water in Dessau. In the eighth decade of last century a large number of persons became ill through lead poisoning. Heyer perceived that the capacity to dissolve lead was due to the amount of free carbonic acid present. After various other experiments he finally proposed the neutralisation of the water with caustic soda and sodium carbonate.

There are many types of apparatus for measuring the amount of chemicals to be added. It is stated and agreed concerning this method that it makes the carbonic acid quite harmless. The general public, however, has generally an instinctive aversion towards a drinking-water treated with chemicals. This fact is, doubtless, the main objection to this otherwise good system.

3. If a water containing carbon dioxide is allowed to rain down in a fine state of division, or allowed to trickle slowly over coke, glass, gravel, etc., it is freed from carbon dioxide.

With larger amounts of carbon dioxide present, the raining process has to be repeated many times to remove the carbonic acid. Further, the height of the fall has an influence. The removal of carbon dioxide in this way is disadvantageous for the reason that the water is greatly enriched with oxygen. A water rich in oxygen is also not good as, in its turn, it causes severe rusting of the iron pipes.

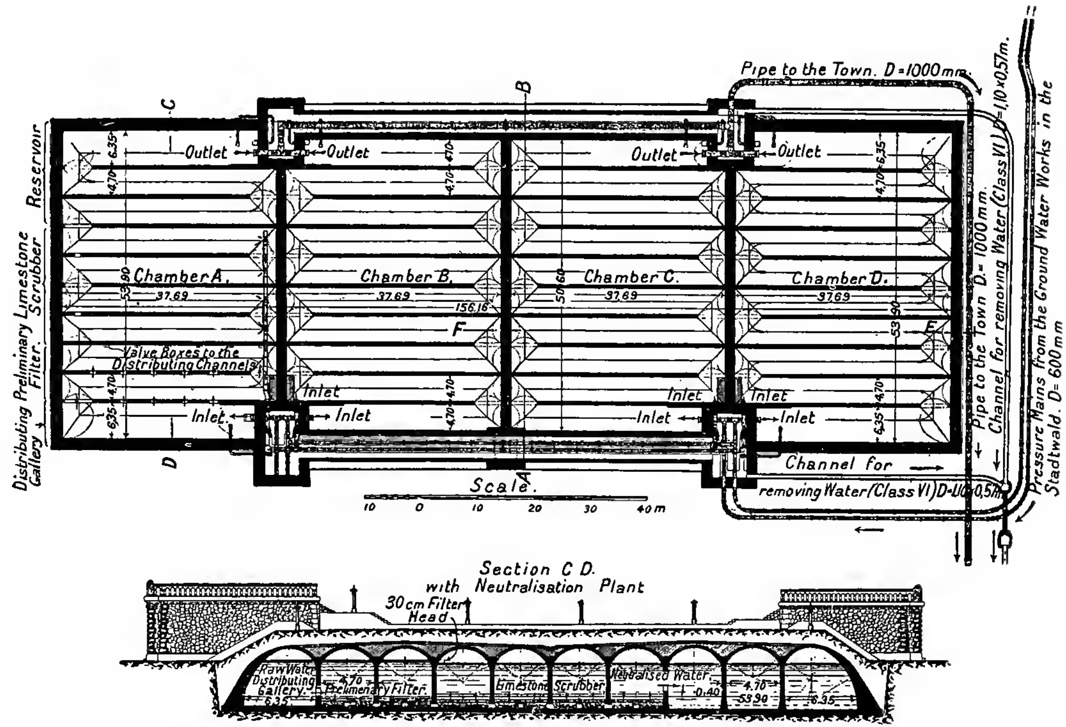

FIG. 8.

ACID NEUTRALISATION PLANT IN THE SAXONY DEEP RESERVOIR, FRANKFORT-ON-MAIN.

H. Wehner has now advanced the idea of effecting the trickling process in a vacuum. According to the accounts of the inventor, not only ought the carbon dioxide to be removed more rapidly, and with less height of fall necessary, but also, simultaneously, the amount of oxygen should be considerably diminished.

Wehner's vacuum process is to be used in some English and German towns.

II. PURIFICATION OF DRINKING-WATER ON A SMALL SCALE.

The greatest advantage of a central water supply is this, that, owing to the size of the project, there are more extensive preliminaries for securing a water free from any objection, greater certainty for carrying out the process according to conditions, and greater possibility of expert supervision of the process, so that disturbances are easily recognised and prevented.

Over and above this there exists in all small-scale purification processes the main weakness that the points of preference named above with regard to large-scale operations are either non-existent or are not sufficiently assured.

Isolated houses, estates, establishments, etc., would do well, therefore, to choose for their water supply, water free as far as possible from any objection, and not needing any purification.

Should unforeseen circumstances intervene, making the water of a central water supply, or even a single supply, seem doubtful, then methods of purification on a small scale can find application. Of first importance is boiling of the water before use.

Moreover, the employment of purification apparatus on a small scale is to be regarded as a makeshift, since it should be constantly controlled to determine whether it works well and continuously. This, naturally, in the majority of cases, cannot be accomplished.

Circumstances like epidemics, war, journeys in unknown or quite uncivilised lands, constitute an exception. In such cases it is often impossible to procure water free from objection. The small amount of water necessary, comparatively speaking, on such occasions can be purified with sufficient certainty by the aid of purification methods on a small scale. This is all the more true when, as, for example, in wars, or in times of epidemic, the necessary personnel is at one's disposal. The observance of the regulations can then be supervised.

This review of apparatus for water purification on a small scale naturally refers only to methods which aim at the removal of bacteria. Of apparatus for removing substances prejudicial to the appearance of the water, such as iron, etc., there are also many on a small scale, as already set forth above, and it appears that the small apparatus has the same action as the corresponding apparatus on the large scale.

(i) **Purification by means of Small or Household Filters.**

The household filter serves a double purpose: firstly, it removes suspended matter and makes the water clear; secondly, it is used for retaining bacteria also. Household filters are much less germ-tight than sand filters. The bacteria are washed through the filter if it is not very frequently cleaned, and not infrequently does it happen that the filtered water is richer in bacteria than the raw water. Small filters, therefore, are to be used with great caution.

The number of different forms of domestic filters is legion. They are all based on the filtration of the water through some porous material with or without the employment of increased pressure. Von Esmarch divides them into the following groups:—

(*a*) *Charcoal Filters.*

These are the oldest form of apparatus of this kind. They are composed of plastic retort carbon or finely sieved charcoal, powdered coke, and compounds of the most varied preparations. They generally cost between 30 and 70 shillings each.

Charcoal filters are scarcely used nowadays, since their bacteriological effect is practically *nil*. Indeed, if a charcoal filter is in use for some time, the filtrate is often worse than the raw water, since the bacteria which have remained behind in the charcoal have increased considerably, and are then carried along with the stream of water passing through. Also, as regards the removal of turbidity these filters are of little use.

(*b*) *Stone Filters of Sandstone, Pumice, and the like.*

The stone is burnt from coarse or fine sand, quartz, lime, and magnesium silicates. For filters that work without pressure coarse material is used, whilst for pressure filters extremely fine material is employed.

The clarification of the water may be rather good with such apparatus. The bacteria, on the other hand, go through the filter fairly readily, at the latest after two or three days. The productivity of the filters is generally small, usually about 1 litre per hour. Frequently the yield falls off quickly also, and cleaning then becomes necessary.

(*c*) *Asbestos Filters.*

Asbestos of very fine fibre is used as the filtering medium, and is employed as a pulp, or compressed or mixed with other materials. Asbestos filters are also used in technical work for the filtration and clarification of turbid liquids (beer, oil, wine, etc.), and for the retention of ferric oxide in iron-removal plants.

The filter of C. Piefke and the micro-membrane filter of Friedrich Breyer are capital asbestos filters. Asbestos filters retain bacteria fairly well ; but in general they choke up very quickly ; this necessitates frequent cleaning and sterilisation of the apparatus, which takes up much time.

According to Gärtner, Breyer's micro-membrane filter ought to be germ-tight.

Good asbestos filters are supplied by the firm of Arnold and Schirmer, 123 Grosze Frankfurter Strasze, Berlin, N.O., or by H. Jensen and Co., 20 Reichenstrasze, Hamburg.

(*d*) *Clay Filters.*

Of these filters there are likewise a number of different specimens as, for example, those of Olschewski and Hesse. They only filter free from bacteria for a short time. The greater the yield of water the shorter time are they germ-tight.

(*e*) *Porcelain Filters.*

The principal example of this type of filter is the Chamberland Filter. It consists of a metal cylinder, which can be screwed on to the water-tap. Inside the cylinder there is fastened an inner hollow mould, made of fine porous kaolin and attached to the cylinder so as to be water-tight. The water enters between the outer shell and the porous mould, penetrates inwards through the porous cylinder, and flows away through the opening situated underneath.

The filtrate is bacteria-free and so the yield of the filter is small, amounting after a few days to but a few litres per day.

The apparatus is cleaned by boiling and thoroughly heating the dried apparatus. The purified filter then regains its original productivity.

The Chamberland Filter can be obtained from the firm of Lautenschläger, Dramenburger Strasze, Berlin.

(*f*) *Kieselguhr Filters.*

The chief representative of these filters is the Berkefeld Filter, which is constructed on the same principles as the Chamberland Filter, but is composed of baked infusorial earth (see Fig. 9). They filter free from bacteria for various lengths of time, as a rule several days. They generally yield from $\frac{3}{4}$ to 2 litres per minute at a pressure of 1 to $2\frac{1}{2}$ atmospheres. Gradually the yield diminishes, but it can be raised again to just the original amount by brushing the cylinders clean. They can be sterilised by simply warming slowly on the water-bath.

The filters are, as far as freedom from bacteria and yield are concerned, certainly the best small filters. With daily sterilisation one can rely with tolerable certainty on a filtrate continuously free from bacteria.

The price of a filter for attaching to the water-tap in houses is from 30 to 35 shillings; smaller types from 13 to 16 shillings, and as pump filters from 46 to 200 shillings. The price of a repair cylindrical mould is 4s. 6d., of an army filter (yielding $\frac{1}{2}$ litre per minute) 30 shillings, and a transportable pump £8. The filters can be obtained from the Berkefeld Filter Co., Celle (Hanover).

P. Schmidt has studied the mechanism of bacterial filtration with Berkefeld Filters. He finds that the effective size of the pores in Berkefeld Filters (with Liliput moulds) is probably about 0·5 μ. By finely grinding Berkefeld Filters choked up with bacteria, it was shown that the choking only takes place on the surface of the filter, so that complete cleaning is possible in the mechanical way by reversal of the water-current.

Staphylococcus and organisms of about that size never pass through the filter, but, on the other hand, a number of small bacteria pass through in measurable amount if they are washed

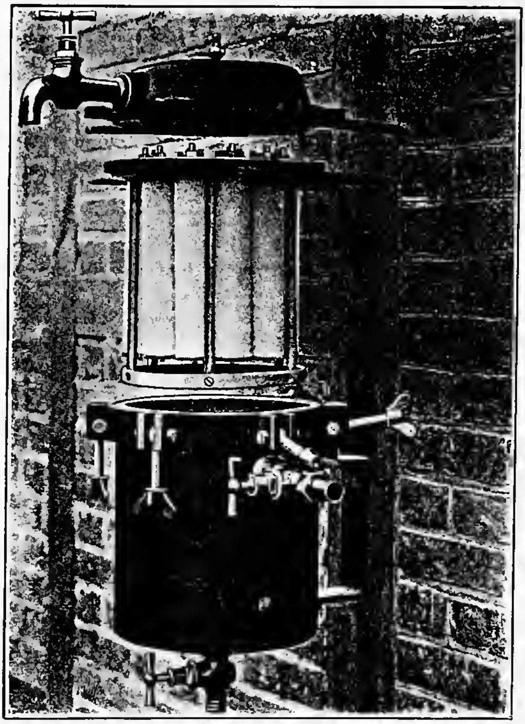

FIG. 9. BERKEFELD FILTER.

along in the water in very large quantities. Schmidt is of the opinion that for the passage of bacteria through a filter their size is of primary importance, and their mobility next in importance.

In general, according to König, the capacity of a domestic filter to retain bacteria depends: (1) on the nature of the filtering medium; it must be uniform, with the pores not too big; (2) on the water-pressure; this should not be more than 1 to 2 atmospheres, and should not act jerkily, since such pressure assists the passage of bacteria through the filter ; (3) on the amount of pollution in the water ; the more suspended matter a water contains, the more quickly does the filtrate cease to be free from bacteria ; high temperature also assists the passage of bacteria.

Generally speaking, the more germ-tight a filter is, the less productive it is also.

(ii) **Boiling the Water.**

All vegetative forms of bacteria are killed by long-continued heating of water at the boiling-point. Those bacteria which form endogenous spores withstand, of course, for the most part, the process of boiling, but even they are considerably weakened.

The pathogenic varieties coming mainly into consideration—cholera and typhoid—form no endogenous spores. For this reason boiling has been employed with advantage for the sterilisation of drinking-waters on a small scale.

If larger quantities of water have to be boiled—for families, hospitals, schools, factories, ships, etc.—and if this sterilisation, as for example in times of epidemic, has to be undertaken for a long time, then the following apparatus, according to von Esmarch, are to be recommended :—

(*a*) The apparatus of the German Continental Co. (Deutschen Continentalgesellschaft), of Dessau, for gas-heating, yields 6½ gallons per hour, using 10·5 cubic feet of gas (price £3 15s. 0d.).

(*b*) An apparatus by Grove, Friedrichstrasze, Berlin, also for heating by gas an attachment to the water-pipe. This apparatus yields 15 to 22 gallons per hour with 14 cubic feet consumption of gas (price £15). The water flowing out is about 5° warmer than that flowing in.

(*c*) Apparatus by Siemens and Co., Berlin, yields about 8 gallons of water hourly ; 100 gallons require 80 cubic feet of gas. The price is £2 5s. 0d., or, with a control apparatus which is to be recommended, £3 15s. 0d. The effluent water is from 5 to 10° warmer than the inflow.

(*d*) Apparatus by Schäffer and Walcker, Berlin, for gas-heating, yielding 6 to 8 gallons per hour.

(*e*) Apparatus of Pape and Henneberg, Hamburg, for burning gas, petroleum, or coal with automatic self-regulation of the inflow. The smaller apparatus yields 55 gallons hourly, and costs

£38; 220 gallons of water require about 300 cubic feet of gas, or 28 lb. of coal.

(*f*) Apparatus by C. Aug. Schmidt and Sons, Hamburg-Uhlenhorst. The firm supplies apparatus for houses, hospitals, etc., also with automatic self-regulation of the inflow. For a yield of 20 to 30 gallons per hour the apparatus costs £37 to £60 (see Fig. 10).

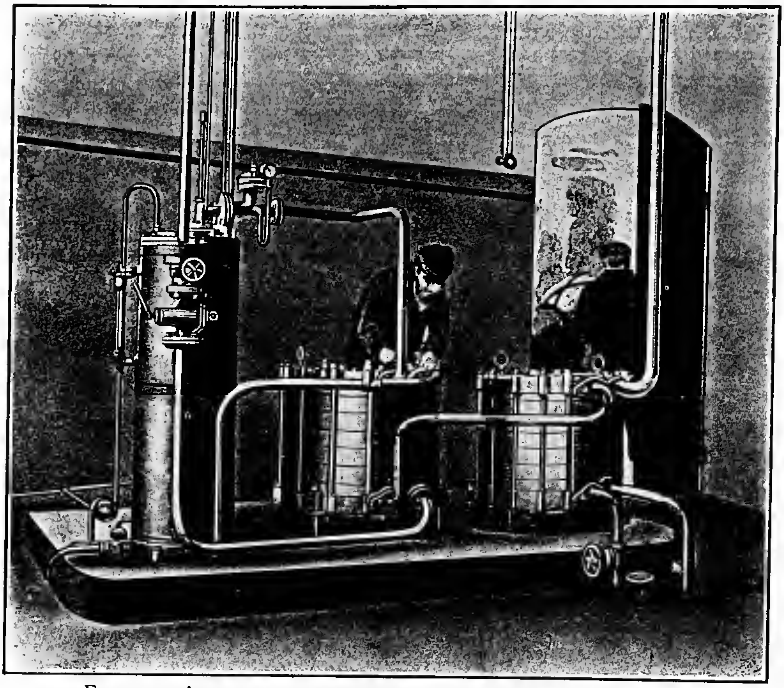

FIG. 10. APPARATUS FOR BOILING WATER OF THE FIRM OF AUG. SCHMIDT AND SONS, HAMBURG-UHLENHORST.

(*g*) Transportable apparatus of Rietschel and Henneberg, Berlin, for the use of armies and in case of epidemics. The plant yields about 66 gallons per hour; smaller portable apparatus can be had, yielding 20 gallons per hour.

As against filtration, purification of drinking-water by boiling has the following disadvantages:—

(1) It only kills the bacteria, and does not remove the suspended matter.

(2) The upkeep of the apparatus is expensive.

(3) As a result of loss of gases and salts, and as a consequence of the rise in temperature, boiled water is generally much less palatable than filtered water.

As opposed to these disadvantages there are the following points of preference :—

(1) The productivity remains continuously the same, whilst with filters it falls away.

(2) Boiling the water renders the destruction of disease germs absolutely certain. It is, on this account, the best of water-purification methods in this direction.

(iii) Small Ozone Plants and Ultra-Violet Light Apparatus.

The ozone method of sterilising drinking-water, as set forth previously, has proved itself good in central water supplies. Lately, various firms, especially the firm of Siemens and Halske, have constructed small ozone plants for sterilising smaller quantities of water for communal and private industrial concerns, as well as for the purpose of supplying drinking-water to troops in the field.

Both stationary and transportable small ozone plants have been designed.

They are used in the Munich Brewery, for the purification of the water used for cleansing vessels and for similar purposes. Transportable ozone plants are employed for the supply of water to troops in the field. Such plants were used by the Russian authorities in the Russo-Japanese war, and their use for military purposes is said to be under consideration by various other Governments. The whole apparatus is lodged on two waggons, the machine-waggon and the sterilisation-waggon.

In practice the raw water is brought, by means of a water-pump on the machine-waggon, through a thick suction and pressure pipe to a filter, and from there to the sterilising-tower. The filter and tower are on the sterilising-waggon. Through a thinner air-suction and pressure pipe the air passes from bellows on the machine-waggon into the ozone apparatus on the sterilising-waggon, and from here passes to the base of the sterilising-tower. By means of a cable the primary current of an alternating-current machine on the machine-waggon is conducted to the transformer on the sterilising-waggon, which is set up directly underneath the ozone apparatus to generate the requisite working-tension.

Each waggon requires one horse,and weighs about 1 ton.

The plant yields 400 to 600 gallons per hour, and requires for the process about 2 horse-power.

For safety the ozone is generated in such excess that with very dirty water only one-third to one-half is consumed.

The apparatus was tested by Proskauér, the Russian hygienist and bacteriologist, K. Kressling, and a Russian military commission prior to its despatch to the seat of war in Manchuria. The results of these tests were very satisfactory.

M. Neiszer made a report on experiments with two ozone plants for work on a small scale, which were placed at his disposal by the firm of Felten and Guilleaume-Lahermeyer-werken A.G. of Frankfort-on-Maine.

In both apparatus the ozone was generated by current from the supply for lighting purposes. The mixing of the ozone with the water was effected by means of an aspirator attached to the water-tap.

Opening the water-tap started both the generation of ozone and its mixing with the water. The ozone generator consists of a 120 to 5000 volt high-tension transformer enclosed in a protecting box, with plate condensers. The ozone generator is attached to the town supply (120 volts, 45 periods) and consumes 0·55 ampere. The amount of ozone generated is about 5 to 6 milligrams per litre of air, with about 2 litres per minute. The experiments were conducted with staphylococcus (*Staph. pyog. Aur.*) and with bacterium coli. They showed that with suitable water (no suspended matter, no iron, and little organic matter), thousands of bacteria per cubic centimetre can be killed with certainty, provided they have a resistibility intermediate to that of staphylococcus and bacterium coli. It is important to observe that when mixing was intimate, and when sufficient quantity of ozone was used, momentary contact was sufficient to kill the germs.

Further, the firm of Siemens and Halske have designed, as a result of their previous experience, a sterilising apparatus, making use of ultra-violet light rays, for affixing to the domestic supply and also for single water-supplies. Their contrivance is characterised essentially by a mechanism whereby, on turning a single handle, the lamp is set working through being tilted, and at the same time the water-tap is opened. An electro-magnet is further provided which only allows a flow of water through the apparatus when the lamp is properly alight. Also, if the lamp goes out during the process the water-inflow tap immediately closes, so that water which has not been sterilised cannot be drawn from the apparatus.

(iv) The Removal of Iron from Single Wells.

The methods of iron removal, using small plants, whether it be for the purposes of a central water supply or for industrial application, have already been discussed on page 32 and the following pages. There remain still to be mentioned those methods which serve especially to remove iron from single wells.

The oldest and simplest method of removing iron from well-water is to pour into the well iron-free water which has taken up oxygen (generally by standing in the air). The oxygen precipitates the iron as hydroxide, which then settles to the bottom. Water can in this way be freed for many days from the iron it contains. The chief disadvantage lies in the fact that the precipitated iron remains in the well. In addition to this the water poured into the well should, of course, be hygienically free from any objection, which it never is.

For this purpose the Dunbar Filters are very suitable. Of such filters the simplest and cheapest construction consists of a tub filled with sand, having a tap in the side at the bottom. The water is allowed to flow out of the pump on to the sand. The iron-free water is removed through the tap underneath. About every three months the sand must be freed from the precipitated oxide of iron by washing. Such an arrangement is not suitable to wells situated in the open, since they are liable to freeze. Still, this objection can be overcome, as the whole plant can be housed against the frost in a special small hut.

The Deseniss and Jacobi system of so-called bastard pumps (see Fig. 11) differs from all other systems in this, that by means of a pump the water is taken from the well already freed from iron. All intermediate apparatus, such as scrubbers, clarifying reservoirs, etc., are therefore not required.

The following is the arrangement and method of working such pumps: To the pump employed for raising the water there is attached a second cylinder of double the circumference of the cylinder of the water-pump. In both cylinders there move

FIG. 11. THE BASTARD PUMP OF DESENISS AND JACOBI.

tightly closing pistons, provided with valves and fastened to a piston-rod. The water streaming in from the lower cylinder to the one above, since the latter has double the capacity of the former, is thus mixed with an equal volume of air, sucked in through a valve laterally placed in the higher cylinder. After being mixed with air the water is forced on to a forged-iron filter, carrying sand of 0·5 millimetre grain as filtering material. It is thereby freed from the hydroxide of iron that has been formed. The filter can be set up in a small shaft standing in close proximity to the pump, or it may even be placed in the pump uprights itself.

It is not necessary to renew the filter layer at all; the purification of the filter is effected by temporary automatic flooding in the reverse direction, and is attained by simply reversing the stop-cocks.

Schreiber has tested this method in an experimental plant, set up in the chief pumping-station of the Charlottenburg ground-water works. He finds that the pump removes even the last traces of iron, or at most leaves an inconsiderable amount behind. It further fulfils all the demands made upon a hand-pump as regards simplicity in construction, slight supervision, and protection against pollution.

Moreover, the bastard pump is not only supplied for hand-work, but also for working by machinery.

According to the declarations of the firm, the removal of the iron should be alike complete with a hand-pump of usual size, or with a large-scale plant yielding many thousands of litres per hour.

B. Purification of Water for Technical Purposes.

Besides the use of natural water for drinking purposes, water is needed for almost all human occupations. In most cases with a natural water purification is not necessary for technical purposes, since the demands made upon the quality of such a water are naturally less than with a drinking-water.

For cleansing public urinals and lavatories, for fountains, and for watering the streets and gardens, untreated river-water is frequently used. Where the river-water is very dirty, at most a coarse gravel filter is employed, and this simply serves to retain suspended matter, but not, as is the case with drinking-water, the bacteria. Many towns, like Frankfort-on-Maine, have alongside the drinking-water pipe, one for river-water, which serves the purposes mentioned.

For many industrial purposes the water, however, must undergo treatment. For example, in paper manufacture, the presence of iron is troublesome, since iron forms a compound with cellulose and makes the paper spotty. The removal of iron in such cases is effected in small iron-removal plants, which have already been described on page 32 and the following pages. In many industries —for example, with laundries, dye works, and others—hard water is a great disadvantage, as a part of the working material is precipitated by the constituents causing hardness, and is thereby rendered useless. Hence, for such purposes the water must be softened. Quite generally, however, the softening of water plays a large part in industry, owing to the use of water in boilers.

The Softening of Boiler-Feed Waters.

The hardness of a water is due to the calcium and magnesium salts dissolved in it. A distinction is drawn between temporary hardness, or hardness due to carbonates, and permanent hardness, or hardness due to mineral acid salts. Carbonate hardness is caused by the bicarbonates of calcium and magnesium which, unlike the normal salts, are soluble in water. On boiling the water these bicarbonates give up half their carbon dioxide in the free state, change to the normal salt, and therefore become insoluble. The observation that a part of the hardness of water disappears on boiling has earned for such hardness the title of temporary hardness.

Permanent hardness is due to the presence of the salts of calcium and magnesium with sulphuric, hydrochloric, and nitric acids, and therefore to calcium and magnesium sulphates, chlorides, and nitrates.

Hardness is measured in German or French degrees of hardness. 1° on the German scale is equivalent to 1 mg. CaO or 0·74 mg. MgO per 100 c.cs. of water. 1° on the French scale is equivalent to 1 mg. $CaCO_3$ or 0·84 mg. $MgCO_3$ per 100 c.cs. water.[1]

If hard water is used for feeding boilers, in process of time there settles on the boiler plates a scale, consisting of precipitated calcium and magnesium salts. With a large amount of temporary hardness, there further results in the boiler a big sludge of loose, precipitated normal calcium carbonate. The troublesome effects of this boiler scale are well known. In the first place, once a boiler scale has reached a certain thickness, the conductance of heat to the water is greatly hindered, and so coal is consumed very uneconomically. Boiler scale can also lead, however, to the direct deterioration of the boiler plates, since the scale possesses a different coefficient of expansion from that of the boiler plates. In this way fissures and cracks result. The chlorides of lime and magnesium, when present in water in fairly

[1] 1° on the English scale is equivalent to 1 grain $CaCO_3$ per gallon.—*Trans.*

large amounts, are very troublesome as they are hydrolysed with formation of free hydrochloric acid, which passes away with the steam and attacks the equipment.

At the present time three methods are principally employed for softening water, namely, the Lime-soda method, the Reisert Baryta process, and the Permutit process.

The lime-soda method, as the name implies, consists in adding to the water lime and sodium carbonate. The temporary hardness is removed, by the addition of lime, in the form of calcium carbonate and magnesium hydroxide, according to the following equations :—

1. $Ca(HCO_3)_2+Ca(OH)_2=2\,CaCO_3+2\,H_2O$.
2. (*a*) $Mg(HCO_3)_2+Ca(OH)_2=CaCO_3+MgCO_3+2\,H_2O$.
   (*b*) $MgCO_3+Ca(OH)_2=Mg(OH)_2+CaCO_3$.

Permanent hardness is removed by means of sodium carbonate according to the following equations :—

1. $CaSO_4+Na_2CO_3=CaCO_3+Na_2SO_4$.
2. (*a*) $MgCl_2+Na_2CO_3=MgCO_3+2\,NaCl$.
   (*b*) $MgCO_3+Ca(OH)_2=CaCO_3+Mg(OH)_2$ (Pfeiffer).

All calcium salts in the water are therefore precipitated in the form of the normal carbonate ; all magnesium salts, no matter in what form they are present (whether as temporary or permanent hardness), are finally precipitated as the completely insoluble hydroxide. Hardness due to carbonates is therefore entirely removed from water by this method, but in place of the precipitated salts causing permanent hardness, an amount of sodium equivalent to the calcium and magnesium originally present passes into the water as sulphate, chloride, or nitrate.

From the equations given it can easily be calculated that, for each degree of temporary hardness, 10 g. of lime (100% CaO) are needed to soften 1 cubic metre of water. Also it is obvious from the equation that for each milligramme of magnesia present in a litre of water, no matter what the form, 1·4 g. of lime (100% CaO) must be added to a cubic metre of the water. For each degree of permanent hardness 19 g. of sodium carbonate (100% Na_2CO_3) are needed per cubic metre. In the measurement of the quantity added, it is to be borne in mind that natural waters generally contain some free carbon dioxide. Since carbonic acid combines with lime to form bicarbonate, which then, of course, combines with more lime to form the normal carbonate, for every milligram of free carbon dioxide per litre an addition of 1·27 g. of 100% CaO must be made per cubic metre, in order to neutralise this free carbonic acid. The addition of lime, therefore, must be increased by such an amount for every milligram of free carbon dioxide present.

From various investigations, however, the amount of lime to be added, thus theoretically reckoned, proves to be too high in practice. It must be cut down by about 20 to 25 per cent. Various reasons for this have been put forward.

Instead of calcium hydrate, caustic soda can be used. From the bicarbonate there results sodium carbonate which, in its turn, serves to remove permanent hardness.

$$Ca(HCO_3)_2 + 2\,NaOH = CaCO_3 + Na_2CO_3 + 2\,H_2O.$$
$$Mg(HCO_3)_2 + 4\,NaOH = Mg(OH)_2 + 2\,Na_2CO_3 + 2\,H_2O.$$

If precisely so much temporary hardness is present that the sodium carbonate resulting according to the above equations is just sufficient to remove the permanent hardness, then the water can be completely softened with sodium hydrate. If more permanent hardness is present, then the sodium carbonate still required has to be added. If, on the other hand, there is too little permanent hardness, only so much sodium hydrate should be added as can form the amount of sodium carbonate requisite for the removal of the permanent hardness. The remainder of the unprecipitated carbonates must then be removed by means of lime.

Formulæ for reckoning the necessary addition of caustic soda, sodium carbonate, and lime have frequently been given. If a is the combined carbonic acid, b the total lime, and c the total hardness expressed in equivalents of hardness, then the following formulæ of Kalmann give the necessary additions of caustic soda, lime, and sodium carbonate :—

$$m = 2a - b\,; \qquad n = c - a.$$

If m and n are positive, the water contains more temporary than permanent hardness ; m is then the lime to be added, n the caustic soda.

If $2a - b = 0$, there is present in the water as much temporary as permanent hardness. No lime is then needed, but only n units of caustic soda.

If $2a-b$ is negative, the water contains more permanent than temporary hardness. There must then be added m parts of sodium carbonate and $c-a=n$ parts of caustic soda (Wehrenpfennig).

The caustic soda is generally prepared by mixing sodium carbonate solution with lime and allowing the precipitated calcium carbonate to settle.

In ascertaining the necessary addition, if lime and sodium carbonate be reckoned, and not caustic soda, precisely the same amounts require to be added as were given above, on page 53, for lime and sodium carbonate. Therefore, with caustic soda as the softening agent, the numbers given with respect to lime and sodium carbonate can be adhered to.

The lime-soda process is the oldest, and doubtless, also, has the widest practical application at the present time. Softening with lime and sodium carbonate never attains 0° hardness, but generally only about 3° to 4°, which, however, is quite sufficient for general requirements. There are numerous firms who construct softening plants of the lime-soda type, which are used with the greatest success in practice. Among others are the firm of Humboldt in Kalk, Dehne in Halle a. S., Reisert in Cologne, and the " Voran " firm of Frankfort-on-Maine. Figure 12 represents a lime-soda softening plant, " Voran " system.

This plant may be briefly described as an example of a lime-soda softener.

The automatic water-purification apparatus of the " Voran " System (Model BI) consists essentially of reservoir A, divided into three parts by means of partition-walls, the clarifying tank B, the lime saturator C, the sodium carbonate regulator D, and the filter of wood shavings and wood-wool arranged under the clarifying tank B.

The raw water which is led into the apparatus through the pipe E next flows through the discharge pipe F into the part of the tank A set aside for the raw water.

In this section, at equal heights, are placed two stop-cocks G and H, through which the raw water can flow away. The larger portion goes, through the stop-cock G and the pipe G_1, directly to the funnel-shaped central portion I, in which it takes up a violent whirling motion owing to its tangential entry.

The smaller quantity of raw water, arranged exactly according to the amount of lime-water required, flows through the stop-cock H and the discharge tube H_1 to the lime saturator C, to the

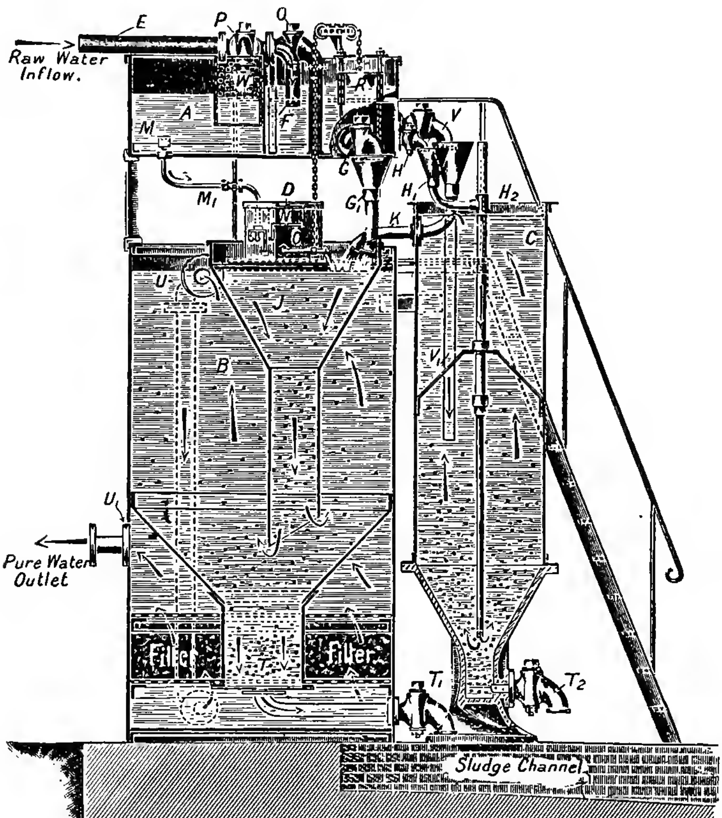

FIG. 12. LIME-SODA WATER SOFTENER. "VORAN" SYSTEM.

bottom of which it is led through the central funnel-pipe H_2 in order that it may pass into the saturator equally distributed on all sides.

From here on its way to the overflow K the raw water is compelled to percolate through the milk of lime which, since it is specifically heavier than water, has settled to the bottom. The water is thereby itself completely saturated with caustic lime and flows away at the top completely saturated and clear lime-water, through the overflow-pipe K to the mixing-trough.

If the ratio of clear saturated lime-water to raw water is once fixed, then it will always remain the same, whether much or little raw water is flowing in, for the amounts of raw water flowing through the two stop-cocks G and H should always be proportional.

The soda solution necessary flows from its particular part of the reservoir A through a hair-sieve M and the attached pipe M_1 to the sodium carbonate regulator D, in which the inflow is regulated by the float N. From the regulator D the sodium carbonate solution passes to the mixing-trough through the exit pipe Q, so arranged that it can be revolved, and which is attached in its turn to the float R in the raw-water reservoir. When the float R sinks the discharge-pipe Q is raised and the discharge reversed.

If the raw-water section of the reservoir becomes empty at any time, the float R will sink to the bottom, thereby raising the discharge-pipe so high that no more sodium carbonate can flow out.

On the other hand, the three streams of raw water, lime-water, and sodium carbonate solution commence to flow simultaneously, as soon as raw water flows into its particular section of the reservoir.

By this means the amount of chemicals added always bears a fixed ratio to the amount of raw water consumed, that is to say, the apparatus is automatically self-regulating.

If too much raw water be led into the raw-water reservoir it is run off by means of an overflow-pipe.

The lime-water and sodium carbonate solution, after mixing, flow from the mixing-trough to the central funnel-shaped pipe I, and of course meet the circular motion of the raw water there. In this way an intimate mixing with the water is ensured, and the commencement of the reaction is hastened. It is especially advantageous for the rapid progress of the reaction to have the cross section of the pipe I wide at the top and decreasing downwards, since with a constantly increasing velocity of water a stronger whirling motion is produced and a more intimate mixing ensues.

After leaving I the water is reversed in direction and then distributed uniformly in the reaction space and clarifying portion B. Owing to the comparatively large cross section of the chamber the water rises to the top with very slow velocity, and on this account is freed as far as possible from fine suspended matter.

The greater part of the sludge does not alter its direction with the water, but in consequence of its higher specific gravity sinks to the bottom. It settles there in the sludge tank T, from which it can be withdrawn as required through the stop-cock T.

The water rising to the top of the clarifying space B, by the time it has reached the discharge-pipe U, has allowed the greater part of the insoluble precipitated components to settle out.

Consequently through the discharge-pipe M, water carrying only floating particles passes to the underneath side of the filter. These remaining particles are retained during the passage of the water through the filter, with the result that the water leaves the apparatus at U_1 softened and filtered, to be led away to the place of consumption.

The wood-shaving or wood-wool filter will only need cleaning or renewing at long intervals of time, perhaps after six to twelve months, since it is only very slightly used. Renewal should easily be effected at a cost of a few shillings.

The disadvantage of the lime-soda process is simply this, that in place of permanent hardness, as has been already mentioned, an equivalent amount of sodium salts passes into solution. These sodium salts are, of course, quite neutral and readily soluble in water, but in course of time attain to such a strong concentration in the boiler that they cause inconvenience. The salts crystallise at the valves, irregular boiling of the water occurs, and so on. The lye must then be blown off. A further disadvantage of the process is this, that with the addition of too much lime and sodium carbonate the boiler plates may be attacked. Generally, however, with frequent checking of the pure water produced, the process can be worked in such a way that just the right amount of substances is added. Blacher rightly calls attention to the fact that it is not sufficient to control only the softened water, but that the control must extend also to the water in the boiler. For, even if only a slight excess of the reagents be present, these excesses are concentrated in the boiler in such a way that the boiler plates will be attacked.

According to Blacher it is considered permissible for the water to contain up to 3° of permanent hardness and excess of sodium carbonate up to 57 milligrams Na_2CO_3 per litre.

The Reisert Baryta process for softening water removes temporary hardness by means of lime exactly as in the first-named process. The most troublesome permanent hardness in boiler-water is due to gypsum, as this yields hard boiler scale, which adheres very tenaciously to the boiler plates. The Reisert method is therefore confined to the removal of that permanent hardness due to gypsum, and this is effected, of course, by the addition of barium carbonate. Barium carbonate is practically insoluble in water. It is deposited in the water, care being taken that it remains in contact with the water for a period of time, during which the following decomposition with the calcium sulphate takes place :—

$$CaSO_4 + BaCO_3 = BaSO_4 + CaCO_3.$$

Gypsum and barium carbonate are therefore converted into insoluble calcium carbonate and completely insoluble barium sulphate. The lime necessary is naturally the same as in the lime-soda process, no matter what the amount of barium carbonate is. Also, the whole of the magnesia is finally precipitated as hydroxide, so that it holds in this case also that each milligramme of MgO present in the water requires double the amount of lime. Therefore, for each milligramme of MgO per litre the amount of lime to be added per cubic metre must be raised to 1·4 grammes of 100 per cent CaO, according to the methods of estimation on the basis of hardness discussed previously.

The chief point of preference in the baryta process lies in the fact that the sodium carbonate, which when present in considerable excess in the softened water acts very corrosively on the equipment, is done away with. Since barium carbonate as mentioned is practically insoluble in water, the baryta process possesses the further advantage that the addition of carbonate may be liberal. An excess of barium carbonate is thrown into the water, which is then allowed after a certain time to settle free from the undissolved matter, whereupon it can be employed immediately. An excess of barium carbonate is impossible in the water softened. Further, in the baryta process, another inconvenience mentioned in the lime-soda process disappears.

In that process in place of the permanent hardness sodium salts enter the water. By the baryta method the temporary hardness and that due to calcium sulphate is removed practically quantitatively. It can therefore be said of this process that there is less risk of corrosion in the boiler than is the case with the lime-soda process.

Against these advantages of the baryta process there stand a number of disadvantages. Only sulphate hardness and not that of chlorides or nitrates is removed with barium carbonate. It is consequently only applicable to water which does not contain these salts in appreciable amounts. Waters containing alkali sulphates cannot be softened by the baryta process, since in this case sodium carbonate would be formed by the interaction of the barium carbonate with the alkali sulphates, according to the following equation :

$$Na_2SO_4+BaCO_3=Na_2CO_3+BaSO_4.$$

Sodium carbonate would therefore be present in the softened water, would get into the boiler and ruin it.

The most recent method used in practice is the Permutit method. Permutit is a complex compound of sodium, aluminium, and silicic acid. Such compounds occur in nature as zeoliths. Permutit is the name for the artificial product obtained by melting aluminium silicate with sodium carbonate, and has the peculiar property of removing lime, magnesia, manganese, or iron from water when such water is slowly filtered over it. At the same time equivalent amounts of sodium are given up to the water. The process would scarcely have come into practical consideration at all if it had not been discovered simultaneously that permutit or zeolith, through which water has been filtered for a long time, and which has quite lost its softening capacity, can be easily regenerated by washing it with a solution of common salt. Thus the process can be reversed. The bases removed pass back into solution, and in their stead sodium from the common salt passes into the compound. The product so washed is precisely of the same utility as the original, and after working itself out again can be regenerated anew.

The advantages of the process are manifest. Above all, the process is extraordinarily simple to manage. It is simply a question of filtering the water to be softened through a layer of permutit of a certain depth at a velocity determined by tests. Unlike the two softening processes previously mentioned, which both reduce the hardness only to about 3 to 4°, with methodical control the softening in this process readily reaches 0°. A further advantage is naturally that the necessity for the addition of definite amounts of reagent is obviated. The main disadvantage of the process lies in the fact that with water rich in carbonates (and most hard waters are rich in these salts), in place of the substances removed an equivalent amount of sodium bicarbonate enters. In the boiler the sodium bicarbonate gives up half its carbon dioxide and is converted to the normal salt. There will therefore be constantly present in the boiler water containing sodium carbonate which may cause corrosion as already mentioned.

The method is employed, as previously noted, not only for softening, but also, especially of late years, for removing iron and manganese from waters.

Softening plants of the Permutit type are supplied by the Permutit Filter Co., Berlin.

For the correct working of a softening plant, expert supervision, by examination of both the softened and the boiler water, is of the utmost importance. Blacher a short time ago suggested a very subtle method, by the aid of which exact insight can be obtained into the existing conditions in boiler management. The method consists in finding out the acid required to neutralise the boiler water by titration with $\frac{N}{10}$ acid, first using phenol phthalein and then methyl-orange as indicator. In addition the total hardness is estimated with potassium stearate and phenol phthalein. From these three values, which can be obtained in quite a short time, one is in a position to suggest how the water is constituted. Professor Blacher has constructed a box for testing raw water, softened water, and boiler-water, which with the accompanying instructions can be obtained at a cost of 25 shillings from the Vereinigten Chemischen Fabriken für Laboratoriumsbedarf of Berlin. Every boiler user is warmly recommended to provide himself with one. The necessary experimental work can be learned by an intelligent foreman.

In conclusion it may further be pointed out that the so-called boiler-scale preventatives which are often recommended are very much advertised and overrated. In the majority of cases they are crude swindles, for it is self-evident that substances like sugar, starch, and others are not such as would prevent boiler scale. Of late, remedies have come into the market whose action depends on simultaneous deposition of the medium along with the boiler scale, whereby the scale is of a softer nature and more easily removed. It is not impossible that such a remedy might actually be successful, but a certain amount of scepticism exists in regard to them. The most rational method of protecting oneself against damage due to the formation of boiler scale is always a properly managed softening plant.

SEWAGE DISPOSAL

THE SIGNIFICANCE OF RIVER POLLUTION AND THE IMPORTANCE OF SEWAGE DISPOSAL.

ALL water, whether for drinking or domestic purposes generally, or whether employed in cleansing, washing, and industrial processes, when not consumed through leakage, evaporation, or in some such manner, eventually becomes sewage. Unlike purified water, or even a natural unpurified surface-water, sewage varies considerably in composition. It contains suspended and dissolved organic and inorganic matter in more or less large quantities, and on this account is characterised by a muddy appearance and frequently also by a foul odour.

The purification of sewage is quite recent in its origin. Even up to a few decades ago short work was made of effluents. Generally speaking, the water used in dwelling-houses was conducted in ordinary open sewers to the nearest river.

The vast increase of large towns and the unexpected progress of industry led to the most serious nuisances in this disposal of sewage into rivers. The evil, which is every day becoming more apparent, is both hygienic and economic.

Many large towns are dependent on river-water for their water supply. As was explained in the previous section, the bacteria are generally removed by means of a sand filter. Apart from the consideration that the filter naturally cannot remove dissolved filth, substances which owing to their origin may be harmless seem to leave a water unappetising as a drinking-water. Also a greater pollution of surface-water with sewage produces a larger number of bacteria in the filtered water, since no filters are completely germ-tight. This is all the more serious, as, naturally, in sewage waters which contain all human excreta, disease germs may very easily be present.

In those places where surface-waters are not used for the water supply, river-water is nevertheless often used for baths, washing, watering the streets, and similar purposes. All these processes ought to be carried out without any danger to health.

It was shown by the Director of the Pasteur Institute in Constantinople that cases of cholera that occurred in the year 1908 could be attributed to infection of the hands with the water of the Bosphorus and the Golden Horn. Similarly it was medically established with absolute certainty that a number of typhoid cases in the French army had resulted through bathing in polluted waters.

These examples show that river pollution may be very serious both as regards washing and bathing. Apart, however, from these direct dangers it is greatly to be regretted if river baths, which in the view of experts are decidedly superior from the standpoint of health to baths in closed rooms, are avoided as a result of the foul and unattractive nature of the water.

Besides, a river polluted with sewage, choked with mud, or even smelling badly, will excite in every normal man feelings of repugnance and displeasure which may have economic results, for the banks of such a river are avoided as places of residence. Where a polluted river flows through or by a town, there is always a danger of the river-banks depreciating in value.

In addition to the great economic disadvantages of the pollution of rivers, harm also results in the destruction of fish. Often the fish are ruined in large quantities by the introduction of sewage into the river. The delicate and precious varieties especially are very sensitive to pollution of the water, and very soon disappear entirely with continued pollution. With certain kinds of sewage containing substances of specific taste or smell, the fish assume similar taste and smell. An embarrassing point of social significance relative to this is, that lower middle-class people, like fishermen and proprietors of baths, the protection and maintenance of whom in these days of the capitalist on the one hand and the proletariat on the other seems to be demanded, are either annihilated or grievously injured economically. A disadvantage too of river pollution, by no means insignificant economically, is demonstrated also in this, that as a result of the deposition of mud on the river-bed, expenditure has to be incurred in dredging operations to remove the mud and in similar processes of purification.

Consequently the most diverse and weighty reasons have constrained authorities in most civilised lands to face the problem of excessive river pollution, and to require of towns and factories adequate purification of sewage before disposal.

Self-purification of Rivers.

Up to a certain point, of course, rivers are able to purify themselves from the filth that becomes incorporated. It is by no means seldom that just beyond a town a river-course is seen to be very dirty, but that a few miles further on the water has already reassumed a good condition. This so-called self-purification of rivers is explained as being due to a wonderful co-operation of physical, chemical, and, above all, biological forces. The suspended matter deposited in a river by the sewage gradually settles to the bottom as mud. Here it is disposed of by snails, mussels, insect-larvæ, beetles, worms, and other organisms, which consume it, or by continually loosening it prepare it for a gradual washing away. Since the organisms mentioned represent the chief source of nourishment for the fish feeding on the river-bed, it follows that they can never get the upper hand. The dissolved organic matter which an effluent water carries to a river, especially the more molecularly complex portions, and therefore above all the albumens and their decomposition products, are mainly decomposed by bacteria. There then appear Ciliata, Rotatoria, and Infusoria, which in their turn live on these bacteria. Green Algæ also join in. These and the previously mentioned groups are able to absorb dissolved organic matter directly from the water. In the main, however, the green algæ provide for their own nourishment by assimilating carbonic acid, nitrates and nitrites which again originate from the activities of the bacteria, and from them with the help of their green colouring matter, chlorophyll, they build up the necessary albumens. During these processes of assimilation oxygen is liberated, and this produces powerful aeration of the water. This aeration accounts for the existence of the inhabitants of the water already mentioned, and also for that of the more highly organised parts. The green algæ, rotatoria, ciliata, and infusoria, etc., serve in their turn as food for the small water-crabs or water-fleas, and these again play quite a considerable part as food for fish. So, finally, the sewage deposited in the water is converted into useful fish.

Industrial sewage containing heavy metals deposits these as insoluble sulphides or basic carbonates on the river-bed. Owing to the bi-carbonates present in river-water many river-waters have a considerable capacity for neutralising acid. The Maine, for example, at Frankfort, shows an average alkalinity of about 3 cubic centimetres of normal acid per litre of water. Since with the Maine at average height, 80 cubic metres of water pass through its cross section per second, it follows that the amount of water passing one point in twenty-four hours would be able to take up in round numbers 830,000 litres or 500 tons of concentrated 100 per cent sulphuric acid without the water giving an acid reaction. For this it is, of course, presumed that these amounts of sulphuric acid could mix thoroughly with the amount of water under consideration, which naturally is not possible. It always happens in the introduction of acids into river-water that only a small portion of the river-water at disposal will mix with the acid effluent, and the consequence is that the river-water becomes acid over a certain stretch.

The same limitation operates as regards what was said above with respect to the biological self-regulating process. The wonderful co-operation of all these forces and the accompanying correct self-purification, are only attained in a satisfactory manner when the amount of sewage bears a certain relation to the purifying forces. If this relation is unsuitable the river-bed becomes covered with mud and with foul suspended matter. In the water, large amounts of putrefying bacteria appear, the above-mentioned organisms do not get their requirements of life and disappear. When this occurs important links in the chain are wanting and the orderly co-operation of the whole is destroyed. The water at these stages will assume a foul nature and cannot sufficiently purify itself.

As a rule, good limiting values cannot be given as regards the amount of sewage that a river can absorb. The amount of effluent with which a river may be burdened without being harmed is a question which cannot be decided generally, but only from case to case with tests of all the factors coming into consideration. In the first place, for example, the composition of the sewage varies greatly. Also, every river possesses its own specific biological activity, and with that its own specific capacity for self-purification which varies from river to river. Quite generally it may be said that a river can absorb more sewage the more water there is present, and the greater the velocity of that water. Demands as to purification of sewage must be correspondingly stricter the smaller the flow of the river into which it is to be conducted. On the contrary, large rivers, containing much water affected by the tide, and having a swift current, can fully absorb sewage that is only quite superficially purified.

Sewage can be divided into domestic and industrial sewage. Domestic sewage comprises, in the main, waters from dwelling-houses, containing therefore fæces, cleansing and washing waters, kitchen refuse, and similar substances. It is therefore rich in easily decomposable organic substances which very soon become foul. Many towns, however, now receive large amounts of industrial effluents into their sewage, and consequently in many industrial towns the domestic sewage is often mixed with very considerable quantities of industrial sewage.

The sewage from many industrial concerns is characterised, as with domestic sewage, by a large content of dissolved organic matter which causes it to putrefy readily. Many industrial effluents have, however, quite a different composition. Definite information on this point cannot be given, since it is dependent wholly on the nature of the manufacturing process.

Although the particular methods of purification are capable of equal application in their main features to both classes of sewage, the kind of purification necessary for normal domestic sewage is always the same, while for industrial effluents, quite frequently, variations in the processes occur, adapted to the individuality of the sewage coming at the moment into question. A distinction between the methods of purification for domestic and industrial sewage is therefore to be recommended.

A. Purification of Domestic Sewage.

The different methods for the purification of domestic sewage may be thus distinguished :—

Mechanical purification (rakes, screens, sieves, grease extractors, grit chambers, settling-tanks, settling-wells, septic tanks, Travis and Emscher wells).

Coal-pulp processes.

Artificial biological purification (contact beds and percolating filters).

Land treatment (broad irrigation or sewage farming and intermittent filtration).

And lately also fish-ponds.

Mechanical methods of purification aim solely at the separation of suspended matter. They have no action on dissolved substances.

The coal-pulp method, on the contrary, has a small influence on the dissolved matter, whilst the artificial biological processes and land treatment remove dissolved substances so largely that the water loses its capacity to putrefy. There is consequently this distinction between sewage purified mechanically and that purified biologically, that the former becomes foul on standing, whilst the latter is incapable of so doing. Mechanical methods of purification are therefore applied in those cases where, owing to the nature of the river into which it is run, the sewage need only be partially purified. Dilution with large quantities of river-water prevents a mechanically purified sewage from becoming foul. Where the ratio of river-water to sewage is small and the dilution does not guarantee that the purified sewage will not putrefy, biological treatment must be adopted, in which case land treatment is generally superior to artificial biological processes.

I. MECHANICAL PURIFICATION OF SEWAGE.

(i) *Rakes, Screens, and Sieves.*

Apparatus of this nature serves to separate the undissolved substances over a certain size. Of first importance are the coarser floating substances such as paper, vegetable leaves, orange-peel, match-boxes, corks, etc., which are removed from sewage by this treatment. According to Fruhling, one understands by screens all the particular varieties of such devices for removing coarse suspended matter, such as bear the particular names of bar-screens, sieve-screens, grating-screens, etc. Bar-screens consist of bars set parallel to one another, grating-screens of wires crossing each other, and sieve-screens of a network of wires or of perforated metal plates.

There are both coarse and fine screens. Coarse screens are mostly iron rods about 10 to 20 centimetres apart, obliquely placed at an obtuse angle to the surface of the water. These only serve to keep back the coarsest suspensions, such as tin boxes, the larger pieces of wood, large pieces of entrails, large rags, and the like.

Fine screens are generally stationary, or automatically moving apparatus. Stationary screens are mostly bar-screens, also

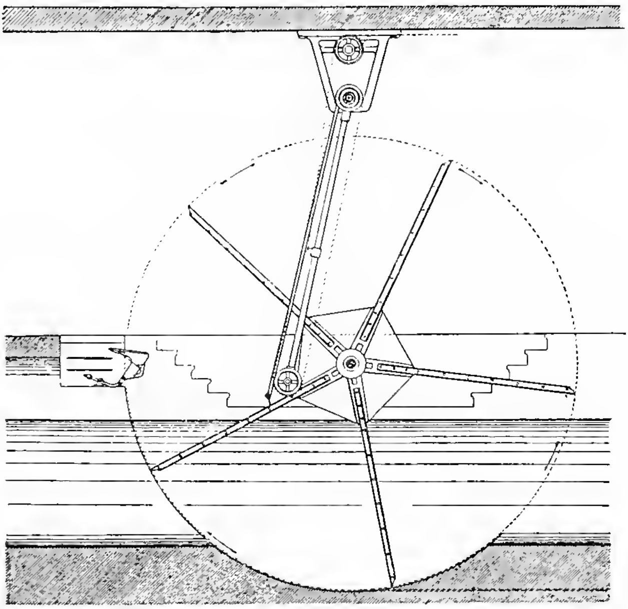

Fig. 13. Uhlfelder's Revolving Screen.

consisting of bars laid alongside one another, and placed at an obtuse angle to the surface of the water. The distance of the bars apart is, however, considerably less than with coarse screens, usually between 10 and 25 millimetres. The water flows against these bars and leaves there substances of larger size. Movable screens differ from the stationary type in that they are driven through the water and fish out the floating material. Of the best constructed and most frequently used movable bar-screens in municipal clarifying plants (Frankfort, Elberfeld) is the Uhlfelder Revolving Screen (Fig. 13). It is a circular revolving screen, composed of five single screens, which rotate uniformly against the current of water. The coarser matter floating upon or suspended in the water is removed by the screens while in motion and is raised out of the water. An automatic brush follows which, pressing through the screen, brushes it outwards and casts the material on to a platform underneath. This is then tipped up by the motion of the screens and empties the contents on to a travelling platform which carries the material away. With such

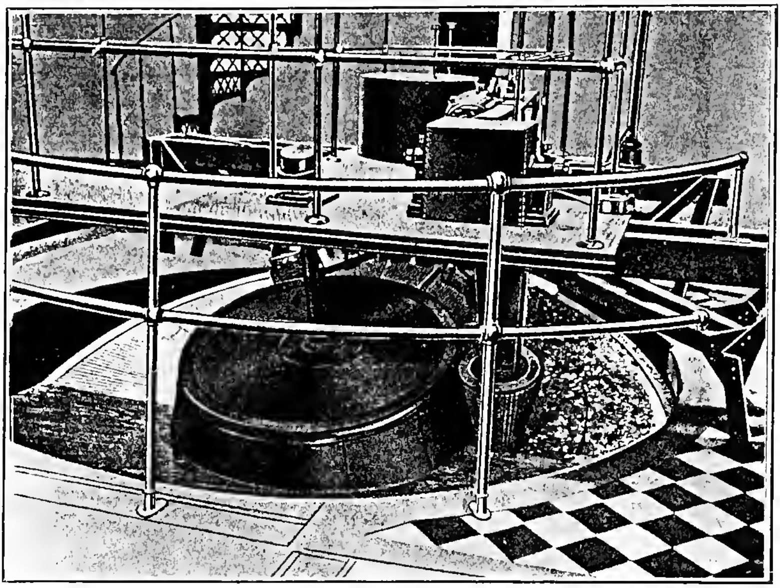

FIG. 14. RIEN SIEVE.

screens the work is purely automatic and the purification mechanical. Other kinds of screens may be cleaned by hand.

Among automatically working sieve-screens the Rien has frequently been employed. It is used to screen Dresden sewage, which is then run into the Elbe without further treatment. The Rien apparatus, as is shown in Figure 14, consists of a metal disc set obliquely in the water and composed of sheet-metal sieving or sieve plates. In the centre of the disc there is placed a truncated cone of the same material. The water flows against the disc, which is continually turning. As a consequence the suspended filth remains on the disc, whilst the water passes through the openings. Owing to the motion of the disc, the sludge is removed from the water, and then scraped away from the screens, and from the truncated cone also, by means of brushes.

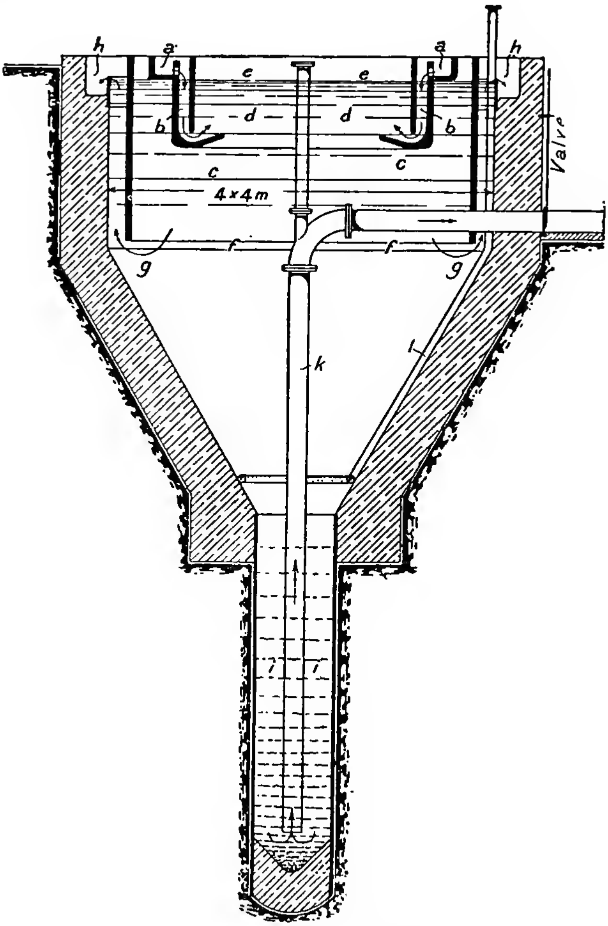

FIG. 15. KREMER APPARATUS.

a, Inlet channel. *b*, Lateral inflow pipes. *c*, Space for attaining an upward thrust in the water. *d*, Grease extractor. *e*, Floating layer rich in fat. *f*, Clarifying space. *g*, Reversal of the direction of the water at the edge of the circular partition. *h*, Circular overflow channel, an outlet for the clarified water. *i*, Sludge cylinder. *k*, Sludge drain. *l*, Cleansing pipe.

(ii) *Grease Extractors.*

Many effluents, such as those from slaughter-houses, kitchens, and other similar places, contain a large amount of grease. Since the fats are lighter than water they cannot be separated in grit-chambers, settling-basins, and other contrivances. They can, however, be removed from sewage in grease extractors, and in certain circumstances these allow of a recovery of the grease.

There is a whole series of plants for the recovery of grease. The best known of these is the Kremer apparatus. This apparatus

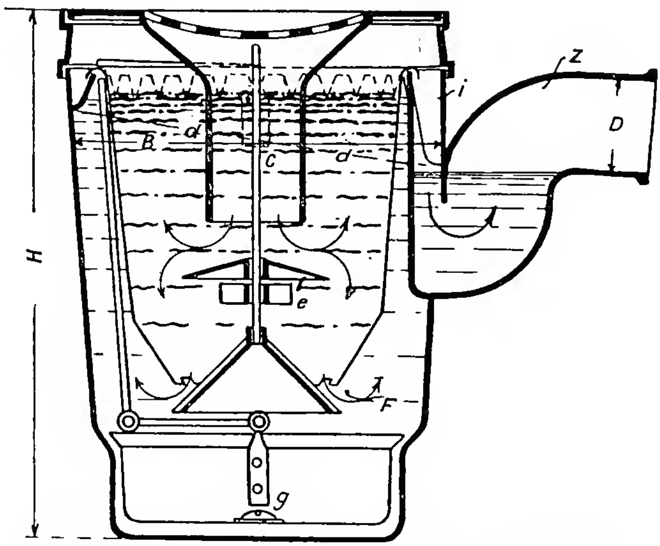

Fig. 16. Grease Extractors of the "Städtereinigung Firm" of Berlin-Wiesbaden.

can also be used independently as a clarifying plant, since it also separates from the sewage any suspended matter that is heavier than water. The apparatus (Fig. 15) separates the undissolved substances by means of a peculiar motion of the stream working in such a way that the substances are divided into two layers of sludge, according to their specific gravity. Grease particles adhering to light organic matter form the upper floating layer, whilst the lower layer is composed of the heavy particles of suspended matter. According to Vogelsang, the Kremer apparatus is to be recommended strongly for preliminary purification with the biological processes, since it separates much of the light suspended matter, such as grease, paper, straw, and the like, which cannot be removed by sedimentation processes, and which consequently choke up the contact beds and percolating filters with mud. The "Gesellschaft für Abwässerklärung" (Sewage Clarifying Co.), of Berlin-Schöneberg, supply this apparatus. The firm also employ them in combination with Emscher wells (see page 82 in this book). They call the combination the Kremer-Faulbrunnen (Kremer septic well), and warmly commend its great utility.

A grease extractor of another type is that of the "Städtereinigung und Ingenierbau A.-G." firm of Berlin-Wiesbaden. As shown in Figure 16, the greasy water enters through the funnel *c* into the space *d*, where by means of a deflector *e* it is uniformly divided and diverted in direction upwards. The particles of grease have time to separate out in the upper parts of *d*, whilst a quantity of water in the space *d*, corresponding to the inflow from above, passes out below through the circular opening *F*. The sludge sinks lower and falls eventually into the sludge-pail *g*, whilst the water, freed from grease and mud, rises to the brim of the reservoir and, overflowing at *i*, passes into the outlet pipe at *z*.

Of other systems the grease extractors of Kaibel, Darmstadt, of Kremer-Schilling, and of Heyd, Darmstadt, may also be named.

(iii) *Grit Chambers.*

Many plants for preliminary purification also make use of grit chambers. Whilst screening removes the coarser floating matter, grit chambers are intended to separate the heavier and coarser sinking suspensions. This is attained by allowing the pipe conveying the water to the clarifying plant to suddenly discharge its contents into a larger space known as the grit chamber. As a result, the velocity of the sewage, owing to the increase in cross section of the chamber, is quite considerably reduced. Consequently the coarse suspensions, like rags, bones, sand, and such-like, settle to the bottom. The cross section of grit chambers varies greatly. They may be funnel-shaped or rectangular, or they may have arched bottoms, etc. The mud which settles is removed either by hand or mechanically, and the removal may take place either after emptying or during the process. The mechanical sludge-remover generally consists of a dredging-machine, which dredges the sludge and casts it on to a travelling platform. With grit chambers built funnel-shaped, the dredger can remain standing in the one place. With other forms the dredger can often be moved from one end of the chamber to the other, as at Frankfort-on-Maine. According to the investigations of the author in Frankfort, with a good grit chamber and a system of fine screens, about one-fifth of the total suspension in a sewage is removed.

(iv) *Sedimentation Tanks, Wells, and Towers.*

These contrivances serve for the deposition of the finer suspended matter. The sewage is simultaneously introduced into a number of such tanks or wells, so that, owing to the increased cross section, the velocity of water is very considerably diminished, and consequently the finer particles of suspended matter can settle to the bottom.

Sedimentation tanks are generally elongated rectangular chambers, constructed either open or covered, though they are most frequently open. They are generally about 40 metres long, but there are, however, sedimentation tanks considerably shorter and longer. The inflow generally occurs through openings situated below the surface of the water, in order that the already precipitated sludge shall not be disturbed by the motion of the water. The beds of the tanks are built both rising and falling towards the outlet. According to the researches of Steuernagel and Grosze-Bohle, the rising bed has proved satisfactory for sedimentation work. Generally at either inlet or outlet, or even at both places, sump-pumps are placed to pump away the deposit which collects there. The Frankfort sedimentation tanks are 40·6 metres long and have pumps at 7·5 metres distance from the inlet and outlet. The chamber bottom is so constructed that in the middle it is raised and falls away with a fall of 1 in 10 to the sumps. There is the same fall from both inlet and outlet. This arrangement of the chamber bottom serves to lead the mud of itself to the pumps, through which it is removed. This renders superfluous the cleaning of the tank bottoms with shovels or similar contrivances. In Figure 17 the form of the Frankfort sedimentation tank is shown in cross section.

It was formerly thought that to effect good sedimentation the chambers must be built so large that the velocity of the water

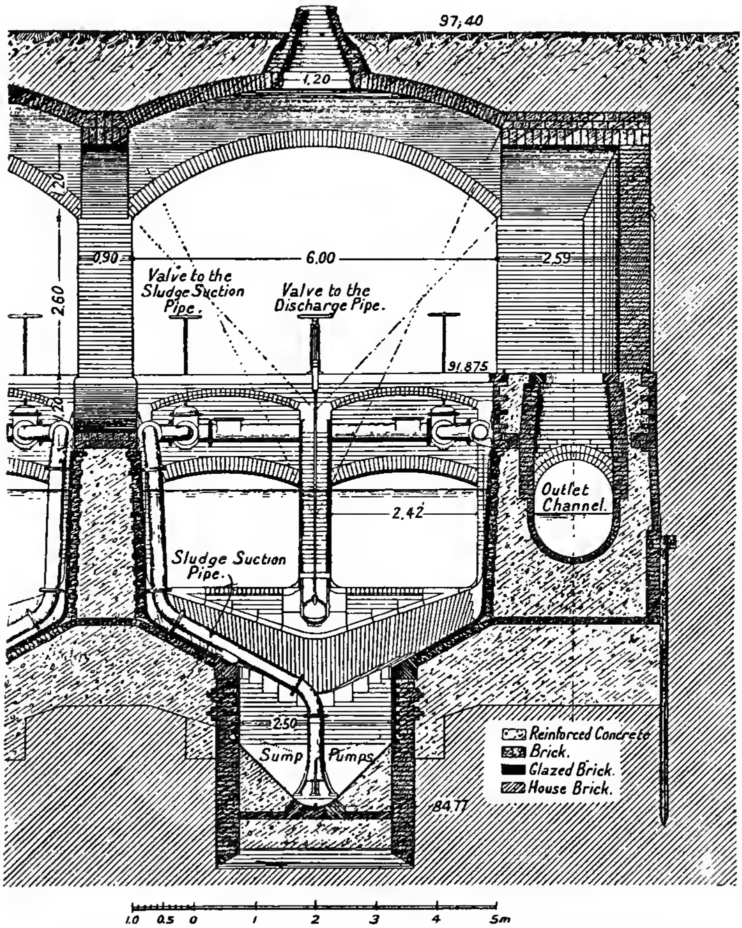

FIG. 17. FRANKFORT SEDIMENTATION TANK (CROSS SECTION).

would be extraordinarily small (2 to 4 mm. per second). Experiments of Grosze-Bohle in Cologne have shown, however, that with a velocity of 20 to 40 millimetres the same sedimentation is attained. Also in Frankfort it could be demonstrated that the abnormally small velocity of 2 to 4 millimetres per second gave no better results than one of 12 millimetres per second. With higher velocities than 12 millimetres per second considerable diminution of the sedimentation was obtained, so that one cannot generalise on the results from Cologne without further details. According to Schiele, in England they still keep quite generally to the small velocity of 2 to 4 millimetres.

In the settling tanks there also separate out a number of floating substances which are composed firstly of the fatty matter in the sewage, and secondly, especially when the tanks have been in use for a long period, of particles of sludge rising up on account of fermentation. In order to avoid admitting these floating particles into the outlet, a board is generally partially immersed in the water and set obliquely a short distance in front of the outlet. The particles collect in front of this.

The mud is generally disposed of first by running off all the water. The sludge is then pumped away from the slime deposit. In some sedimentation plants sludge-pumps working under water might be tried; these naturally would be advantageous in that the sludge could then be removed during the sedimentation process without the chamber that is to be purified being emptied. In general, however, sludge-pumps do not appear to have worked well. The main difficulty lies in this, that the sludge does not slip along sufficiently towards the pumps; on the contrary, a crater is often formed in the sludge and the sewage is suddenly sucked over instead of the sludge.

The settling process is frequently assisted by the addition of chemicals. Alum and lime, or ferrous sulphate and lime, and other substances are used. The principle upon which the use of these substances is based is as follows: The chemicals form gelatinous and voluminous precipitates (alum + lime = gypsum and aluminium hydroxide), which on sinking to the bottom carry the suspended matter along with them. The chemicals have also a slight action on the dissolved organic matter. This action, according to some, will be insignificant in itself, the main action being the assistance which the chemicals render towards settling out the suspensions. With domestic sewage the action of chemicals is frequently denied. Thus, parallel experiments have been carried out by Lepsius and later by Freund in Frankfort-on-Maine with chemical precipitation and with purely mechanical sedimentation, by which it was established that the influence of chemicals on sedimentation was practically insignificant. According to Schiele, however, in opposition to this view, the addition of chemicals to domestic sewage is still practised in England. In the author's opinion chemicals certainly have an effect on the dissolved substances, and also act in the case of domestic sewage on the pseudo-dissolved substances, the colloids, to no inconsiderable extent. Aluminium hydroxide and ferric hydroxide are, as is well known, also colloids, and have an adsorbent action on the colloids in the sewage. Frequently, addition of chemicals to industrial effluents must be made. The main drawbacks to the addition of chemicals are the considerable increase in cost of the sedimentation process, and the difficulty of disposing of the sludge. The sludge obtained when chemicals are used is, in the first place, far more aqueous, and so takes up much more room, while secondly, on account of the sludge containing chemical substances, which at least are indifferent from the manurial point of view, it is considerably depreciated in value as a manure. The amount of chemicals added varies greatly according to the composition of the sewage to be purified. It varies between about 43 and 950 grammes per cubic metre (7 to 150 oz. per 1000 gallons) of sewage. The chemicals are added either in the liquid or solid state. In the liquid form it is allowed to flow into the sewage in a thin stream. When applied in solid form the chemicals are added to the water in wire baskets, so that the water flowing through dissolves out the chemicals. For these to work properly it is of great importance that care be taken to get good mixing between chemicals and sewage. If there be sufficient space between the place of addition and the settling tanks, the water itself ensures adequate mixing. Now and again, however, various devices are employed to attain good mixture. Thus, tongues are placed in the sewage-pipe, by which means the water is broken up.

The amount of suspended matter separated out, expressed as a percentage of the total content of suspended matter in the crude sewage, amounts, with good sedimentation tanks and not too high a velocity (12 mm.) in the basins, to 60 or 70 per cent.

Sedimentation wells and towers are generally cylindrical in form and are distinguished essentially from tanks in that the water flows through them upwards and in a vertical direction.

whereby the suspended matter settles out underneath. In such sedimentation reservoirs the velocity of the sewage is generally considerably less than in sedimentation tanks. With towers and wells the sludge can be removed more easily while the process is in operation than is possible with tanks, since it is in such cases more conveniently concentrated into a certain space. To guard against the water breaking through (see page 76), various constructions have been proposed, based on the closing of the water space whilst the sludge is being pumped off.

(v) *Septic Tanks.*

Septic tanks are only employed as preliminary purifiers in biological purification plants; they do not come into consideration as separate clarifying plants. They are employed in a manner similar to the usual sedimentation tanks, but with the difference that the sludge which separates out is allowed to lie for a long period. It is thereby converted into a foul state of fermentation, which is then communicated to the sewage. The sewage is coloured black, owing to the presence of ferric sulphide, and assumes a very foul odour. As a result of the activity of the fungi setting up putrefaction a portion of the organic matter is decomposed. There forms on the septic tank after a short time a scum consisting of grease mixed with particles of sludge raised by the fermentation. This scum shuts off the air from the sewage, and is of great importance in the putrefactive action which is caused by anaerobic bacteria. In some English septic-tank installations the floating layer, according to Schiele, now and then becomes so strong that one can actually walk upon it.

Moreover, these septic tanks act like sedimentation tanks as regards removal of suspended matter. With the slow passage of the water through the septic tanks the suspensions settle out. A certain amount of time always elapses before a septic tank is in good working order, that is, until it yields a thoroughly putrefied effluent. Septic tanks are built both open and covered. The open tanks have the drawback that they cause annoyance from their smell. Septic tanks, according to Schiele, must be capable of holding at least half a day's dry-weather drainage. Smaller plants are generally built large enough to hold from three to six times the dry-weather discharge.

Naturally the removal of sludge takes place less frequently in this case than with the usual settling tanks. It is useful never to remove the whole of the sludge, but always to leave some still lying; the tank then gets into working order afresh more quickly, because the putrefactive fungi from the thoroughly putrefied sludge can more easily communicate themselves to the sewage.

The main advantages of septic tanks may be thus noted. In the first place, the sludge need not be removed so often, which naturally means cheaper working; and secondly, the sludge from septic tanks, especially according to the results of recent work, is by no means so disagreeable as the sludge from the usual sedimentation tanks. It is more easily freed from water and contains a considerably larger bulk of dry substances. These relations will be more carefully dealt with in the chapter on sludge. As a further advantage of septic tanks, there has to be considered the decomposition of a portion of the organic substances which, from the observations of Dunbar and his pupils, takes place both in the sewage and the sludge.

With septic tanks there is the disadvantage that the effluent is not so completely freed from suspended matter as with sedimentation tanks. Owing to the fermentation set up in the sludge, fine particles are propagated upwards and so pass into the discharge. Since suspended matter vitiates bacterial action in contact beds and percolating filters to a considerable degree, and also causes their more rapid pollution, sieves are often placed in the discharge-pipe to check this annoying feature.

(vi) *Travis and Emscher Wells.*

These apparatus are distinguished from sedimentation and septic tanks by the separation of the sludge from the actual sedimentation space.

According to Collins ("Surveyor," 1909), the Travis plant in Norwich consists of rectangular tanks, whose lower parts are wedge-shaped in cross section (see Fig. 19). Lengthways in each tank a roof is built, which is cut open at the coping in the long axis of the tank and is carried upwards above such axis. Where the roof is joined to the tank-walls and to the coping, gaps are left. Through these gaps the three compartments of the tank, arising out of the mode of construction, are in communication with one another. Both the outer compartments serve as sedimentation compartments. The sludge on settling out slides down the sloping surface formed by the roof and falls through the gaps into the middle section of the tank, the reduction or sludge chamber. In the central portion of the settling tank there are placed grating-like frames (colloiders) about 10 inches from each other. These devices should serve to retain and to exert a certain coagulating influence on the colloids; 80 per cent of the sewage enters through the two outer settling tanks, whilst 20 per cent enters the reduction chamber or sludge area through the openings at the coping of the roof. The water passes out over

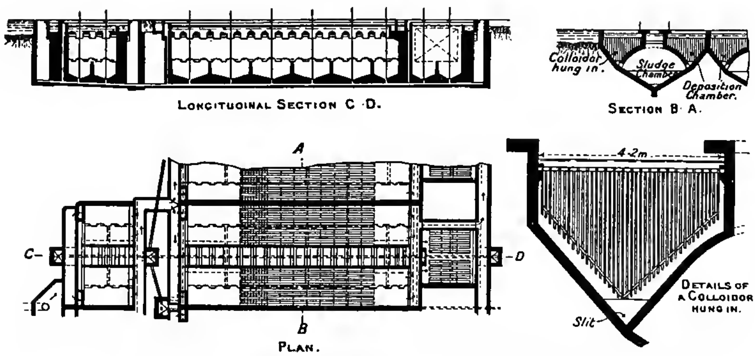

FIG. 18. CLEARING WELL INSTALLATION AT NORWICH ON THE TRAVIS HYDROLYTIC SYSTEM, WITH COLLOIDER HUNG IN.

(From "Wasser und Abwasser," 1909-10, II, 71.)

a weir which occupies the whole breadth of the tank, and which, corresponding to the three tanks, is three-sided. The effluent from the liquefying chamber is subsequently purified in a special tank provided with "colloiders" like the sedimentation tank. The removal of sludge, necessary from time to time, is conveniently attained by having the bed of the sludge chamber composed of a number of funnels. The walls of these funnels are so inclined that, on opening the outlet situated at the lowest point of the shoulder, the sludge is pressed out by means of the pressure of water above.

Travis tanks have come into use considerably, especially in England, and presumably have proved excellent. The main difference between the Travis tank and Emscher wells consists

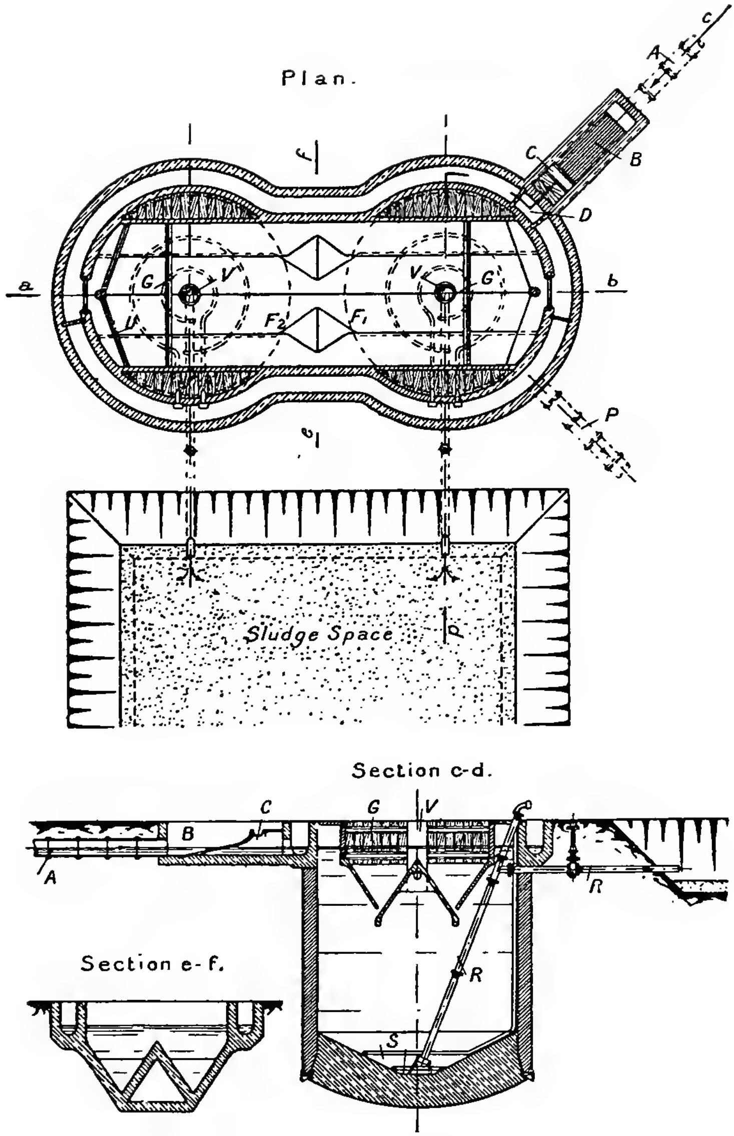

FIG. 19. EMSCHER WELLS.

Arrangement of several wells with settling channel in common. Removal of sludge by excess water pressure to the lower lying sludge storage grounds.

A, Inlet. *B*, Screening chamber. *e*, Channel for screenings *u*, Circulating channel. *P*, Outlet. *D*, Fume Chamber. *G*, Partitions. *u*, Waste-weir. F_1 and F_2, Liquefying chambers. *R*, Sludge pipe. *S*, Cleansing pipe.

in this, that with the former from time to time fresh water is purposely led through the liquefying chamber in order to remove the liquid constituents of the sludge generated by the putrefaction. With Emscher wells the principle is to avoid any flushing of the liquefying chamber.

Emscher wells (Fig. 19) consist in the main, according to Middledorf, of deep wells which are intended for the reception of the sludge. In the upper part of these wells by means of a partition-wall a settling tank or well is apportioned off, and through this the water flows. As soon as it touches the sloping bottom the sludge, settling out in the tank, flows of itself through gaps at the lowest parts of the sedimentation space into the sludge wells. The water flows only through the sedimentation area and, in agreement with the principle, not through the putrefactive area. The putrefaction is thereby confined to the sludge alone, and the water flowing away is obtained as fresh as possible, unmixed with any of the polluted water. The amount of water from the sludge which gains access to the sewage should amount to about one part in a thousand. With variation of temperature also there should be little tendency for water from the sludge to rise into the sedimentation tank, since it is specifically heavier than fresh sewage. As the sludge from the settling tanks is withdrawn uninterruptedly and automatically, there is absolute certainty that it is always removed at the right time and does not remain lying in the settling tanks, injuring the clarifying process by its foulness. The particles of mud propagated upwards by fermentation cannot pass through the clefts in the partition-wall, but are forced against the wall underneath the sewage and sink again from there to the bottom. The sedimentation in Emscher wells should be equally as good as with other good settling plants with the same period of sedimentation. The sludge putrefies in the liquefying chamber, and thereby becomes more suitable for disposal (see under Sludge). The fact that water is not allowed to flow through the chamber has not proved a hindrance to the putrefaction of the sludge. It is because of this that the freshness of the water to be purified is maintained, and it may be reckoned an advantage in the process. With Emscher wells, in contradistinction to other liquefying chambers through which the water is allowed to flow, scarcely any trace of sulphuretted hydrogen is evolved. According to the investigations of Spillner, the gases which escape from the liquefying chamber and pass both through the sewage and around the sedimentation tanks consist mainly of methane and carbon dioxide. Odourlessness of the sludge should be attained equally well with purely domestic sewage purifiers, and with plants receiving industrial effluents. The sludge is led through pipes from the liquefying chamber to the sludge drying-place. The end of the pipe reaches to the lowest point of the funnel-shaped bed of the well. Only the underneath portion of the most thoroughly putrefied sludge is led away. If the area for drying the sludge can be situated from 1·5 to 2 metres lower than the water-level in the wells the sludge can then be removed by the natural fall, since for this purpose a head of 1 metre is generally sufficient. If this head cannot be obtained the sludge is removed either by a Wagner suction apparatus, with a hand or air-pressure pump, or with a vacuum plant driven by an air-pressure pump. In all plants of the Emscher Co. the sludge should be displaced through the sludge-pipes without any difficulty. The reason for this is largely because the sludge during the septic action loses its felt-like nature and forms a black, pulpy, fluid mass, in spite of its low percentage of about 70 to 80 per cent water. The removal of the sludge takes place perhaps once every two or three months. The liquefying chamber should be so large that it can hold the sludge falling in during this length of time.

Meanwhile, the question of Emscher wells has been vigorously debated in the literature. In the main the following points have been contested: Whether the plant is practically odourless; whether the sedimentation is as good in Emscher wells as in other good sedimentation plants; whether liquefaction actually occurs in the sludge; whether the water remains at rest in the liquefying chamber, or whether rather, just so much of the polluted water from the liquefying chamber enters the sedimentation tank as sludge separates out.

It must be pointed out, however, that Emscher wells are coming more than ever into application, both as separate sedimentation plants and also as plants for the preliminary purification of sewage about to be bacterially treated.

The main advantage of Travis and Emscher wells over the usual sedimentation tanks is therefore the simplicity with which the sludge problem is solved.

"There is this great advantage in a joint plant working with automatic separation of sludge. A small velocity of sedimentation can be chosen without the process becoming more difficult as regards the handling and disposal of large amounts of thin sludge containing high percentages of water, such as generally settle out under such conditions" (Schmidtmann, Thumm, and Reichle).

II. DEGENER'S COAL-PULP PROCESS.

As regards the nature of its action, this method stands midway between the mechanical and the bacterial methods, for like the former its main action depends on the removal of the suspended matter, and like the latter it has an undoubted action on the dissolved substances.

1 to 2 kilograms of ground-peat or 2·5 to 4 kilograms of turf are added to a cubic metre of the sewage to be purified. Chemicals, such as aluminium or ferric sulphates, are simultaneously added. Generally, the sewage is then allowed to settle in sedimentation towers. The sludge is fairly aqueous, but is usually freed from water in filter-presses, and in this case is then no longer capable of putrefaction. The air-dried sludge, on account of its high carbon content, is a valuable burning material. Lately it has been rendered more valuable by gasification (see under Sludge).

The whole process should work without smell, and on this account, and because the troublesome sludge question with its dangers is obviated, it is a method of great importance. The further advantage of a reduction in the dissolved organic substances has been referred to previously. Against these advantages there is the main disadvantage of cost, which is very considerable. It is because of this that the number of plants working the process on a large scale remains so limited, in spite of the method being so superior.

III. BACTERIAL PURIFICATION OF SEWAGE.

As already mentioned, the dissolved organic matter is unchanged in a mechanically purified sewage. If such an effluent be allowed to stand for some time it very soon begins to putrefy and, from the plentiful development of putrefactive bacteria, assumes a stinking condition.

The task of bacterial sewage purification is so far to remove the dissolved organic matter from the sewage that putrefaction, with its accompanying disagreeable phenomena, is avoided. As the name indicates, in bacterial purification processes bacterial agencies come into play.

In particular two processes are distinguishable, viz. artificial biological sewage treatment, and broad irrigation or sewage farming.

(i) *The Artificial Biological Method.*

Artificial biological sewage purification is the designation applied to that treatment whereby, after suitable preliminary purification by mechanical methods as detailed in Part I, the sewage is led over large pieces of slag, coke, or similar materials. The organic matter is by this means so far removed from the sewage as to prevent subsequent putrefaction in the effluent.

Biological processes for the treatment of sewage arose in England, where they were first used and tested on a large scale. That this method was first improved in England is quite reasonable, since England is the classic country for sewage disposal. In consequence of the peculiar circumstances operating there, its position as the premier country in the world, England was compelled to work out good methods of sewage purification. The largest English rivers have not the capacity and velocity even of our Spree or Havel (tributaries of the Elbe, *Trans.*). With industry flourishing in the middle of the last century there went hand in hand alarming pollution of the whole river system of England.

Thorough preliminary purification is of vital importance for the continued good working of biological processes. Grit chambers, screening, and the mechanical purification involved in sedimentation and septic tanks, all come into consideration. For domestic effluents the sewage is generally first purified in sedimentation or septic tanks. If much industrial effluent be admixed with the household sewage, chemical treatment is generally indispensable. Moreover, it is advisable to find out in each case, by special experiments, the most suitable preliminary treatment for the sewage.

Many substances are used as material for the beds employed in these biological processes. Clinkers from refuse destructors, slag, earthenware, bricks, coke, pieces of slate, and such-like materials have all been tried. According to Schiele, the main requirements in such a material are great hardness, capacity to withstand the action of sewage, roughness, and firmness.

Large beds are laid down composed of lumps of these materials loosely collected together. Distinction must be made between contact beds and percolating filters. The distinction between the two lies in the manner of their impregnation with sewage. Contact beds are filled with sewage; the sewage remains for a period of time lying in the beds and is then led away again, by which means air is sucked into the beds. With percolating filters the sewage is continually percolating through the beds. The size of the pieces of material used should be about 3 to 8 millimetres ($\frac{1}{10}$th to $\frac{1}{3}$rd in.) in the case of contact beds, whilst with percolating filters it is considerably larger, amounting to 15 to 75 millimetres ($\frac{1}{2}$ to 3 in.), and there are even larger in use (Schiele). With contact beds there are two processes, known as single-contact and double-contact treatment. In the single-contact process treatment is complete after leaving the bed. In the double-contact process the sewage from the primary bed is delivered to a secondary bed. The material of a primary bed is coarser in grain than that of the secondary bed. Percolating filters are generally worked with single contact.

As with septic tanks, so here the beds have to be prepared for the work in order that in course of time they cease to yield effluents capable of putrefaction. The time for this process to take place may amount to some months. It is generally shorter with percolating filters than with contact beds, and depends on the gradual formation of a slimy layer on each piece in the bed, a discussion on the nature of which layer will be detailed below (see page 89). Contact beds are so worked that they are filled with sewage, which is then allowed to stand some time in contact with the beds, and then to drain away. The sewage is generally led on to the contact beds from above, and is drawn off from underneath. After each impregnation contact beds must be allowed to stand some time, in order to work up the substances taken from the sewage. In England good results have been obtained with the beds full for two hours and standing empty four hours (Schiele). In practice single-contact beds can be impregnated twice per day, double-contact beds three times daily. According to this, 1 cubic metre of single-contact bed can be treated with, at most, 0·66 cubic metre of sewage, double contact with 0·5 cubic metre per day.

Percolating filters can be continuously impregnated with sewage without the purifying action falling off.

The beds are either built in the ground or on the ground. It is important for good working that they should be maintained at uniform temperature. They should therefore be protected under certain circumstances against cold in winter.

Contact beds are generally rectangular; percolating filters are either rectangular, octagonal, or circular in shape.

In the case of contact beds the water is distributed on to the beds in a very simple manner. It takes place through feed channels, perforated clay, or stoneware pipes, open, perforated drains, perforated gutters, and other devices. With contact beds good uniform distribution is not by any means so important as with percolating filters. In the case of contact beds the main concern is the quickest possible filling. They are generally filled and emptied by sluices and valves worked by hand. Frequently there are also automatic devices for filling and emptying. Uniform distribution is, however, a matter of very special importance in the case of percolating filters. The number of devices invented to attain this is almost legion. There are sprinklers, movable revolving sprinklers, stationary perforated pipes, portable sprinklers, etc.

In general, according to Schiele, with regard to distributors for percolating filters, the following can be said: The system employed must always be adapted to local circumstances. It is most suitable to carry out experiments beforehand. In Birmingham the following requirements were demanded of a good distributor :—

(1) Uniform distribution, so that each portion of the surface of the bed contains precisely the same quantity of water.

(2) Distribution in the form of drops.

(3) Absolute control over the distributor.

(4) Limited cost of plant.

(5) Small working expenses.

(6) As few movable parts as possible.

(7) Small consumption of power in distribution.

With regard to the water-pressure necessary for working, fixed sprinklers are at a disadvantage when compared with the automatic revolving sprinklers. The revolving sprinklers are found in English experience to be limited to a bed of 30 metres diameter, or at the most 35 metres. When they are to be worked mechanically, large rectangular beds with movable or fixed sprinklers prove more useful and advantageous than circular beds with revolving sprinklers. In Germany automatic revolving pipe sprinklers, with a bed 20 metres diameter and perforations every 10 millimetres, have proved the best for withstanding strong cold in winter. In England at the present time stationary sprinklers, especially the Fiddian type, are being increasingly employed.

Contact beds and percolating filters are on the whole to be regarded as of equal value. Both have their advantages and disadvantages. The advantages of contact beds are: Simple distribution of the sewage on to the beds, small trouble due to smell, no plague of flies, little suspended matter in the discharge; small need for a head of sewage on account of the small depth of the bed, greater certainty of working in the cold weather. As opposed to these the main advantages of percolating filters are: Greater mechanical power than with contact beds; since the beds can be built higher smaller space is necessary; coarse-grained, cheap material; little attention. Whilst contact beds are always gradually getting choked with sludge, and on this account need purifying more frequently, percolating filters do not get choked with sludge, or at most with very little. Percolating filters also withstand an overload of sewage in rainy weather, since the admittance of air is never quite cut off. On the contrary, percolating filters always contain a great deal of suspended matter, and the discharge must be subsequently freed from this. In percolating filters small flies establish themselves in extraordinary numbers. Especially is the Psychoda (the butterfly gnat) to be noted. Further, smells are never quite avoided in the treatment of sewage with percolating filters. After the invention of percolating filters one often heard the opinion expressed that contact beds would soon disappear. This view has not proved correct. For the purification of sewage in large towns it is true that percolating filters have proved themselves superior to contact beds, since all the above-named advantages of percolating filters mean cheaper cost of construction and of upkeep. For the centralised clarification plants of towns, therefore, percolating filters are nowadays generally erected. Still, even in the most recent years in England, in large towns like Manchester, contact beds have been put down and have proved excellent. They are especially suitable where the proximity of places of residence, as, for example, with small domestic or manufacturing plants, compels one to avoid smell or flies.

As has been already mentioned, the percolating filter effluents always contain large amounts of suspended matter which are washed out of the beds. These substances differ greatly from those in the raw sewage, in that they are not capable of putrefaction. They impart to the purified water an objectionable appearance, and would lead to the deposition of sludge in the river; consequently percolating filter effluents are always subsequently clarified. In England this is frequently effected by land irrigation (1 acre to 1000 inhabitants). Generally, however, the discharges are subsequently treated in simple sedimentation tanks or wells. Since the sludge is no longer capable of putrefaction, it is easily freed from water and its disposal causes no difficulty.

The cost of sewage treatment by the biological process varies greatly. The price of material for the beds varies, according to Schiele, from 3 to 12 marks per cubic metre (2s. 6d. to 10s. per cubic yard), whilst 1 cubic yard of ready-prepared material costs from 5 to 35 shillings. The cost of the bed in England cannot, as a rule, be less than 15 shillings per cubic yard.

As to the nature of biological purification of sewage there exist two views. According to one, which is put forward by Baurat-Brettschneider of Charlottenburg, and which in its essentials coincides with the so-called Hampton doctrine championed by Travis, the whole so-called biological sewage treatment consists of nothing more than a filtration of the organic filth, which, in the main, would be present in the colloidal form in sewage (together with the greater part of the so-called dissolved substances). This theory is opposed to that of Dunbar and his pupils, according to whom biological sewage purification is to be explained in the following manner: Each single portion of the bed is gradually covered with a slimy surface of bacteria and other organisms. During impregnation the greater part of the organic matter is adsorbed by this covering. The film also adsorbs oxygen in large quantities. With the help of this oxygen and of the oxygen otherwise entering the bed, the adsorbed substances are decomposed by the organisms in the intervals of rest between each impregnation. This theory is supported by numerous experimental data, so that there can be no doubt as to its truth.

(ii) *Land Treatment.*

Treatment of sewage on the land is the oldest form of sewage treatment. Within the memory of man it has always been known that the surface of the earth was able to remove the evil smell of sewage and to make polluted water pure.

Two methods of land treatment must be distinguished, namely, broad irrigation or sewage farming, and the intermittent sand filtration of Frankland.

(a) *Sewage Farming.*

Broad irrigation or sewage farming was first practised in England. To-day there is still in existence an irrigation bed that has been in use two hundred years. As is well known, sewage contains a number of substances which are valuable as nutriment for plants (nitrogen, phosphates, potash). The irrigation process makes use of this fact, and on the farms all kinds of useful plants are grown. Thus by this method of sewage disposal, the sewage is purified and use is made of the nutritious substances present in it.

In England alluvial soil is considered to be the best for sewage farming. Soil lying over high waters generally in river valleys, or sandy loam over gravel or gravelly sand, or even gravelly, sandy subsoil with light or medium mainsoil about 40 centimetres deep, are all good. Gravel without a finer covering layer serves also as regards permeability (Schiele). The poorest earth is clay, loam, clayey soil and turf. Clayey soil, since it is not permeable, can only be used for the so-called surface or rude irrigation.

According to Dunbar, there are two main kinds of irrigation processes. In the first kind the water flows down from the highest point of the land. After trickling over the surface of one field it is collected into a ditch, from which it is again uniformly distributed over the next field. With a sharply inclined tract of land, dams must be thrown up to retard the flow of the sewage and to distribute it afresh. When the track is not so steep the operation is carried out in the following manner: The sewage flows from the distributors, passing transversely from the irrigation plant into smaller trenches arranged perpendicularly to the larger. These are dammed up at the ends so that the sewage must overflow from the trenches at the sides. It then flows over the sloping surfaces of meadow into lower lying ditches. Then from these second distributing ditches, in precisely the same manner, the water is again distributed over a second series of meadows. This process is generally used for surface irrigation only, and in those cases where the land lies so low that it cannot be drained. A good drainage is not usual, therefore, with the plant.

In Germany and also in France, as far as possible, it is endeavoured to lay out sewage farms on the principle known as bed irrigation. In this process surface treatment with sewage is done away with, as the water passes through the ground. It is therefore true irrigation. The sewage is led on to the farm in ditches. The distributing canals are only allowed to fill so far with sewage that this has to pass into the bed sideways and below the surface. Wetting the stems and leaves of the plants is thus avoided. The beds are usually only 1 metre broad by 20 to 40 metres long, as otherwise uniform distribution of the sewage cannot be attained. In this process many distributing ditches are required, and also paths from which the beds can be attended to. This means, therefore, considerable loss in working space.

Further, a process may also be briefly described here which, up to the present, has not been widely employed, but which might render good service in those places where no suitable land for sewage farming is to be had in the neighbourhood of towns and manufactories. The method consists in conducting the sewage to farms, and here by means of hoses it is squirted on to the fields. In the year 1897 it was first used by Nöbel in Eduardsfeld, near Posen, with 5½ million gallons of sewage yearly from the town of Posen. The process is named after the inventor, and is known as "Benöbelung" (The Nöbel Treatment), or the Eduardsfeld process, and also as hose irrigation.

In most cases the subsoil is drained. The purified sewage is conveyed to the river in collecting ditches. Under loam or clayey soils drainage is naturally not effected, since it would serve no purpose. The action in sewage farming is first of all a filtration process, since all suspended matter exceeding in size the pores of the ground is retained. Further, a large number of bacteria are removed. Then again, in a manner similar to that occurring with contact beds and percolating filters, but still more pronouncedly, dissolved organic matter is decomposed by the aid of micro-organisms in the ground. The sewage flowing away in the effluent drains differs from the raw sewage in that it is quite clear and no longer capable of putrefaction. It contains considerably less oxidisable matter, and the nitrogen compounds are to a great extent removed and converted in part to nitrous and nitric acids.

The action in surface irrigation is not so effective as that in true irrigation.

In all circumstances purification of the sewage before disposal on the farm is to be recommended. If this be done larger amounts of sewage can be disposed on the surface. In this preliminary purification there come into consideration screens, grit chambers, and septic tanks, as well as sedimentation processes with or without chemical precipitation. Indeed, in certain cases the sewage is treated in contact beds or percolating filters before disposal on the farm.

With good management the purifying action of sewage beds is quite unlimited. Bad working is generally attributable to false application of principles, or to errors in the original plant. Corn and potatoes are not suitable products to cultivate in the view of English authorities (Schiele) ; on the contrary, grass, carrots, and cabbages are very suitable. As regards pasturage opinion is divided.

The main purpose of sewage farms must always be sewage purification ; the yield of the process must not be increased at the expense of good purification. It is inadvisable on this account for towns to lease their sewage farms to farmers, as the latter have always got the profit uppermost in their minds. Large sewage farms can, as a general rule, be better and more rationally arranged than smaller ones. In England, therefore, small municipalities are advised rather to join with several others in order to set up a joint sewage farm than to erect several small plants. There are no scruples in England against keeping cattle on sewage farms.

Heavy rainfall has naturally a very deleterious influence on the capacity of a sewage farm to take up the sewage.

On the whole, according to Schiele, sewage farms can be regarded as percolating filters. The fineness of grain demands similar treatment to that with contact beds, viz. they must have periodical rests. The sewage farm must consequently be chosen so large that a portion of it can always remain unemployed. The last English Royal Commission on Sewage Disposal concluded that the most useful ratio of working surface to surface unemployed was in the case of surface irrigation 1 : 5, and for true irrigation 1 : 3. The same Royal Commission has placed in Volume IV of their Proceedings the results of searching experiments on the land treatment of sewage. Thereby the following figures, per unit of land, are obtained as admissible amounts of sewage which has undergone preliminary mechanical or chemical treatment :—

	At a given time per 24 hours.		On year's working over whole area.		
Soil.	Gallons per acre.	Inhabitants (calc. at 40 gal. per head per acre per day).	Gallons per acre.	Inhabitants.	
Best kind for filter purposes (light sandy loam overlaying gravel and sand).	23,000 (strong mixed sewage).	600	Over 10,000	250	
	100,000 (rather weak sewage).	2500	30,000 (rather weak).	750	
Soil less well suited (sand and partially peaty soil lying upon sand and gravel).	25,000 to 46,000	600 to 1150	8000 to 23,000	200 to 600	Domestic sewage (weak).
Bad soils (from gravelly loam to heavy loam or clay).	12,000 to 57,000	300 to 1400	4000 to 9000	100 to 225	Combined surface irrigation and filter farms.

Rents of sewage farms vary considerably. Whilst many sewage farms lose large sums of money, others not only pay for the total cost of working, but even create a surplus. This is explained on the grounds that the original outlay, especially the cost of obtaining land, shows great differences. Further, it must be borne in mind that sewage farms making a profit are generally the leased farms, in which case, as already mentioned, purification is often insufficient, as the profit is the primary consideration of the management.

The cost of sewage farming, apart from surpluses, amounts, according to Fruhling, to 1·2d. in Berlin, 0·37d. in Breslau, 0·87d. in Brunswick, 0·25d. in Magdeburg, 0·81d. in Dortmund, and 0·39d. in Freiburg per 1000 gallons of purified sewage.

(b) *Intermittent Sand Filtration, according to Frankland.*

In the year 1871 Frankland showed that domestic sewage could be effectively purified by irrigation if it were filtered through a sufficiently large layer of sand. Choking of the filter could be avoided if the sewage were not conveyed to the filter uninterruptedly, that is, if after each impregnation an interval of rest were allowed to ensue. The sludge abstracted is then decomposed by organisms as in contact beds, percolating filters, and sewage farms. It was on account of these periods of rest that Frankland named his process "Intermittent Sand Filtration."

Intermittent sand filtration differs from irrigation processes chiefly in this, that filtration is effected in specially prepared beds of sand which can be dosed with far more sewage than sewage farms with equally effective purification. The portions of the sewage valuable as plant nutriment cannot however be utilised agriculturally, and so cultivation of the surface must be sacrificed.

The method was first used most frequently in England. It was badly managed, and gave rise to various troubles such as stoppages in the sand, evil smells, and the like, with the result that the process was for a long time discredited.

Then the State of Massachusetts, U.S.A., demonstrated the value of the process by means of searching experimental work, using an experimental plant at Lawrence, and with large plants based upon this. They established, as a consequence, the good repute which the process to-day enjoys.

Henneking studied the plant closely in the State of Massachusetts, and reported in the "Mitteilungen der Konigl. Prüfungsanstalt fur Wasserversorgung und Abwasserbeseitigung"

(Proceedings of the Royal Test Institute for Water Supply and Sewage Disposal) upon his own observations on the spot and on the results obtained. The practical knowledge gained during more than eighteen years in Massachusetts shows that with the conditions present there it is most suitable not to submit the sewage to preliminary treatment before disposal on the filter-beds. American sewage is always thin, about half as thin as mean German domestic sewage.[1] It also contains no noteworthy amounts of industrial effluents. Purification is more complete the sooner the sewage is conveyed to the filter-bed. Suspended matter is retained on the surface of the bed, and can be scraped off in a cheap and convenient manner after it has sufficiently dried. In this process, for an unlimited number of years good purification continually results with doses of 40,000 to 80,000 gallons per acre. The amount of impregnation within these limits is adjusted according to the concentration and composition of the sewage on the one hand, and to the nature of the filtering medium on the other.

The most suitable soil for the filter-bed is one free from organic matter, porous sand, and gravel of 0·04 to 0·75 millimetre size of grain. It should be of uniform nature throughout; that is to say, the whole bed must contain per unit volume approximately the same number of sand grains of various sizes. Loamy surface layers and intermediate layers must be removed. The surface of the filter must be horizontal, or possess a slight inclination of 1 : 200 to 1 : 500. The depth of the filter layer should be at least 4 to 5 feet on an average. The main purification of the sewage is accomplished in the upper layer to a depth of 2 to 3 feet. A rectangular bed about 1 acre area has proved the most suitable arrangement. The beds must be well drained so that the treated sewage can flow away easily. It is distinctly worth while striving to design the drainage on the separate system (Trenn system).

Subsequent treatment of the purified sewage is unnecessary.

The periods of rest given after each application vary considerably. They vary between several hours and three days, and generally last about 24 hours, so that the filter can be dosed once a day. Since, as already mentioned, the filter-beds are much

[1] English sewage of mean concentration is regarded as thin for German working conditions.—*Trans.*

more heavily charged with sewage than in the case of sewage farms, expense is considerably less with intermittent sand filtration. That is to say, whilst an acre of filter-beds can be treated with the sewage of 1250 persons daily, an acre of sewage farm can only purify sewage from 110 persons. Intermittent filtration therefore only requires about one-eleventh of the total surface necessary for sewage farming. The cost of intermittent sand filtration fluctuates correspondingly between 0·04d. and 1·34d. per 1000 gallons of sewage, and, according to Henneking, should only amount to 8·2 per cent of the cost in sewage farming. The purifying action of the sand filter is never so complete as that occurring in broad irrigation. In Germany the process has not come into practical application up to the present.

(iii) *Sewage Purification by means of Fish-ponds.*

Frequently it has been proposed to purify sewage by conveying it to fish-ponds. The putrefactive matter decomposes there in agreement with the observations made in the section on " Self-purification of Rivers " by various organisms, of which the larger always prey upon the smaller. The organic matter introduced with the sewage is thereby converted into fish tissues. Naturally, therefore, the sewage must be so diluted that, in the first place, direct harm to the fish is avoided, and secondly, that purification can proceed normally. In the former case with too high concentrations of sewage, sulphuretted hydrogen and other inimical substances cause damage.

Cronheim carried out experiments in this direction which demonstrated the important fact that fish requiring little oxygen, like carp and tench, withstood an introduction of sewage to the extent of 10 per cent of the total volume of the pond. Decomposition did not occur in the water, nor did sludge collect on the bottom of the pond.

In later experiments Cronheim introduced 10 per cent of sewage every 4 to 8 days into a pond which, besides carp and tench, also contained trout and perch. In these experiments also, with fish needing oxygen in high degree like trout, no harm resulted. Whilst an acre of sewage farm can only absorb the sewage of 100 people, a pond containing carp, of half an acre area should, according to Höfer, continuously absorb the sewage of 300 persons without extensive decomposition setting in. This method is especially suitable for flat land, single farms, hospitals, etc., but Höfer also maintains that it is applicable to large towns like Munich.

According to Schick, the method is employed with the best results for the Kreisirrenanstalt, Kutzenberg in Oberfranken (300 persons), with a pond 0·5 acre in area. At Bau the same author points out that there should shortly be plants for the South Bavarian townships of Weinding and Ichenhausen with about 3000 inhabitants. Further experience with regard to expense and management must be awaited.

IV. THE DISPOSAL OF SEWAGE RESIDUES AND THEIR VALUE.

(i) *Residues from Grit Chambers and Screens. Sludge from Sedimentation Tanks.*

The residues resulting from sewage treatment are grit-chamber residues, residues from screens, the sludge from sedimentation tanks, and the sludge from the plants for purification of the effluents from percolating filters. With the exception of the last they are all more or less capable of putrefaction. The disposal of sludge is the most difficult and most important question in sewage disposal. A solution of the sludge problem that is satisfactory in every case is not yet known.

The residues from grit chambers and screens are not large in amount. Generally not more than 15 to 20 per cent of the undissolved substances present in the sewage is displaced in these purification processes. Grit-chamber residues mainly consist of sand, rags, bones, coffee grains, and similar substances. They usually contain 60 to 70 per cent of water. The dried material generally consists of two-thirds mineral and one-third organic matter. In Frankfort, with about 400,000 inhabitants and 22,000,000 gallons dry-weather flow per day, approximately 350 to 550 cubic feet of grit-chamber residues are obtained in 24 hours. Its disposal generally occasions no great difficulty. The material is quite firm when it contains 60 to 70 per cent of water. It is dried by being laid on level ground. No great area is needed for this storage ; and it dries fairly quickly. The dried residues are sold to farmers as manure. The Frankfort grit-chamber residues contain about 0·12 per cent N, 1·01 per cent phosphoric acid (P_2O_5), and 0·12 per cent potash (K_2O) in the dried substance. The residues accumulating every day from a fine screening plant are about as considerable as those from grit chambers. They consist mainly of excreta and paper. They contain about 80 per cent of water. The dried substance consists almost entirely of organic matter. They also are stored, dried in the air, and are sold either wet or dry as manure. Although these residues do not occupy much room in their storage, still, on account of the fæces they contain, and the consequent offensive smell, they may be very disagreeable. Residues from the Frankfort screens contain, when dry, about 0·82 per cent N, 1·57 per cent P_2O_5, and 0·40 per cent potash (K_2O).

By far the most important portion of the residue accumulating is the sludge from the sedimentation tanks. It settles to the bottom of the tanks, wells, etc., in the sedimentation process and forms a continually decomposing black mass which is of pulpy or watery consistency, always evolving an extremely offensive smell. The sludge consists mainly of triturated fæces, paper fibre, coffee dregs, sand, etc. Its black colour arises from small quantities of sulphide of iron, formed by the interaction of the sulphuretted hydrogen resulting from the fermentation in the sludge with the iron salts present in the sewage. It generally contains 90 to 95 per cent water. The composition of the dried substance depends upon the local circumstances and the sedimentation process employed. Sludge separated mechanically and without the addition of chemicals contains, in the dried material, about 50 per cent organic and 50 per cent mineral matter. It further contains, in substances of nutritive value to plants, approximately 2 to 3 per cent N, about the same amount of phosphoric acid (P_2O_5), and about 0·5 per cent potash (K_2O) in the dry substance. The high grease content of the sludge from sedimentation tanks is noteworthy. Frankfort sedimentation sludge contains on an average about 18 per cent grease in the dried substance. This grease arises in part from the grease of factories, cooking refuse, and fæces, mainly, however, from the soap used in washing. The alkali soaps are decomposed by the lime salts in the sewage and yield insoluble lime soaps, which are precipitated in flakes and settle to the bottom of the tanks or wells in the sedimentation process. The grease, which is separated from the sludge by slightly acidifying with sulphuric acid, has the following composition: 68 to 73 per cent free fatty acids coming from the soaps; 18 to 20 per cent neutral fats (fæces, fat, grease from cooking effluents); 7 to 14 per cent unsaponifiable portion (lubricating oils). It can readily be understood that these numbers may be very different with sludge from a sedimentation plant which works up large amounts of industrial effluents, as is the case in Frankfort.

The chief difficulty in sludge disposal is the large amount of water it contains. Since this amounts to 90 per cent or more, it not only occupies very valuable space, but also the large amount of water offers to anaerobic or putrefactive fungi of the most varied kinds a nutritive substrate which very quickly assumes a foul and stinking condition.

The whole problem of sludge disposal is the removal of the water.

(ii) *Drying the Sludge.*

The most widely disseminated process, and the one longest in use for drying sludge, is to spread it on the land. A part of the water thereby drains away into the ground and another portion evaporates. The removal of water takes place very slowly, however, on account of the slimy nature of the sludge. Months and years go by before the sludge is dry. The consequence is that the place where sludge is stored is very noticeable, especially in warm years, on account of its extremely disagreeable smell. The gas arising during the fermenting process from the sludge is combated by covering the sludge with some protecting material like turf, tar, etc., or decomposition is checked by covering the uppermost layer with disinfectants (saprol, tar, chloride of lime, etc.). As too deep a layer of sludge cannot be deposited on the storage-ground if it is not to take too long to dry, the storage of sludge becomes rather costly, as considerable expenditure is entailed in purchasing land. Fresh sludge from sedimentation tanks and wells shows all these unacceptable features when spread out on the land, but septic-tank sludge has much more favourable properties. It has a higher percentage of dry substance than fresh sludge, its smell is less offensive, but, above all, it gives up its water much more readily when brought on to the soil.

According to Spillner, Emscher-well sludge should have all the good properties of septic-tank sludge. It contains considerably less water than sludge from septic tanks. With 70 per cent water it is pulpy and quite mobile, and it has no offensive odour. Spillner carried out parallel experiments on the removal of water from fresh and from Emscher-well sludge. The experiments showed that the fresh sludge needs a much longer time to reach firm consistency than does the sludge which has been liquefied, and also that fresh sludge gives up much less drain-water than the liquefied sludge.

The favourable results obtained with liquefied sludge are due, according to Spillner and Imhoff, to the higher content of dry substance which septic-tank sludge possesses, to the greater amount of gas which partially putrefied sludge contains, and to the fact that in such sludge the colloids, which are the main cause of the tenacity with which the water is held, are destroyed during the decomposition process.

Sludge-drying by drainage is carried out on a large scale with Emscher wells in the plants at Essen, N.W., Bockum, and Recklinghausen-Ost. The results, so Spillner reports, are as yet very favourable.

A drying process employed in England consists in bringing the sludge into a freshly opened ditch. The water is drawn out more quickly by the loosened soil. As soon as the sludge is so dry that it can bear the soil which has been dug out, the latter is filled in. With sludge from sedimentation tanks the drying is still a very wearisome process.

In Göttingen and Kassel the sludge is compounded with refuse.

It is readily understandable that efforts have frequently been made to replace the method of drying sludge on the land by a process permitting quicker drying. Filtration is the most important of the methods considered. It has given poor results in many localities. The colloids in the sludge render the removal of water by filter-presses impossible, since they very soon choke up the filter fabric. If the mud be expressed when hot, or chemicals be added, the results obtained are better, but the process then becomes very expensive. To the knowledge of the author filter-presses are on this account never used in Germany. In England, nevertheless, they are not infrequently used for removing water from sludge. In these cases the sludge is obtained in sedimentation processes in which chemicals are employed, and therefore contains considerable amounts of lime.

Much better results have been aimed at in recent times by the use of centrifuges. At Frankfort-on-Maine, Harburg, and Hanover the sludge from the sedimentation processes is freed from water by centrifuges of the Schäfer-ter-Mer type. This apparatus is, mechanically and hygienically, the most perfect apparatus designed for the removal of sludge by the aid of centrifuges. It works perfectly automatically, and the workmen do not come into contact with the residues at all (Figs. 20 and 21). The sludge flows from the feed reservoir through a vertical rotary axle and into the centrifuge in such a way that it is distributed into six presses arranged radially to the axle, and separate one from another. These presses or compartments are divided by vertically placed sieves into a sludge space and sewage space. The sludge enters the sludge portion, in which the coarser particles are whirled to the outside by centrifugal force (about 750 revolutions per minute), whilst the sewage is conveyed through the sieves into the neighbouring sewage space. The sieves are prevented from choking by an automatic cleaning device. When the centrifuge has been working from one to two minutes the sludge chambers are completely filled. The sludge supply is then automatically cut off by a circular disc. Immediately subsequent to this another circular disc opens which serves to close the presses usually, and through the opening so obtained the centrifuged sludge is hurled out of the presses. After the disc has automatically closed the press, the disc at the sludge inlet opens, and the process is repeated. The machine works without any stoppages. The opening and closing of the discs is automatically set working by oil-pressure with the help of a certain mechanism. The machine requires no attention apart from the removal of the oil. The cost is rather considerable; it amounts, according to Reichler and Thiesing, to 1 shilling per 10 cubic feet of dried sludge, whilst removal of water by filter-presses should only amount to 8d. A further disadvantage of the process is that the sewage flowing out of the centrifuge still contains a large quantity of solid substances.

This disadvantage, however, does not alter the fact that the method is at the present time the only one permitting rapid removal of water from sludge in a relatively simple manner, and one free from objection from the point of view of hygiene.

In Frankfort, experiments carried out on a small scale to

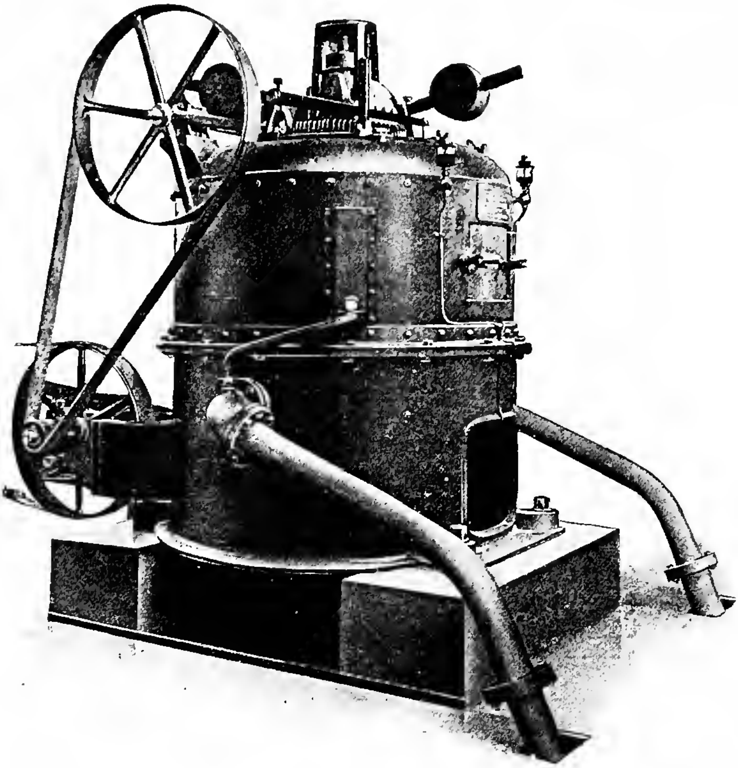

Fig. 20. Centrifuge for Sludge: Schäfer-ter-Mer System.

remove water by an electro-osmotic process have not yet been tested on a large scale.

Towns near the sea often get rid of sludge in the handiest way by sinking it in the sea. Though the method is one of the cheapest, it is not so cheap as might at first be believed, for sludge vessels must proceed a good way out to sea if the tide is not to throw up the sludge on the shore. According to Spillner, the method is employed, among others, in London, Manchester, and Salford, and it is proposed for many other localities, e.g. Belfast. London possesses a whole fleet of sludge vessels, each of which holds 1000 tons and costs £30,000, not to mention the large iron

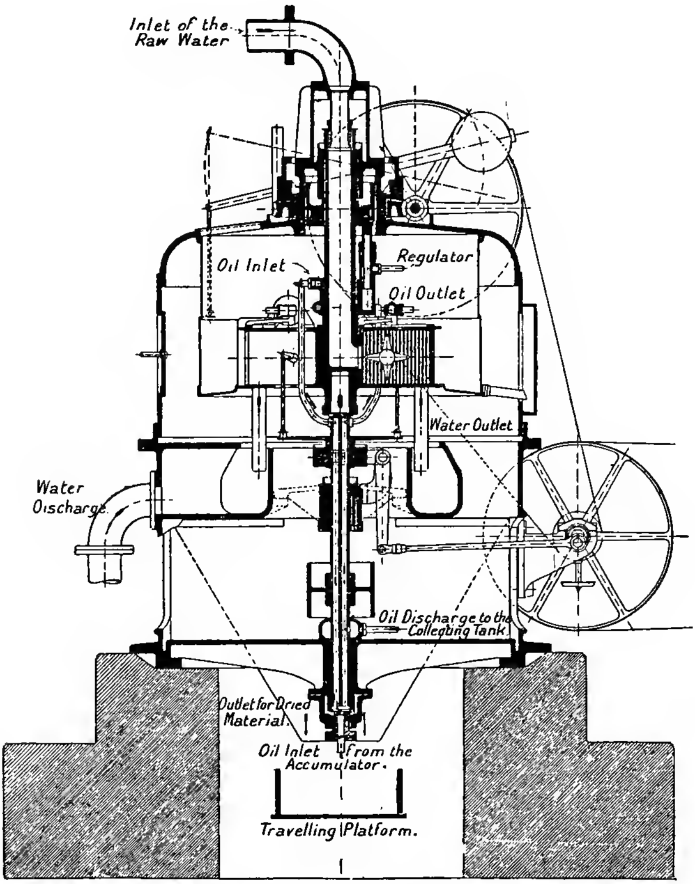

FIG. 21. CENTRIFUGE FOR SLUDGE: SCHÄFER-TER-MER SYSTEM.

tanks on the plant in which the sludge is stored prior to the arrival of the vessels. The London vessels take the sludge sixty-five miles out to sea, while Manchester and Salford have a ship which goes fifty miles out to sea. On an average three journeys are made per week.

Weldert reports in a preliminary communication that by adding saltpetre, sludge from sedimentation tanks, as well as sewage, loses its capacity to putrefy. As the foul nature of sludge is one of its greatest nuisances, it may be possible to treat it with nitrates and then dry it in the air.

The costs of the various methods of sludge disposal are given by the last English Royal Commission on Sewage Disposal as follows :—

Land treatment	About 2d.
Sinking in the sea	,, 5d.
Digging into trenches	,, 5d.
Filter-presses	,, 6d. to 1s.
Presses and combustion	,, 1s. 6d. (estimated)

per ton of aqueous sludge containing about 90 per cent of water, inclusive of interest on plant capital and all expenses, charges, and taxes, without reference to the value of the sludge as manure or to its calorific value.

(iii) *Profit from Sludge.*

To cover at least a portion of the expense incurred, attempts are continually being made to realise a profit from the disposal of sludge.

Sale for agricultural manuring purposes is the method which has been used most frequently. As has been already pointed out, sludge contains in no inconsiderable amount substances nutritious to plants, especially nitrogen (generally 2 to 3 per cent in the dried material).

Wet sludge, from which no water has been removed, is only employed as manure in those places where there is agricultural work in the neighbourhood of the sewage plant to which it can be delivered. Damp sludge could not bear the cost of carriage to greater distances, as its manurial value would not be in any way proportional to this cost, apart altogether from the consideration that it would not be practicable, on account of the nuisance due to smell. In Frankfort, till recently, the fresh sludge was, in part, directly sprinkled over the fields in adjacent agricultural undertakings. For this purpose long pipes were laid to which movable pipes could be attached.

Frequently experiments have been carried out with a view to further drying the sludge which had previously been freed from a portion of its water by the above-mentioned methods, and with a view to selling the dried product as poudrette (artificial manure). Ten years ago in Frankfort such a plant was worked. The sludge was freed from water on the storage-grounds until quite firm, and was then dried further in a drying plant until it contained 10 to 20 per cent water. The "poudrette" thus obtained contained about 1·7 per cent nitrogen and 2 per cent phosphoric acid. The residue in nitrogen as compared with the above-mentioned numbers, shows clearly that part of the nitrogen is present in the form of ammonia which volatilises on drying. The method was a failure, since a hundredweight of dried poudrette cost about a shilling. Similar results have been obtained in towns that have tried to prepare artificial manure from sludge, so that this method of making a profit can now be considered non-existent.

The large amount of grease in sludge from sedimentation processes has over and over again provided an inducement for determining a rational method of extracting the grease. When no special circumstances are present requiring a recovery of the grease, or when the sludge does not possess an abnormally high percentage of grease, its recovery from the sludge coming from domestic sewage has proved irrational.

The recovery of grease is fairly difficult, as it is so intimately mixed with the remaining particles of sludge that the specifically lighter fatty particles do not rise to the top, or do so with great difficulty. With the aid of the previously mentioned grease extractors, separation into layers of sludge rich in grease and poor in grease could be effected. The sludge rich in fats could then be worked up by extraction on the lines of the method described below. In practice this method has not yet, to the knowledge of the author, been applied.

Further, the greasy scum obtained from sewage from slaughter-houses, hotels, and the like might be worked up, as it consists mainly of fats. Whether this is carried out in practice is also unknown to the author.

According to Schiele, the sedimentation plant at Bradford treats a sewage from wool scouring which is very rich in grease, and a part of the sludge is worked up for grease in the following manner: After addition of sulphuric acid the sludge is heated to 100° C. and expressed in hot filter-presses. The greater part of the water and the grease is thereby removed. The residue after expressing still contains 30 to 40 per cent water and 25 per cent grease. From the filtrate the grease separates out on the top, and after washing and deodorising it is sold, generally to America. In the Bradford plant the total sewage must be treated with sulphuric acid to decompose the dissolved soaps. The proceeds from the sale of grease cover about half the cost of the sulphuric acid. The grease residues remaining over are burned with one-eighth the amount of coal, as on account of the large percentage of grease present it is not saleable as manure. In an experimental plant the recovery of grease from the press residues was tried. The residues are heated in retorts from which the grease distils over. The residue remaining in the retort should then be suitable for addition to artificial manure, since it contains some phosphoric acid and about 1·5 per cent nitrogen.

The town of Kassel has for two or three years worked a grease-recovery plant with a machine attached to their sedimentation plant. The sludge is acidified with sulphuric acid, expressed in filter-presses, and then extracted with benzene. The reports sounded very favourable, but the process was very soon discontinued, due to the firm working it having experienced a loss on the undertaking. The cause of the non-success lay, firstly, in the high cost of drying the sludge, and secondly, in the yield of grease being considerably lower than was anticipated.

In Frankfort, extraction of wet sludge with benzene was investigated with a mechanical arrangement in a small experimental plant. A practical application of this process has not yet been effected on the large scale.

To my mind, therefore, no solution of the problem of grease recovery from sedimentation sludge need be expected. It is easy to be attracted by the, no doubt, considerable value of the grease present in these residues. Thus the grease present in Frankfort sludge obtained in one year has a worth of about £25,000. If, however, in order to recover this sum an expenditure of £50,000 must be incurred, the transaction is not a profitable one. According to Schiele, an English manufacturer whose attention the Royal Commission on Sewage Disposal drew to the fact that in his effluents there was contained so much valuable material, replied: "It is worth no more to me than a piece of gold at the bottom of the sea. It costs me too much to get it up." This answer can be adapted to practically all attempts at the recovery of grease from ordinary sedimentation sludge. In addition I might also for a moment call attention to something to which up to the present, as far as I know, attention has not been directed. To a judge of the circumstances it is at once probable—and the plant at Kassel has established this in fact—that benzene extraction, grease distillation (for the recovery of pure grease from crude grease), and other operations cannot be conducted without smells; on the contrary, a very obnoxious odour is generally developed, which is noticeable for a great distance around. Now municipal sedimentation plants are by no means all far away from the town, so that there is a danger that, with a diminution in the rental value, that part of the town in which the sedimentation plant is situated may depreciate in value. However, quite apart from æsthetic and hygienic considerations, which must be urged against a continual smell owing to the association of a plant and dwellings, this disadvantage might possibly not be accompanied by a profit from the sale of the grease. And so municipalities occupied with the idea of recovering grease from their sewage can only be pursued with the cry "videant consules."

A method of making profit frequently adopted of late years is the destruction of sludge by fire, either by simple burning or by gasification, in which processes the heat or the gases obtained are employed in the production of other forms of energy. If the sludge cannot be burned of itself, combustible material such as turf, coal, borecole, must be added. Even if no profit results, or the cost of disposal be only in part covered, this method of disposal or of realising a profit from these residues is the best, as it is the one most worthy of recommendation from the hygienic point of view.

The town of Frankfort now disposes of its sludge in the following way: It is first pumped out of the sedimentation tanks into large reservoirs which are situated over centrifuges of the Schäfter-Mer system. In these reservoirs a portion of the water is separated and led back to the sedimentation tanks. The sludge is then centrifuged. It is then mechanically forwarded to a drying drum, in which the centrifuged material with about 70 per cent water is further dried by hot gases from the refuse destructor plant. The sludge coming from the drum still contains about 25 per cent water, and is now burned in the refuse ovens. Addition of other combustible material is unnecessary, as the dried sludge burns of itself. From a kilogram of sludge about a kilogram of steam is obtained. Burning of the sludge is therefore attached to the refuse destructor, which is situated near the sedimentation plant. The current obtained from the dynamos driven by the burning of the sludge and refuse not only illuminates the whole plant and yields power for the plant, but there is also a considerable portion conveyed through high-tension cables to a pumping-station in the Stadtwald, where by means of the current, electric motor-pumps are worked and serve to raise drinking-water. Besides this there is a considerable amount of current delivered to the town supply.

In Bury the sludge is mixed with refuse and burned (Schiele).

In Pforzheim (Germany) sludge combustion is similarly provided for alongside the refuse destructors.

In the years 1902 and 1903 gasification experiments were carried out with Frankfort sludge by Bujard. He found, as the mean of two experiments with gasification lasting four hours, using 50 kilograms of dried sludge, the following volume percentages were given :—

Yield per 100 lb. sludge=320 cubic feet of gas.

Carbon dioxide	16·1%
Heavy hydrocarbons	5·8%
Carbon monoxide	22·8%
Methane	13·2%
Hydrogen	35·8%
Nitrogen (residue)	6·3%

Calorific value for 1 cubic metre=3620 to 4072 W.E.

Reichle and Dost report upon gasification experiments with coal-pulp sludge : Its gasification is only possible with a certain amount of water present, which must not be over 58 per cent ; the gas gave on the average in volume percentages :—

Methane	0%
Carbon dioxide	11·0%
Nitrogen	62·6%
Carbon monoxide	14·2%

Oxygen	1·0%
Hydrogen	11·2%

The calorific value amounted to only 800 W.E. The gasification of 2·5 kilograms of the sludge with about 51 per cent water yielded about 1 horse-power per hour. In the gasification a grease-like substance distilled over; the water gas in the dust-bag contained 2208 milligram total nitrogen per litre, of which 1494 milligram was present as ammonia. Reichle and Dost consider that the introduction of gasification with the sludge from Degener's coal-pulp process would considerably reduce the high cost of working which has been a hindrance up to the present, and conduce to the more general introduction of this otherwise very advantageous process.

In the town of Köpenick, near Berlin, coal-pulp sludge is gasified on a large scale. The power gas obtained is converted into electrical energy.

B. Purification of Industrial Sewage.

I. GENERAL.

Most towns take industrial effluents into their drainage system in return for a fee; they then demand that the sewage never contains substances harmful to the drains (acids, alkalies, combustible material, etc.), and that the purification of the whole sewage is not rendered much more difficult as a consequence of the introduction. Consequently, there are already large manufacturing towns whose sewage contains quite considerable amounts of industrial sewage admixed. For purifying such municipal sewage chemical precipitation is to be recommended in the sedimentation plants. With contact beds and percolating filters the plant must be larger in its dimensions than would be necessary for the corresponding amounts of domestic sewage. The reception of industrial sewage makes the process of sewage purification more expensive for municipalities. Nevertheless, the endeavour to receive industrial effluents into the ordinary sewerage system is to be welcomed and recommended. Otherwise separate plants in the various manufactories must result to a great degree. Now larger plants, for the reasons which have already been frequently mentioned in other chapters, are worked more rationally and with greater security than smaller plants. Again, the erection of separate sedimentation plants is contrary to all the fundamental principles of drainage systems, according to which all refuse should as far as possible be conveyed out of the town. With manufacturing plants, however, the residues must be allowed to accumulate on the works' premises.

Although it seems desirable to convey industrial sewage through the ordinary sewers, there are still very many cases in which purification of industrial sewage itself is necessary. Where towns refuse to receive the sewage or demand a previous slight superficial purification, and where there is no sewage system as in works and in isolated places, the industrial effluents must themselves be purified if the stream conducting it away is not to be harmed by the incoming sewage. Therefore the purification of industrial sewage is a question becoming ever increasingly important.

The sewage produced in works can be divided into three groups :—

(1) Closet, cooking, washing, and bathing water.

(2) Condenser, cooling, and washing water.

(3) The particular works sewage.

The first group comprise effluents which are domestic in character, whose purification has been described in the previous chapter.

The kinds of sewage named in section 2 are generally very pure. It is always advisable to keep them separate from the particular forms of sewage of the third group, as if this is not done the sewage is simply diluted and the difficulties of purification are considerably increased. This is to be recommended, as the water from the second class often very considerably preponderates over that of the third. Cleansing and condenser water is frequently so pure that it can be drained away without any purification or after treatment in a sedimentation tank.

To give a general composition for particular works effluents is naturally impossible, as this depends wholly on the nature of the work carried out. It is therefore also impossible to set forth general rules for the purification of industrial sewage. Only this much can be said, that the general principles of purification are the same as in the case of domestic sewage, and therefore consist of either mechanical purification by sedimentation tanks, or biological purification by broad irrigation, contact beds, or percolating filters. In the sedimentation process it is always advisable to make use of chemical precipitation, with the addition of chemicals which have been proved to be suitable by experiment for the particular kind of sewage.

It is to be recommended much more with industrial effluents than with household sewage that tests be made, on the basis of a chemical investigation of the sewage, to determine the most suitable method of purification.

Frequently, of course, partial purification is to be attained by combination of different kinds of effluents. Thus, acid and alkali discharges partially neutralise one another. Effluents containing lime precipitate heavy metals or alumina and the like. Such a combination of the various effluents is often sufficient to effect sufficient purification after sedimentation.

An arrangement which can be recommended for works clarifying plants is the keeping of a reservoir. It is now used in very many works in which at one time highly polluted and large amounts of sewage are produced, and at other times little and only slightly polluted sewage is formed. For if large amounts of strongly polluted sewage are suddenly conveyed to a stream, it means much greater harm is being done to the river than if the whole sewage of 24 hours was slowly and uniformly discharged into the river. For this purpose tanks must be laid down capable of storing the effluent resulting from a day's working. Now and then, when the river is sufficiently high and the sewage does not seem too filthy, further purification than is assured in these reservoirs is quite unnecessary.

Lately, also, industrial effluents have been used to lay the dust on the roads.

According to Weldert, for this purpose, under certain circumstances, there come into consideration effluents from ammonia works, potash works, cellulose works, sugar refineries, coke plants, spinning mills, wool factories, fulling mills, and ammonia-soda works. Experiments of Weldert with ammonia effluents yielded favourable results. The problem of dust-laying will be more closely studied under the various particular classes of sewage.

For the purification of works sewage the filter is frequently used. Under the term " filter " no biological filters are understood, but apparatus, constructed, of course, of similar materials to them, but which, however, are worked continuously. Their action therefore is the purely mechanical one of retaining the suspended matter. They are generally prepared of cheap unsieved material, clinkers from boiler-fires predominating. This filter is used both for the subsequent purification of clarified works sewage and also for the removal of water from sludge (Magma Filter). For the treatment of percolating filter discharge such filters are also used.

II. THE PURIFICATION OF INDUSTRIAL SEWAGE IN PARTICULAR.

With Fowler and Ardern we can classify industrial effluents, according to the substances through which they act harmfully, thus :—

(1) Effluents with large quantities of suspended matter.
(2) Effluents with substances that may decompose.
(3) Coloured effluents.
(4) Effluents containing poisons.
(5) Effluents containing oils, tars, fats, soaps, etc.

Many effluents may naturally come under several of the headings mentioned.

Effluents of the first kind can generally be sufficiently purified by settling devices, sieves, rakes, filters, etc. Effluents from coal-washing and cloth factories, etc., might be named here.

Effluents of the second kind are very disagreeable. They are purified by chemical precipitation with subsequent sedimentation, or by the land treatment, or by means of contact beds or percolating filters, as was set forth in the previous section. The chief and most important effluents belong to this class, for example, those from tanneries, cellulose works, breweries, sugar refineries, etc.

The purification of coloured effluents is still an unsolved problem. No method is yet known of decolorising coloured substances in a satisfactory and continuous manner. In general decolorisation is more difficult, the faster the colours. Chemical precipitation and various biological methods are employed. With contact beds and percolating filters the colouring matter is absorbed by the beds for a time, but after a certain period the colour passes through unchanged.

Purification of sewage containing poisons must naturally depend on the chemical nature of the poison. Acids are generally neutralised with lime, and alkalis with sulphuric acid. Heavy metals are precipitated by lime, etc. Cyanides can be separated as Prussian blue with sulphate of iron and caustic soda. Under this heading is comprised sewage from metal works, gas works, tanneries, sulphite cellulose works, etc.

Sewage containing oils, fats, and soaps are finally purified by the separation of the fat particles, in the case of soaps after the addition of sulphuric acid. Under this heading are the effluents from margarine works, wool-scouring works, slaughter-houses, etc., which may also all be reckoned under section 2.

According to this general point of view an industrial effluent may be classified and the manner in which the purification process has to be carried out may be given. The extraordinary variety of particular effluents in the four groups makes a closer examination of the particular kinds of sewage seem worthy of attention. I shall endeavour to mention all the classes of sewage coming at any time into consideration.

(1) *Sewage from Cloth Factories or Factories whose Effluents contain Fibrous Material.*

Reichle and Zahn describe a drum filter by A. and A. Lehmann that is very suitable for recovering fibre of any kind from sewage. The apparatus consists of a movable drum which is covered with wire netting 1 millimetre mesh. The sewage streams through the drum and leaves the fibre behind. From the works in question 22 tons of wool were obtained in nine months.

(2) *Sewage from Cardboard Factories.*

According to the laboratory experiments of Sjollema, the addition of monocalcium phosphate (superphosphate) is most suitable for the purification of this sewage, as it forms tricalcium phosphate with the free lime present in solution. This is precipitated out and settles down along with the suspended matter, together with, also, a portion of the dissolved substances. The precipitate after drying can be used as manure.

(3) *Sewage from Straw-board Works.*

These works produce very large amounts of sewage, which contain many fine particles of straw mixed with lime.

The sewage can be purified by sedimentation (capacity of the tanks being one hour's supply) and by filtration through mechanical filters without the addition of a precipitant (rate of filtration equal to 95 cb.m. through 1 sq.m. of filter every 24 hours). The filtered sewage can then be used again in the works. According to Kimberley, the sewage so purified can be drained into the river without harm if the stream contains twice the amount of water present in the sewage. Sjollema recommends his above-mentioned precipitation method with superphosphate for this sewage.

(4) *Effluents from Mines (Coal-washing).*

Effluents from waterworks in mines consist of waters from washing coal and from quenching coke. It is not advisable to purify these effluents along with domestic sewage, for then the sedimentation tanks have to be built abnormally large. In the quenching of coke the water is used over and over again ; from time to time, however, it must be withdrawn from circulation and purified. This is generally effected in settling tanks. The Imhoff-Lagemann patent is especially suitable for this purpose. The bottom of this tank is drained. The drains terminate outside the settling tank and are closed during the settling process. They are opened only to dry the sludge.

Sometimes before its entry into the river the sewage is allowed to flow through a filter of boiler-clinkers. The coal sludge obtained is either burned or worked up as coke.

According to the experiments at the Halle Agricultural-Chemical Experimental Station, the resinous water from borecole coke works is especially suitable as manure, since it may develop a considerable nitrifying action without fear of any harm being done to the plants by manuring the roots. It is most strongly recommended as a manure for meadow or pasture land.

(5) *Sewage from works Granulating Slag.*

Many works, e.g., smelting works, have plants for granulating slag. The fluid slag is allowed to flow into water, by which means it is broken into small pieces. The effluents resulting from this are hot and contain large amounts of fine slag, of which a part sinks and another part floats on the surface.

The firm "Städtereinigung und Ingenierbau-A.-G., Berlin-Wiesbaden" have constructed devices for the purification of such effluents which should work quite satisfactorily. The idea of these plants is that the sewage is led with fairly slow velocity through a sedimentation tank, by which means the heavy particles sink to the bottom. The floating material is removed by the aid of several channels which are placed obliquely to the direction of flow, and are provided with various devices corresponding to the purpose for which they are constructed. The floating slag skimmed off is led into a second tank which is at rest, and in this the floating substances are stored up until the layer has reached a certain strength. Thereupon the water underneath is drained away, so that the scum sinks to the bottom. The slag from the two tanks is then bagged.

(6) *Sewage from Paper Mills and Cellulose Works.*

In the manufacture of paper, rags, hemp, jute, esparto grass, straw, and wood are all used.

The main effluent from all these raw materials is the alkaline water obtained by boiling them. To this must be added the water from washing and cleansing the raw materials after they have been digested, the discharge from the Hollanders, the water containing both acid and chlorine from the bleaching process, and finally the discharges from the paper machines and dyeing process.

Separate treatment of the different kinds of effluent is advisable. The sewage coming from the paper machines allows of a recovery of the fibrous material in specially erected settling tanks, and the effluent therefrom may be used again. The above sewage may be purified, however, to the requisite degree by chemical precipitation and sedimentation or by means of sand filters.

The effluents from wood-pulp or cellulose works are of great importance. Cellulose in Germany is entirely prepared by the sulphite process. Fir and pine is treated in so-called digesters or boilers at high temperatures and under pressure with calcium bisulphite. The soluble material is thereby removed and the wood fibre isolated. The fibrous residue is then expressed and washed free from the strong liquors. There thus accrue to the sewage: boiler liquors and washing liquors, water from the sieves, presses, and from the machines for removing water from the cellulose, in addition to condenser water. The boiler liquors are the worst, for they contain about 100 grammes of organic matter per litre, and consequently, if conveyed to the river without further treatment, cause grave inconvenience owing to putrefaction, and especially to the formation of fungi (Sphærotilus).

In most works the sewage undergoes a superficial purification. The suspended matter is filtered off after a partial recovery of the sulphur acids, and the liquors are cooled down and neutralised with lime. The sewage is subsequently treated in sedimentation tanks. Dissolved material is, however, scarcely influenced by this process, and they are the substances that exert a harmful influence on the river carrying the sewage away. The purification of the liquors by the biological process is impossible, even after great dilution of the sewage, firstly on account of the difficulty of decomposing the liquors, and secondly on account of the harmful action on the micro-organisms of the sulphurous acids present in the lye.

Possibilities of making a profit from such sewage have been investigated, and the very numerous proposals made with this object in view have only partly led to practical results. Evaporation and combustion of the product is very costly, and the works' profit comes into the question. In rare cases only is the sewage allowed to trickle away, and this depends on the local circumstances.

Researches on the recovery of sulphur, on the employment of the organic substances in the liquors as combustible material, whether directly or after making briquettes of it with coal, coke, or furnace dust, have not yet yielded any practical results. Further, it is proposed, after the removal of harmful material, especially the sulphur acids, to work up the liquors as feeding-stuffs; these proposals, also, have not been put into practice. On the contrary, the liquors have been used, after certain substances have been added, as adhesives, and most recently have been used to lay the dust on the streets. Their value as manure to be added to "Thomasmehl," and their application in tanneries, are still undecided questions. Fermentation of the sugar products found in the residues and the recovery of alcohol is already carried out in practice in Sweden, but in Germany the pursuit of this process is not profitable owing to the big duty which is paid on alcohol since the recent legislation concerning duty on brandy. The recovery of colouring matter from the boiler liquors is already a successful process, but the problem needs further investigation (Pritzkow).

Besides the " sulphite " process, there is the " soda " process for the preparation of cellulose, in which the wood is digested with caustic soda instead of calcium sulphite. The method is by no means as important as the sulphite process. The caustic soda liquors are the worst effluents in this case, and are to be as carefully treated as the sulphite strong liquors.

Logau evaporates the residues and ignites them ; the heat obtained by the ignition is used in evaporating further quantities of the liquors. Fire for combusting the material only needs to be used at the commencement of the operation. Soda is recovered from the ashes. Rimman saturates the liquors with carbon dioxide after they have been raised to a certain specific gravity by the addition of soluble salts. A part of the organic matter present is thus precipitated.

(7) *Sewage from Breweries.*

The major portion of brewery sewage is cleansing and washing water. It is consequently only slightly polluted. On the other hand, the effluents of the process itself are greatly polluted, especially those from the malting, from the drying of the hops and grain, and from the yeast. This sewage has a strong tendency towards putrefaction on account of the large amount of organic matter that it contains. It has a tendency also to form lactic acid.

Partial purification consists of chemical precipitation followed by sedimentation.

This kind of purification is, however, generally insufficient.

Where more thorough purification is impossible, the sewage should be immediately conveyed to the drains.

Brewery sewage is best purified by land irrigation.

After the addition of lime (neutralisation of the lactic acid) these effluents can be purified on contact beds, but best of all in percolating filters.

(8) *Tannery Sewage.*

In tanneries there are principally three classes of effluent, from the liming process, the dye liquors, and tanning liquors.

The lime effluents, which result from the unhairing or depilation of the hide, contain lime principally, sodium sulphide, and a large amount of decomposable organic substances (pieces of hide, hair). Under certain circumstances, if foreign hides are being worked up, napthalene may be present as a preservative for the skins.

Tanning liquor contains either tannic acid or chromium salts. The tanning effluents therefore contain these substances. Frequently, also, other chemical compounds like sodium thiosulphate, arsenic salts, etc., are present.

The dyeing liquors are used to dye the leather ; the sewage resulting from this part of the industry has the same colour as the dyeing liquors.

All tannery effluents are generally putrefactive to an unusually large extent. They therefore have a very harmful action on the stream conveying them away if they are led into it directly or with insufficient purification.

They are therefore best run into the drains after preliminary purification in settling tanks. According to Schmidtmann, Thumm, and Reichle, they will even then frequently give trouble, when, for example, tan sewage containing sodium sulphide comes into contact with acid effluents, like those from breweries. The resulting evolution of sulphuretted hydrogen will be a great source of annoyance in the streets.

If it is not possible to run the sewage into the sewers, a large reservoir is to be recommended for a works.

A partial purification can be attained occasionally by combining the various kinds of effluent. The lime from the liming process precipitates chromium salts, and then the sewage is clarified in settling tanks. In certain cases, therefore, chemical precipitation can be dispensed with. It is better, however, to add chemicals in calculated quantities.

When more thorough purification is necessary it is best to use broad irrigation, preceded by treatment in septic tanks. If the artificial biological process is employed, double-contact beds seem to work better than percolating filters. Arsenic and other poisonous substances must be removed before any biological purification is taken in hand.

(9) *Sewage from Dairies and Margarine Works.*

The sewage from such places contains particles of milk collected together. One would therefore expect albumens, carbohydrates, fat, lactic acid, etc., in such effluents, which are therefore highly putrefactive.

Kimberley, acting for a Commission in the State of Ohio, U.S.A., undertook a detailed investigation of the sewage from dairies. If the amount of water in the river receiving the sewage be thirty times as great as the sewage itself, then, according to this author, dairy effluents can be discharged into the river after treatment in settling tanks. These tanks should be twice as large as a day's effluent requires.

In other cases, dairy effluents may be purified by intermittent sand filtration until they are incapable of putrefaction (22,000 gallons per acre of filter surface).

In Germany they are frequently purified by ordinary land irrigation. They are generally previously clarified in masonry tanks. To prevent nuisances due to bad odours disinfectants (chloride of lime) are added to the sewage in the tanks. According to Guth a good soil cannot take up more than 6 gallons per square yard. Grass, clover, and trees thrive very well on the fields irrigated. In the opinion of Dunbar, an effluent from a dairy, if not too concentrated, can be purified by the biological processes, and most successfully with percolating filters continuously employed. For the biological process the sewage must be previously purified by chemical precipitation, to neutralise the lactic acid, as otherwise purification would be insufficient. According to Guth, not more than a cubic metre of sewage should be applied to a square metre of surface, that is, 0·5 cubic metre of filter material.

Harm precipitates dairy effluents with acid silicates (the waste from the manufacture of alum) and with lime. He asserts that he has obtained good results from lengthy investigations. Information is lacking as to the cost and the resulting sludge.

Partial purification can be attained by precipitation with sulphate of iron and lime, followed by sedimentation.

(10) *Sewage from Slaughter-houses, Knackers' Yards, and Glue Works.*

Slaughter-house sewage is generally very concentrated, is readily decomposed, and has an especially harmful action on the stream receiving it. It contains blood, fat, flesh, manure, and slaughter-house refuse of every kind.

It may be partially purified by treatment with iron or aluminium sulphates, followed by sedimentation.

For mechanical purification automatically working clarifying boilers by Mertens of Berlin have been employed (Swinemünde, Paderborn-i.-W.).

In Kiel, during 1905, an experimental plant was erected for the purification of slaughter-house effluents by means of the biological process. Meanwhile, many towns have employed it for the work with success. Preliminary purification in septic tanks should be very suitable with such sewage.

Thiesing studied the sewage coming from the knacker's yard and also its disposal. It comprises the water used in cleaning the places in which the horses are killed, the glue liquors, the waste liquors from steaming the carcases, the glue condenser water, and mixtures of these kinds of sewage. They are all very concentrated and readily decomposable. Up to the present, according to Thiesing, the treatment employed with such effluents has always been insufficient. It is necessary to observe that rain-water does not pass through the purification plant. On the other hand, domestic sewage may be treated along with it. Broad irrigation and the biological process should be very suitable for the purification of such sewage. With such treatment preliminary purification in septic tanks and grease separators is to be recommended.

(11) *Sewage from Sugar Refineries.*

The sewage from sugar refineries, besides condenser water, which is harmless, consists of water from the washing of the beet, from the diffusers, and the filter-presses.

The different kinds of sewage must be treated separately. The water used in washing the beet is purified in sedimentation tanks and then used again. Markwart would like to run the water from the diffusers and from the presses into the diffusers again without further treatment. It is then necessary to prevent fermentation from being set up.

According to Herzfeld, the following important preliminary must be observed before using the effluents again in the process, viz. the particles of pulp must be removed by careful sedimentation.

Hoyermann and Wellensiek recommend for the purification of sewage from sugar factories one of their own preparations, which consists of humic acids which are hydrolysed with alkalies. In the process of hydrolysis the solubility of the humins is quite considerably increased. The sewage to be purified is treated with humin suspended in water, and then lime is added till the whole is weakly alkaline. As a result a flocculent precipitate separates out, and the water becomes quite bright and clear; the precipitate settles quickly. According to Schöne, the nitrogen content of the effluent from the slicers should be lowered by about 69 per cent after treatment by the Hoyermann-Wellensiek process. The sewage should then also be incapable of putrefying. According to the report of the Proceedings of the Technical Association of Sugar Manufacturers at their conference in Magdeburg, on the 21st March, 1911, the following managers, Gehrke (Alleringersleben), Thiel, Grünanger (Niederdodeleben), and Dr. Dietrich (Gehrden), who have all employed the process for the purification of their effluents, expressed themselves very favourably with regard to it.

A German ministerial decree of the 4th of July, 1910, by the President of the Government, explains that the question of using the effluents from the diffusion process and from the slicers has proved to be practicable in technical work, so that, in those cases in which nuisances arise from introducing these effluents into the stream unpurified, the police authorities might be justified in forbidding their introduction.

The water from the presses is often purified thus: It is first heated in fermentation tanks, then neutralised, after which it is drained on fields, being subsequently collected and used again.

De Plato treats the filtered water with milk of lime (15° Be) until completely precipitated, and then, after sedimentation, with a five per cent solution of calcium hypochlorite. The water is next decanted and led through five cylinders filled with lumps of coke. Analysis showed that about 50 per cent of the organic matter is thereby removed; the effluent should then be harmless to the fish in the river.

(12) *Sewage from Starch Factories.*

Starch factories may use corn, maize, rice, or potatoes. The sewage varies with the kind of raw material. Starch factories employing rice and maize have effluents containing some free alkali, and now and then some sulphurous acids.

Generally the sewage from starch factories is similar to that from sugar factories. It contains a large amount of organic matter, whilst fermentation and putrefaction readily occur. In Germany potatoes are mainly used as raw material in the manufacture of starch. From a hundredweight of potatoes there is about 50 to 70 gallons of sewage, which consists of waters from washing the potatoes, the by-products and the starch, together with refuse from the pulp-presses.

The sewage is clarified in settling tanks. The effluent, which is acid in reaction, is frequently drained away after this simple clarification. The sludge is from time to time worked up for starch.

With the Hoyermann-Wellensiek process mentioned under sugar-factory sewage, 75 per cent of the organic matter from the starch sewage is separated.

C. Zahn made a detailed investigation of the possibility of purifying sewage from starch factories by means of the biological process. The use of septic tanks instead of sedimentation tanks is not to be recommended. Purification was better the finer the material composing the beds, so that with starch-factory effluents contact beds are superior to percolating filters. It is advantageous here, also, to neutralise the sewage before passing it on to the beds. Zahn effected this neutralisation by mixing acid sewage with some alkaline effluents, or else by means of limestone laid down in the beds. For the preparation of the beds the use of materials free from iron is to be recommended. With a diminution of 80 per cent in the oxidisability of the sewage there was nevertheless subsequent decomposition, so that Zahn urges the adoption, in the case of industrial effluents, of the views held in regard to domestic sewage.

(13) *Sewage from Distilleries and Yeast Works.*

This sewage contains a large amount of organic matter both dissolved and in suspension. It is therefore strongly putrefactive. The effluents from the yeast-presses and from the distillation of the wort are the chief concern in these processes.

They are best disposed of as food for cattle. They may be roughly purified by chemical precipitation (alum and lime) and by sedimentation in tanks.

They may be thoroughly purified by land treatment, by contact beds, or by percolating filters; donble-contact beds can be most strongly recommended.

According to Dibbin, yeast refuse is decomposed very well in contact beds composed of slate.

(14) *Sewage from the manufacture of Sour-krout.*

In this process there result effluents containing large amounts of decomposable substances, which, as a consequence of the sulphur contained in the cabbage, undergo decomposition accompanied by a very strong smell.

The introduction of such sewage into the town drains is dangerous, as good purification of the whole of the town's sewerage is then brought into the question.

There is no information as yet with regard to the direct purification of the sewage, but in my opinion the effluents would be similar in character to those from dairies, and should be purified therefore in a corresponding manner.

In certain places the sewage is purified successfully by allowing it to trickle through deep pits.

(15) *Sewage from Dye Works (Print Works).*

More or less large amounts of organic colouring matter are always found in this type of sewage, which is, consequently, always coloured. The opinion was formerly held that the colour of the sewage caused little harm to the stream receiving it, that, on the contrary, coloured effluents had an æsthetic value in that they allowed the waters of the stream to be coloured with all the colours of the rainbow over considerable distances.

A research of Tienemann of very recent date has, however, shown that this view is not quite correct. On the contrary, many colouring matters used in the manufacture of paper, although they are not poisonous at all to men, have a strongly poisonous action, even at great dilutions, on the most varied kinds of organisms present in water. Victoria blue, methyl violet, charcoal-black, and diamond green B have proved especially fatal to fresh-water organisms even at very great dilutions, so that sewage containing these colours may be very harmful to the fish in the river. This may arise from direct destruction of the fish or from the destruction of the lower organisms in the water, whereby the source of the fishes' livelihood is either ruined or impaired. Besides colouring matters this sewage often contains mordants (mainly aluminium, ferric and zinc salts).

The removal of colouring matters from sewage is still an unsolved problem. The difficulty of removing the colour increases the more permanent the colours are. By biological means, whether by land treatment or by the artificial biological process, the colour is only incompletely removed. The surface of the land or the beds is gradually saturated with the colouring matter, and then allows further quantities to pass through unchanged.

Partial decolorisation is attained in the case of many dye-stuffs by chemical precipitation, using sulphate of iron and lime. After precipitation the sewage is passed through sedimentation tanks or filtered by means of mechanical filters.

The following is a method of decolorisation which has come into general use: The dye-stuffs are reduced to the leuco base and then the colourless sewage is run away. The process cannot be recommended, however. The leuco bases are again oxidised in the river and give coloured compounds, taking from the river-water the oxygen necessary for the oxidation process. In this way, therefore, not only do the colours reappear in the river, but, in addition, the removal of the oxygen from the river-water causes the harm done to the river to be greater and more serious.

It should be best to dilute such sewage considerably, and then run it into the town's sewers.

(16) *Sewage from Chemical Works.*

Sewage from chemical works varies so greatly according to the class of work that it is impossible to give a definite mode of purification ; indeed, this is all the more true as the methods of manufacture are frequently kept strictly secret. Generally speaking, it may be said of this class of sewage that suspended matter may be removed in sedimentation tanks. Substances which are lighter than water (tar, oil, etc.) can be removed from the sewage by means of grease separators.

Nearly all chemical processes require acids or alkalies. By mixing acid and alkaline effluents sufficient neutralisation is attained in some cases. Acids are generally neutralised with lime.

Large amounts of Glauber's salt often result from neutralisation processes. The effluents from organic dye works are often very rich in this salt. In general these salts should be harmless to the living matter in the river, but I might point out that such sewage, in my experience, is capable of destroying extremely rapidly sedimentation tanks made of concrete. These data, which I found in the course of quite different investigations, were confirmed by a manager of a large dye works. The destruction results from the conversion of the free lime of the concrete into gypsum by means of the Glauber's salt. This is accompanied by a disintegration of the concrete.

Very many chemical processes yield coloured effluents. The previous section may be referred to for their purification.

The erection of reservoirs can be strongly recommended for such works, as the sewage is sometimes greatly polluted and large in amount, while at other times it is less polluted and in much smaller quantity.

Occasionally separate treatment of the individual effluents can be recommended. In other cases mixing will be advantageous, as the dissolved substances may precipitate one another. All these circumstances, and, in general, the best methods of purification for sewage from chemical works, are determined in practice by experiment.

(17) *Sewage from Bleach Works.*

In bleach works, sewage is formed which contains alkaline and acid boiler liquors in addition to chloride of lime. The most harmful are the alkali boiler liquors. According to Schiele, superficial purification can be attained thus: The alkaline liquors are stored up in reservoirs, the acid liquors are gradually mixed with them, and then the whole is clarified in settling tanks. The sewage so purified can then be further treated in biological plants. According to a patent process, Keller (Stuttgart) makes the alkaline boiler liquors applicable anew, as he adds dissolved or undissolved lime to them with constant stirring, by which the solution assumes a brighter colour. The liquid decanted from the lime is then used again as it is, or concentrated in some way or another.

(18) *Sewage from Gas Works.*

Sewage from gas plants is generally chocolate-brown in colour, has an obnoxious odour, and contains free alkali, sulphocyanides, phenol, cyanides, tarry products, etc. The disposal of such sewage is a matter of great difficulty, owing to the poisonous substances present. Its admixture with the town's sewage makes purification of the latter considerably more difficult, if there are in any way considerable amounts of sewage from the gas plant.

Chemical precipitation followed by sedimentation is one method of treatment, not, however, very effective.

Radcliffe has worked out and tested a process which proceeds as follows: First, the suspended lime is removed in settling tanks, then the water is pumped into a fractionating apparatus, allowed to trickle down over plates, whilst from below hot exhaust gases containing carbon dioxide and air are blown in. The dissolved lime is thus precipitated and the phenols are destroyed. The lime is separated off in a tank, and the liquid is then driven into a fractionating plant, serving as an auxiliary to the first. Here a stronger stream of air removes the phenols and other substances. They are led into a furnace and burnt. The sulphocyanides are decomposed by dropping in sulphuric acid. After passing through a second settling tank and then being filtered over coke the water should be quite clear. In St. Albans, England, such a plant is used. Many well-known English sewage experts have tested the process and expressed themselves favourably with regard to it.

If gas-works effluents are to be purified by the biological process they must be greatly diluted. Even after considerable dilution or admixture with domestic sewage, the beds may not be loaded too greatly with sewage if sufficient purification is to be obtained.

(19) *Sewage from Ammonia Works.*

This sewage is characterised by a high content of mineral and organic substances. It contains calcium chloride and free lime, under certain circumstances calcium sulphydrate and free sulphur; of organic substances, tarry matter, thiocyanates, pyridine bases, phenol, and other substances are present.

The free caustic lime can be removed by allowing the sewage to trickle over inclined planes, whereby it is converted into calcium carbonate.

By adding caustic soda (1 to 2 lb. per 10,000 gallons of sewage) the sulphur, which is often present in a finely divided condition, should be precipitated along with the calcium carbonate which has separated out. Sulphocyanides are generally present in small amounts, but may amount to 1 per cent. Such large quantities can be precipitated with copper salts and further recovered.

(20) *Sewage from Potash Works.*

Sewage from potash works contains inorganic salts in large amounts, especially magnesium and calcium chlorides. Such sewage cannot be purified by the usual methods. It is generally conveyed directly to the river, and frequently considerably increases the hardness of the river-water and the quantity of salts that it contains. This may be very unpleasant from the point of view of health if towns situated lower down the river draw their drinking-water from the river concerned.

The Imperial Health Commission of Germany has been occupied with the question of this type of sewage. It recommends that the limit be fixed at an increase to 50° of hardness in the river-water. Further, the following procedure was recommended to prevent the river-water receiving excessive amounts of such salts :—

(1) Arrangement of suitable distributors and regulation of the discharge in the case of the final liquors.

(2) Provision of reservoirs large enough to contain the final liquors in individual works.

(3) A number of controls working through a central enquiry office.

Lately these effluents have been used for laying dust on the roads. Owing to the calcium and magnesium chlorides present, which are very hygroscopic salts, the sewage keeps roads moist and thus lays the dust. In Frankfort, with such liquors, it has been shown by investigation that they are specially useful in winter during a dry frost. On such days the streets cannot be watered, as they would very soon freeze. Each watering-cart set in motion on the unwatered streets generates big clouds of fine ice particles. If, however, the streets are sprayed with these liquors, owing to their considerably lower freezing-point, not only is no ice formed, but the surface of the street (asphalt) remains moist for eight days without requiring further watering.

(21) *Sewage from Metal Works and works manufacturing Mordants.*

Such sewage is generally acid and contains metallic salts. It is very harmful if led directly to the river. It discolours the river-water, moreover, owing to the separation of iron and other metallic salts.

Purification can be effected by neutralisation with lime and subsequent treatment in settling tanks. One disadvantage of this process is that it yields large amounts of sludge.

It is better, therefore, to evaporate the effluents and recover the metallic salts. In England, according to Schiele, it pays to use this method.

(22) *Sewage from works manufacturing Photographic Paper and Cards.*

The sewage from such concerns can be divided into two classes, concentrated sewage and washing-waters. The concentrated effluents contain the most diverse chemicals (acids, alkalis, etc.), as must naturally occur in such manufacturing operations.

Pritzkow recommends either leading the concentrated effluent directly into sewers, in which case difficulties should not arise, or the effluent should receive a special treatment. Pritzkow advises the following method of purification: The strongly concentrated sewage (dyeing machines; the working up of the residues) is freed from acids, alkalis, and harmful salts by methods worked out from individual tests. To take one example, it would perhaps pay to recover thiosulphate from the water containing it. Then the water thus obtained, and the concentrated effluent, with which such treatment is impossible, are collected in a tank. Here the various kinds of sewage can mix, decompose, and, as far as possible, neutralise one another. The discharge from this tank might be mixed with the washing-waters, which are freed from suspended matter in a special sedimentation tank, and can then be run away into the river.

(23) *Sewage containing Cyanides.*

This type of sewage has been the object of an enquiry by the Imperial Health Commission (*Reichsgesundheitsrates*) (Rubner and von Buchka). Many sugar refineries work up their molasses for cyanides. Gases from smelting furnaces are often freed from their impurities by washing with water, and are then used again in the process. The sewage resulting from this washing process generally contains large amounts of cyanides. In the sugar refinery at Dessau, according to the description of the Imperial Health Commission, the cyanides are removed from the sewage in the following manner: The effluents containing cyanides are collected in pits. Sacks containing sulphate of iron are hung in the water, and the salt dissolved by the hot sewage. Then caustic soda is added, and it is next made weakly acid with sulphuric acid. The whole is well stirred by blowing in a rapid current of air. The addition of caustic soda and sulphuric acid is made in calculated amounts corresponding to the analytical results from tests of the contents of the pits. The mixture thus obtained is then expressed in filter-presses. Should the water from the presses not be clear, or if the qualitative test (Prussian blue) still shows the presence of cyanides, it is sent back to the pits, and from thence back once more to the presses. The blue sludge, which comes from the presses containing about 70 per cent water, is dried in pans and then contains about 45 per cent of potassium ferrocyanide.

(24) *Sewage from plants employed in scouring, combing, and finishing wool.*

The most concentrated and unpleasant effluent from this manufacturing process is the effluent from the scouring of the wool, containing soap. It is to be recommended that, in all circumstances, such sewage should be worked up by itself. It is generally freed from the threads by means of screens, sieves, or similar apparatus, and is then acidified with sulphuric acid to decompose the soap. Good mixing is obtained by blowing in a rapid current of air or steam. The acidified sewage is then allowed to stand for a time in large settling tanks. The sludge, which is rich in fats, is worked up for fat (see p. 106). The sewage can then be further purified by means of intermittent ground filtration, or by the artificial biological process (percolating filters or double-contact beds being the best). The small amount of free sulphuric acid should not occasion any trouble in the biological treatment. In some plants, however, the acid effluent is neutralised with lime before the biological process. Frequently the sewage is conveyed directly to the river without any biological treatment, after acidification with sulphuric acid and sedimentation.

(25) *Sewage from Petroleum Refineries.*

The sewage resulting from the refining process consists of waste acid, acid washing-water, caustic soda, and alkaline wash-waters. According to a decree of the authorities in Austria, the disposal of such sewage is to be effected somewhat in the following manner : The waste acid is allowed to stand some time, during which the tar separates out on top ; this can be skimmed off and burned (mixed with sawdust), or it is worked up as asphalt. The dirty and dilute acid may be sold to artificial-manure manufacturers. If the acid cannot be sold it is neutralised with lime ; the resinous mass thus separating out is skimmed off, and the neutralised effluent is freed from suspended material, oily, tarry, and such substances, both in settling tanks and by filtration through wool-waste or peat, etc.

The acid and alkaline washing-waters are mixed; if the acid is not sufficient to neutralise the alkaline portion, part of the muddy acid from above (after the removal of the resinous mass) is added to the mixture. This mixture should still have a distinctly acid reaction; it is then boiled to decompose the petroleum soaps. After skimming off the oily layer on top, the aqueous and still acid liquid underneath is also purified in the above-mentioned settling tanks and filters.

For larger works a special clarification plant for acid and alkaline sewage is to be recommended.

(26) *Sewage containing Soaps.*

If it is a question of an effluent containing soap without the addition of other polluted water, as is the case with many laundries, good purification can be effected, according to Heydt, in clarifying wells having large plates to oppose the passage of the sewage, which is made to flow at a very small velocity. Milk of lime is automatically added to the sewage at the inlet to the well. The amount added must be estimated by experiments on the particular effluent. After passing through a sand filter of small depth the sewage is sufficiently purified for it to be led without harm to any small stream. It is important to take care that the floating particles which are formed are retained in the clarifying plant and do not reach the filter. It is advantageous to have the sewage exposed suitably to the air (to absorb carbon dioxide) before coming on to the filter, and to interpose a reservoir or second clarifying well.

Use of septic tanks for this class of sewage is considered inadvisable by Heydt, and only a biological plant with a very large surface is practicable. Lubbert also regards the biological process for the purification of laundry sewage as unsuitable, and likewise recommends precipitation with lime.

In the opinion of the author it must be possible to purify such soapy liquors by the addition of sulphuric acid till weakly acid, followed by the separation in a grease separator of the precipitated fatty acids, which could then be recovered. The fatty acids would be separated all the more easily, as such sewage generally reaches the sewers warm.

(27) *Sewage from Oil Works.*

The sewage, on account of its high content of organic substances, was used in South France as manure for pasture-land. Its success, however, was very small. The reason for this is, no doubt, the large amount of acid in the sewage. According to Ventre, the sewage should lose its acidity on standing in the air, and then after mixing with superphosphate or with animal manure it should give a good manurial material.

C. The Disinfection of Sewage.

Sewage generally has a germ-number of one or more millions. As Spitta has shown, most of the bacteria are associated with the undissolved matter, so that by separating off the suspensions a considerable reduction of the germs is effected. The bulk of these bacteria are of a harmless nature, but there are undoubtedly also many disease germs among them.

Since these disease germs under ordinary circumstances can only exist a limited time in the river under the changed and hostile conditions there, disinfection of the sewage is generally unnecessary, the more so as nowadays river-water is no longer used by municipalities for the water supply without undergoing some treatment.

It is naturally very advisable in this state of affairs that the excreta from people suffering from all infectious diseases, especially typhoid, should be disinfected. The Prussian law takes this into account, since it prescribes disinfection of all the refuse from persons suffering from notifiable diseases.

It is best, likewise, to disinfect the sewage of houses where there is sickness, before it enters the general sewage system.

Disinfection is necessary in times of epidemic, as the many disease germs deposited in the river favour the spreading of contagion. In most sewage plants there are for cases such as these devices which disinfect the whole of the sewage. Chloride of lime has proved the best disinfectant, but this only acts sufficiently well when all suspended matter over 1 millimetre in size has been removed. According to Schmidtmann, Thumm, and Reichle, in times of epidemic the storm overflow-water of the town constitutes an especial danger.

Industrial sewage in general need not be disinfected. Only in the sewage from slaughter-houses and knackers' yards can disease germs be present. Tannery sewage also may contain inflammatory spores. Chloride of lime is the best disinfectant for such sewage also.

According to Kurpjuweit, good regulations for the amount of chloride of lime required cannot be given. In general, treatment for two hours is sufficient. With a concentration of 1 part of chloride of lime in 5000 parts of water, and with treatment lasting two hours, Kurpjuweit was able to disinfect the sewage in Charlottenburg sufficiently.

On the contrary, Kranepuhl asserts that for certainty a concentration of 1 : 1000 must be employed for two hours' treatment, or a concentration of 1 : 2000 for four hours.

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