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OSAL WORKS

RAIKES

SEWAGE DISPOSAL WORKS

THE DESIGN, CONSTRUCTION AND MAINTENANCE OF

SEWAGE DISPOSAL WORKS

BEING A PRACTICAL GUIDE TO MODERN METHODS OF SEWAGE PURIFICATION

BY

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ERRATA.

Page 43.—B. Nathan *should be* Baldwin Latham.

Page 105.—Fourth line from the bottom *should be* Fig. 15, *not* Fig. 14.

Page 172.—Bottom line, page 184, *not* 29.

Page 300, line 23.—spalsh *should be* splash.

PREFACE.

In view of the fact that many millions of pounds sterling are spent annually on Sewage Disposal Works, it is obviously a matter of the utmost importance, in the interests both of economy and of the public health, that those who are entrusted with the design and construction of such works, or with the expenditure of public money upon them, should not only clearly understand the essential principles involved, but should also have at their disposal the latest results of contemporary experience to guide them in the practical application of those principles.

The chemical and biological aspects of Sewage Disposal have been very fully and ably dealt with by a number of eminent scientific authorities, but no book has recently been published from which equally full and reliable information can be obtained regarding the more practical side of the question, considered from the point of view of the engineer, although the design and construction of Sewage Disposal Works are essentially the occupation of an Engineer, and Consulting Engineers engaged on this kind of work have unequalled opportunities for collecting information under widely varying conditions.

In attempting to make good this deficiency I have endeavoured to present an impartial review of the " Modern

Methods of Sewage Purification," on the practical application of which I have been engaged for the past 15 years, in conjunction with my partner, Mr. J. Edward Willcox, M.Inst.C.E.; and I venture to hope that the collection and classification of the large amount of valuable information now available within the compass of a single book may lead to the circulation of ideas, and so prove of some benefit to those who at present find it difficult to get a comprehensive view of an exceedingly interesting but complex subject.

No one is yet entitled to claim that he has solved the problem of Sewage Disposal by determining the most efficient and economical means of preventing the pollution of our rivers and estuaries in all circumstances; and although the concentrated attention of so many thoughtful observers on the subject has naturally resulted in the very rapid development of our knowledge regarding it, the full benefit of their independent researches in various places is only to be obtained by the collection and comparison of the valuable data which have been published from time to time, but only in scattered and disconnected form.

It is, however, most unsafe to assume that because a particular method of sewage purification or disposal has proved successful in one case, a similar arrangement of works will give equally satisfactory results elsewhere, since the wide variations in local conditions require the most careful consideration before it is possible to determine the system or combination of systems by which the essential principles of a process can be most conveniently applied.

An impartial judgment, based on a wide experience of practical work, is therefore of the first importance in designing works which will not only be certain to comply with the requirements of the Local Government Board and River Authorities, but will also produce the best possible results with the minimum of expense, and for those who may not have had an opportunity of acquiring this qualification by their own observations a comprehensive book of reference such as this may, perhaps, afford the most convenient means of studying the subject.

In the hope of avoiding the confusion of ideas which so frequently results from the mere accumulation of ill-assorted information, my particular attention has been devoted to the classification of the subject and to its arrangement in chapters, in order that the various alternative means of sewage purification in practical operation during the first seven years of the twentieth century may be separately considered to the best advantage.

The systematic use I have made of the information contained in papers contributed to scientific societies and technical journals is in itself sufficient to indicate my appreciation of their value, and so long as such publications as the "Surveyor," the "Contract Journal," and the "Engineering News" maintain the very high standard of excellence that they have now reached, no writer can afford to ignore them.

It remains for me to express my deep obligation to the many authorities consulted, either by correspondence or

otherwise, on the various sections of the subject, and to add that although references are given as far as possible to all books and papers that have been used, these can only represent a small proportion of my indebtedness for the help I have received. My thanks are particularly due to Dr. Gilbert J. Fowler, D.Sc., and Mr. J. D. Watson, M.Inst.C.E., for their kind assistance in revising some of the proofs, in furnishing material for illustrations, and in providing me with much valuable information regarding the works under their control at Manchester and Birmingham respectively.

Since mistakes and repetitions are inevitable in a book of this description, compiled and written during the irregular intervals of relaxation from strenuous professional work, I should greatly appreciate any suggestions or corrections which might enable me to improve a future edition.

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January, 1908.

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SEWAGE DISPOSAL WORKS.

INTRODUCTION.

Purification of sewage due to action of bacteria—American experiments at Lawrence and Columbus—England the pioneer in practical sewage disposal—Co-operation of Engineers, Chemists and Bacteriologists—Royal Commission on Sewage Disposal—Classification of alternative processes—Sludge disposal and sterilisation—Principles of bacterial action—Examination of bacteria in sewage.

"SEWAGE DISPOSAL WORKS" comprise all the artificial means employed for facilitating the purification of sewage; and although such works may be designed for the application of many different mechanical, chemical, and biological processes, the ultimate aim and object of them all is to separate the organic matters contained in the sewage from the water in which they are dissolved or suspended, and to render them innocuous by decomposition and oxidation, while at the same time restoring the water itself to a state of comparative purity, so that it may not injuriously affect any stream, river, or tidal estuary through which it may pass on its way back to the sea.

No useful purpose can be served by tracing all the successive stages by which modern methods of sewage disposal have been gradually developed, as this would simply amount to a statement of many historical facts which have already been repeatedly dealt with by other writers, while any attempt to apportion the credit for what has been done among all the different Authorities who have contributed more or less directly to the accumulated knowledge which we now possess regarding this subject would not only be a very thankless task, but could be of no practical use in solving the problem of sewage disposal.

It will therefore be sufficient to emphasise the fact that, no matter what method of treatment may be adopted, it now seems to have been well established as a fundamental principle that the purification of sewage is mainly due to the action of living organisms or bacteria, by whose natural agency all the waste products of animal and vegetable life undergo a process of decay which results in the separation of their constituent elements, so that these are rendered available for forming fresh chemical combinations of an entirely different character to those from which they were derived.

This theory of sewage purification cannot be described as entirely new, since the idea of bacterial fermentation on which it is based has formed the subject of scientific research for at least 30 years, and a vast amount of time and money has been devoted to its development during that period by many investigators both in England and other European countries; but public attention has been more particularly drawn to it since 1888 by the valuable reports so liberally published by the Massachusetts State Board of Health regarding the experimental work conducted at Lawrence, in the United States of America.

When the Author had the privilege of visiting this experiment station in October, 1903, he was not only presented with 10 volumes of annual reports, containing about 850 pages each, in which the results of all the experiments are admirably tabulated and described, but Mr. H. W. Clark * (the Chemist in charge) also showed him the utmost courtesy in explaining the various methods adopted in conducting the experiments, together with the constructional details and general equipment of the temporary plant, so that he

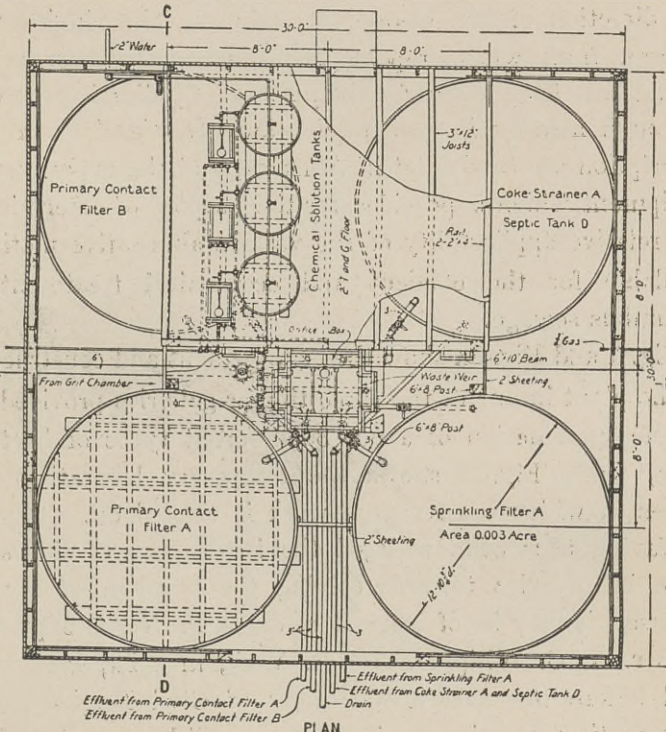

Fig. 1.—Sewage Testing Station at Columbus, Ohio, U.S.A.
Plan of East Gallery.

(Reproduced by permission of Mr. G. A. Johnson, Columbus, Ohio.)

is in a position to thoroughly appreciate the valuable work that has been accomplished under Mr. Clark's direction, and which undoubtedly did more than anything else to

* Chemist to the Massachusetts State Board of Health.

establish the general principles of biological sewage treatment at the end of the 19th century.

Further experiments of a similar character were also commenced in 1904 by the Board of Public Service at Columbus, Ohio, U.S.A., where a very complete installation of septic tanks and bacteria beds has been laid down under the direction of Mr. George A. Johnson, the Engineer in charge, from whose reports the illustrations Fig. 1 and Fig. 2 have been taken, for the purpose of indicating the very thorough manner in which scientific investigations of this description are conducted in America, and the experimental equipment which is provided for the purpose of determining the relative applicability of the various alternative methods available for the efficient and economical treatment of Columbus sewage.

Fig. 1 and Fig. 1A show the arrangement and construction of the plant in one of the three timber galleries provided for the accommodation of about 30 different types of bacteria beds, while Fig. 2 shows the temporary laboratory and offices in which the research work is carried on.

Having thus acknowledged the importance of the work done in America towards solving the problem of sewage disposal, it may be of interest to quote the views expressed by Mr. G. C. Whipple, of New York, in a Paper recently read before the American Society of Civil Engineers, as representing the impressions of a well-known American Engineer after visiting most of the more important European sewage disposal works in practical operation at the present time, as distinct from those already referred to which are purely experimental.

He says :* " England has taken the lead in these matters, and it is there that one must go to find the latest developments

* Transactions of the American Society of Civil Engineers, Vol. 57, page 92.

in the art. If one asks the reason for this, a fitting reply is found in the old adage : ' Necessity is the mother of inven-

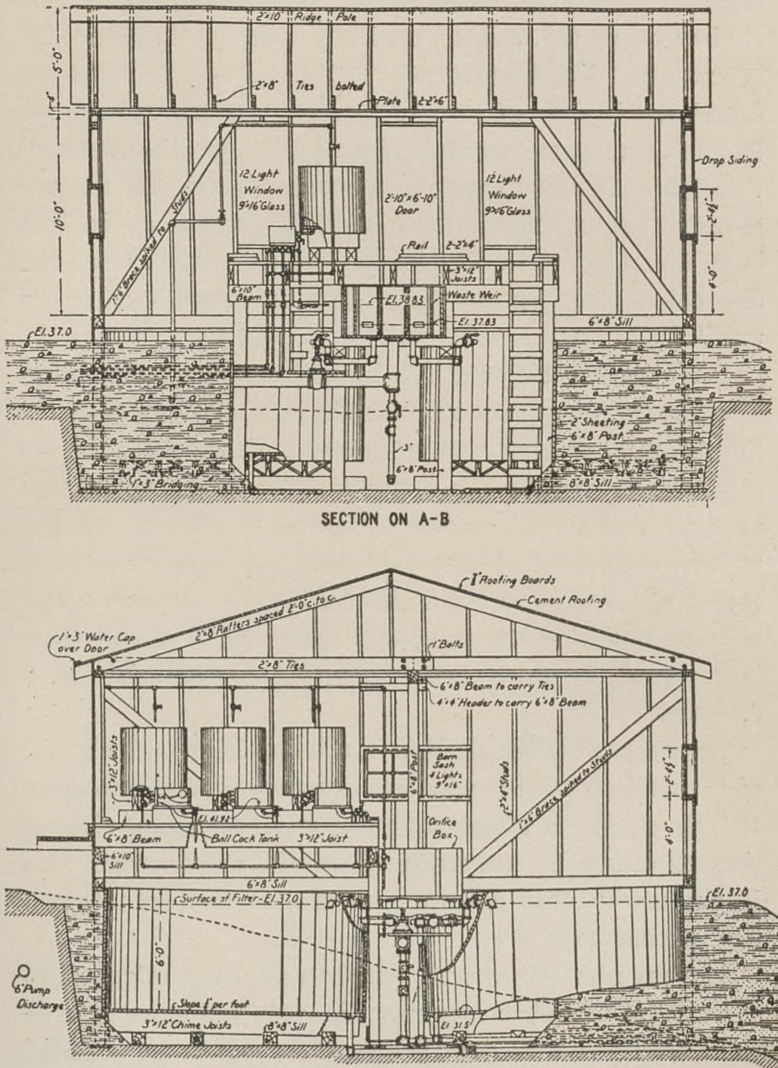

Fig. 1A.—Sewage Testing Station at Columbus, Ohio, U.S.A. Sections of East Gallery

(Reproduced by permission of Mr. G. A. Johnson, Columbus, Ohio.)

tion.' The English rivers are small, the English cities are large and numerous, and the amount of manufacturing carried on in them is very great; consequently the streams are badly polluted, and the need of sewage purification works is pressing. Furthermore, the soil of the country is not well suited for land treatment of sewage, and in consequence English Engineers have been forced to adopt other methods. This has stimulated their ingenuity, and given rise to many modifications of chemical and bacterial processes. In England, therefore, one can see more and learn more of sewage disposal at the present time than anywhere else in the world."

The fact that England has been thus compelled by force of circumstances to set an example in attempting to reduce the pollution of her rivers and streams has afforded English Engineers unequalled opportunities for acquiring practical experience from the success or failure of different methods under widely varying local conditions, and it is by the application of this experience to the design and construction of sewage disposal works on a large scale that English practice has gained the lead which was at one time claimed by America.

The example of England is now being followed by France and Germany, where important experiments are in progress, and the subject is attracting an increasing amount of attention, as shown by the recent visits of French and German Engineers to this country for the purpose of studying English methods.

Any measure of success which may have attended the efforts of the English Engineers in constructing sewage disposal works is very largely due, however, to the scientific study of the subject which has been simultaneously carried on in different parts of the country by so many eminent

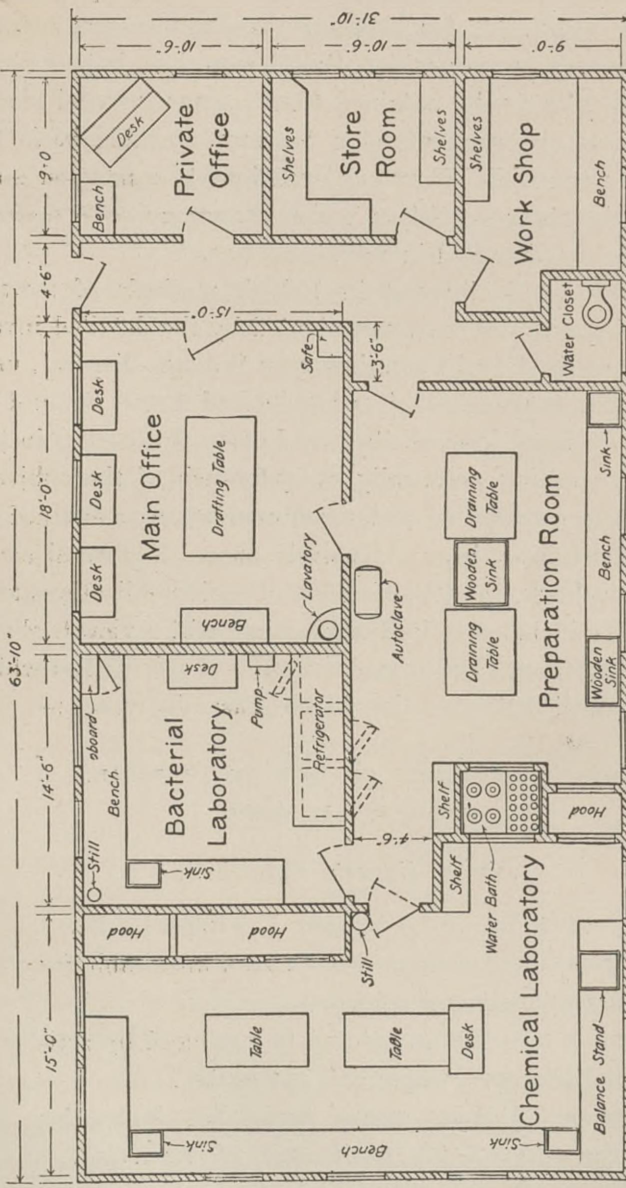

Fig. 2.—Sewage Testing Station at Columbus, Ohio, U.S.A. Plan of Laboratory and Offices. (Reproduced by permission of Mr. G. A. Johnson, Columbus, Ohio, U.S.A.).

Chemists and Bacteriologists, without whose co-operation it would be impossible for Engineers to draw correct conclusions from the works which they themselves have carried out, while the results obtained from sewage disposal plants in practical operation afford a far more reliable basis for research work than laboratory experiments conducted on a small scale under conditions which cannot quite correspond with those encountered in actual practice.

The world-wide interest in British methods of sewage purification has also been accentuated by the detailed investigations of the Royal Commission on Sewage Disposal, now sitting, who have collected and published a vast amount of valuable evidence from all the best known Authorities in the country regarding practically every branch of the subject; and, as the conclusions and recommendations contained in their Reports have been extensively quoted in several chapters of this book, the following list of their publications may properly be included in its Introduction, with a view to showing the wide range and complex nature of the studies which have occupied their attention for the past nine years :—

ROYAL COMMISSION ON SEWAGE DISPOSAL,
APPOINTED IN 1898.

List of Reports Published.

1901. INTERIM REPORT. Volume I.—Report. 2d.

Question 1.—Are some sorts of land unsuitable for the purification of sewage?

Question 2.—Can an effluent be produced by artificial processes which will not purify?

Question 3.—What means should be adopted for securing the better purification of our rivers?

1902. Volume II.—Evidence. 4s. 6d.

1903. Volume III.—Appendices. 14s. 9d.
1902. SECOND REPORT. 4s. 10d.
Special investigations by officers of the Commission regarding :—
The Manchester Experiments.
Biological Standards.
Effect of Filtration in Reducing Bacteria.
Pollution of River Severn.
Self-Purification of Severn.
Methods of Bacteriological Examination.
1903. THIRD REPORT. Section 1.—Trade Effluents.
Section 2.—Central Authority.
Volume I.—Report. 4½d.
Volume II.—Evidence. 2s. 8d.
1904. FOURTH REPORT.—Pollution of tidal rivers and contamination of shell fish.
Volume I.—Report. 4½d.
,, II.—Evidence. 6s. 6d.
,, III.—Dr. Houston's Report. 10s. 10d.
,, IV.—Land Treatment.
,, ,, Part 1.—General Report. 3s. 9d.
,, ,, ,, 2.—Chemical Report. 9s. 7d.
,, ,, ,, 3.—Bacteriological Report. 5s. 3d.
,, ,, ,, 4.—Engineering Report. 11s.
,, ,, ,, 5.—Analysis Report. 7d.

This Commission was appointed on May 27th, 1898, under the Presidency of the Earl of Iddesleigh, to inquire and report upon :—

I.—(1) What method or methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted, consistently with the due requirements of the existing law, for the protection of public health, and for the economical and efficient discharge of the duties of the Local Authorities; and

(2) If more than one method may be adopted, by what rules, in relation to the nature or volume of the sewage or the population to be served, or other varying circumstances or requirements, should the particular method of treatment and disposal to be adopted be determined : and

II.—To make any recommendations which may be deemed desirable with reference to the treatment and disposal of sewage.

The following abstracts from the Commission's Interim Report published in 1901 will serve to indicate the general scope and result of their earlier investigations in regard to certain questions which were considered to be of such urgent importance as to justify the publication of a preliminary report.

"We humbly report as follows :—

"We have examined a large number of witnesses, and visited many sewage works of various kinds. We have also instituted through our own officers a number of necessary scientific investigations.

"Many of these investigations are still in progress, and considerable time must necessarily be taken by the work which still remains to be done, and especially by such work as is needed before the second part of the Terms of Reference can be adequately dealt with.

"We have, however, arrived at conclusions on three questions which appear, for reasons hereafter given, to be of urgent importance, and we have therefore deemed it desirable to make a preliminary report and to publish the evidence already taken.

"The three questions are :—

"(1) Are some sorts of land unsuitable for the purification of sewage?

"(2) Is it practicable uniformly to produce by artificial processes alone an effluent which shall not putrefy and so create a nuisance in the stream into which it is discharged?

"(3) What means should be adopted for securing the better protection of our rivers?

"The first Sewage Commission was appointed in the year 1857. In 1865, as a result of labours extending over eight years, they reported that :—

"'The right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided.'

"The last Commission was appointed in 1882. They were directed to inquire into and report upon the system under which sewage was discharged into the Thames by the Metropolitan Board of Works, whether any evil effects resulted therefrom, and, if so, what measures could be applied for remedying or preventing the same.

"In November, 1884, they issued their final report. They found that evils did exist 'imperatively demanding a prompt remedy,' and that by chemical precipitation a certain part of the organic matter of the sewage would be removed. They reported, however, 'that the liquid so separated would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a permanent measure. It would require further purification, and this, according to the present state of knowledge, can only be done effectually by its application to land.'

"Since the publication of the last-mentioned report, it has been the practice of the Local Government Board to require, save in exceptional cases, that 'any scheme of sewage disposal, for which money is to be borrowed with their sanction, should provide for the application of the sewage or effluent to an adequate area of suitable land before its discharge into a stream.' There can be no doubt, in our opinion, that the Local Government Board were bound, under the circumstances, to insist upon such a rule.

"It is now contended that in many cases, especially in the great centres of manufacturing industry, the *land available is either of unsuitable quality, is available in quite inadequate area for effective filtration through the soil, or is obtainable only at a prohibitive cost*, and it is suggested that sewage purification may, in such cases, be carried out on comparatively small areas artifically prepared. During recent years a variety of artificial processes, differing from those which were considered by the earlier Commissions, have been elaborated for treating sewage, and it is urged that satisfactory effluents can be obtained by such artificial processes.

QUESTION I.—*Are some sorts of Land unsuitable for the Purification of Sewage?*

"We doubt if any land is entirely useless, but in the case of stiff clay and peat lands the power to purify sewage seems to depend on the depth of the top soil.

"There are, of course, numerous gradations in the depths of top soil which are met with in nature, and it is not easy to draw the line between lands which contain a sufficient depth to justify their use, and lands which do not.

"We are, however, forced to conclude that peat and stiff clay lands are generally unsuitable for the purification of sewage, that their use for this purpose is always attended with difficulty, and that where the depth of top soil is very small, say 6 inches or less, the area of such lands which would be required for efficient purification would in certain cases be so great as to render land treatment impracticable.

Question II.—*Is it practicable uniformly to produce by Artificial Processes alone an Effluent which shall not putrefy and so create a Nuisance in the Stream into which it is discharged?*

" After carefully considering the whole of the evidence, together with the results of our own work, we are satisfied that it is practicable to produce by artificial processes alone, either from sewage, or from certain mixtures of sewage and trade refuse, such, for example, as are met with at Leeds and Manchester, effluents which will not putrefy, which would be classed as good according to ordinary chemical standards, and which might be discharged into a stream without fear of creating a nuisance.

" We think, therefore, that there are cases in which the Local Government Board would be justified in modifying, under proper safeguards, the present rule as regards the application of sewage to land.

" No general rule as to what these safeguards should be can be laid down at present, and indeed it will, probably, always be necessary that each case should be considered on its own merits.

Question III.—*What means should be adopted for securing the better Protection of our Rivers?*

" We consider it of the utmost importance that the simplest possible means should be provided for adequately protecting all our rivers, and we are further of opinion that it will be desirable, probably for some time to come, that scientific experiments should be carried on in order to ascertain all the real dangers of pollution against which they should be protected.

"In the present state of knowledge, and especially of bacteriology, it is difficult to estimate these dangers with any accuracy, and it seems quite possible that they should be either exaggerated or undervalued according to the predisposition of those who have to deal with them. An authority guided by medical considerations might not unnaturally be inclined to insist on a degree of purity which may ultimately prove in certain cases to be uncalled for, while another authority, with his mind fixed upon economy, might shrink from taking essential precautions.

"It is, perhaps, scarcely for us to say what arrangements should be made, but we are of opinion that the general protection of our rivers is a matter of such grave concern as to demand the creation of a separate Commission, or a new department of the Local Government Board, which shall be a Supreme Rivers Authority, dealing with matters relating to rivers and their purification, and which, when appeal is made to them, shall have power to take action in cases where the local authorities have failed to do so."

In the same report the Royal Commission also give a list of the artificial processes investigated in considering Question II., which, together with the alternative forms of land treatment, comprise all the methods of sewage purification in general use at the present time; but before proceeding to define these different methods, it may first be advisable to briefly explain their classification and the essential principles involved in the theory of bacterial action which they are designed to facilitate.

Broadly speaking, modern sewage purification may be divided into the two stages of clarification and oxidation: the first or preliminary stage consisting in the reduction of solid suspended matter by screening or straining and various systems of treatment in tanks, while the removal of dissolved impurities, together with any matters remaining in suspension, is accomplished in the second stage by a process of oxidation in the interstices of the soil or artificially-constructed bacteria beds, it being usually found that the liquid remaining after the removal of the suspended solids still contains about 50 per cent. of the original impurity in the sewage, and even if it is completely clarified the liquid will again become dark-coloured and offensive when allowed to stand owing to the putrefactive changes which take place in the organic matter retained in solution.

Although each of these two stages of purification may be effected by the four distinct methods of treatment mentioned in the following classified list, the works required for the complete disposal of sewage will usually consist in a combination of several methods to suit the special circumstances of each particular case.

Classification of Methods.

(1) *Clarification Processes.*	(2) *Oxidation Processes.*
(a) Screening	(a) Broad irrigation
(b) Sedimentation	(b) Land filtration
(c) Precipitation	(c) Contact beds
(d) Liquefying	(d) Percolating filters

It should, however, be observed that although the solid matter intercepted in the form of sludge during the process of clarification may largely consist in indestructible minerals, it also contains a considerable proportion of highly putrescible organic matter, and since its purification cannot be readily accomplished by the ordinary processes of oxidation in the interstices of the soil or bacteria beds, its economical disposal frequently involves some of the greatest difficulties encountered in the whole problem of sewage disposal, and the special means employed for its treatment are therefore dealt with separately in Chapter V.

Even after the complete oxidation of all the suspended and dissolved impurities in the sewage, it has also been suggested that all pathogenic organisms should be destroyed by some system of sterilisation or disinfection before the purified effluent is discharged into any water courses or river estuary, where its presence might affect public water supplies or shell fish; but, apart from the heavy expense which any such system must involve, the fact that it would become quite impracticable to apply it during storms renders it far more likely to increase the danger than otherwise, by creating a false sense of security among those responsible for the purification of the water.

Although certain forms of bacteria have been identified as disease germs, the vast majority are decidedly beneficent in their action; in fact, it is mainly by their agency that animal and vegetable waste is rapidly destroyed, and the earth is thus maintained in a habitable condition by the continual conversion of matter from one form to another in accordance with the great natural laws of perpetual change.

The enormous numbers of these bacteria which exist in sewage may be judged by the fact that a single drop may contain several millions, no less than seven millions having been found in a cubic centimetre (about a thimbleful) of London sewage at Barking,* and the bacteriological examination of sewage for the purpose of distinguishing different

* "The Purification of Sewage and Water," by W. J. Dibdin, F.I.C., F.C.S. 1903.

varieties of bacteria is, for this reason, attended with considerable difficulty.

There are, however, two main classes of bacteria which are chiefly concerned in the purification of sewage, and these may be distinguished by their respective aversion to and affinity for oxygen, and it is owing to these characteristics that they are now generally known as anaerobic and aerobic respectively, the presence of air and light being prejudicial to the first and favourable to the second; the one producing putrefaction, which is accompanied by the escape of offensive gases, while the oxidation affected by the other is free from all obnoxious characteristics.

No one should be misled into thinking that these bacteria exist in sewage alone, since they abound in the surface layers of the soil, and considerable numbers are also present in both air and water, while they multiply at an amazing rate under conditions favourable to their development.

Assuming that a fresh generation is produced every hour, it has been estimated by Professor Cohn* that about 16½ millions might be produced from a single microbe within 24 hours; but it will be understood that this almost incredible rate of increase is purely theoretical, being calculated on the assumption that their growth is not impeded in any way, which is a condition quite unattainable in practice.

The above figure is, however, still interesting, by way of showing the vast possibilities that exist in the study of this subject, as by creating conditions that are far less favourable than the ideal the power of these bacteria may be increased to an enormous extent, and the purification of sewage may therefore be immensely accelerated and simplified by the

* "The Purification of Sewage and Water," by W. J. Dibdin, F.I.C., F.C.S. 1903.

proper application of the vast natural force which is at present so very imperfectly understood or appreciated.

The purifying effect of bacteria on sewage is due to their power of absorbing certain substances, whose combination with other substances being thereby destroyed the remainder are liberated and decomposed into simpler form, this action being carried on by the bacteria present in the sewage working jointly with those which have found lodgment in the soil or other media through which it passes for the purpose of purification, so that rapidity of sewage purification practically depends upon the number and activity of bacteria with which it comes in contact, the chemical changes taking place being briefly summarised as follows :—

"The nitrogenous matters are resolved with either the production of ammonia or the oxides of nitrogen, or possibly the evolution of uncombined nitrogen. The oxygen and hydrogen, forming a considerable portion of the matters, are recombined into water, and the carbon becomes carbon dioxide, or carbonic acid gas, as it is generally called. Similar transformations take place with these elements in vegetable matters, but a longer time is usually required for the completion of the process than is the case with animal substances, as they do not form so suitable a medium for the support of microbic life." *

In order to estimate the number of bacteria present in sewage or any other fluid, it is first necessary to isolate them, and then to cultivate a colony from each, so that the colonies may be readily counted with the aid of a miscroscope.

This method was devised by Koch, and the colonies are usually cultivated in a thin film of some nutrient media,

*Report by Colonel T. W. Harding and W. H. Harrison, M.Sc., on the Leeds experiments. 1905.

such as a mixture of meat broth and gelatine, in a shallow glass dish, which can be placed on a plate ruled in centimetre squares to facilitate counting; but as only about 200 colonies can usually be cultivated in an ordinary Petri dish without overcrowding, only a minute fraction of a cubic centimetre of sewage is required for each experiment.

It would, however, be impracticable to measure such an exceedingly small quantity of sewage by itself, and it is therefore found more convenient to take a cubic centimetre as being the standard unit of measurement, the number of bacteria contained in this quantity being first reduced to the required extent by diluting the sewage with sterile water, so that the proportion of water to sewage represents the figure by which the number of bacteria found in a cubic centimetre of the mixture should be multiplied in order to obtain the number per cubic centimetre in the original sewage.

This cubic centimetre of diluted sewage is then mixed with about 10 c.c. of melted gelatine and poured into the shallow glass dish above referred to, which is covered with a close-fitting lid and placed on a levelled plate.

The gelatine is then allowed to set, and after about 48 hours' incubation at from 20 deg. C. to 22 deg. C. the colonies of each individual organism will gradually develop until many of them become visible to the naked eye, and can be easily counted with a microscope.

In case the colonies are found to be overcrowded or unnecessarily isolated, this may be corrected by increasing or reducing the proportion of water added to the sewage before taking the sample cubic centimetre from which the culture is made, and the required degree of dilution can thus be determined by a process of trial and error.

There are many other methods of preparing cultures which have been specially devised to suit the peculiarities of the different kinds of bacteria which it may be desired to investigate; but as it is beyond the scope of this book to explain the details of their application, it will be sufficient to mention the methods most commonly employed, and to point out the necessity for excluding free oxygen from the vessel in which anaerobic organisms are to be cultivated, which may be accomplished by enclosing the cultures in a jar containing a solution of alkaline pyrogalate to absorb the oxygen in the air.

It is found convenient in some cases to first prepare the film of nutrient gelatine on a glass plate, and when it has become quite firm, 1 c.c. of the diluted sewage can be spread over the surface, so that none of the organisms are retarded in their development by being covered with gelatine, while the whole of them can, by this means, be more easily examined and counted.

Since different varieties of bacteria require different kinds of food it naturally follows that they cannot all be successfully cultivated in the same nutrient media; for example, although the meat gelatine already referred to is the best media in which to develop cultures from most of the ordinary organisms in sewage, it has been found to be useless for nitrifying bacteria which require a food material free from organic matter, and it is therefore necessary to use a silica jelly plate for the cultivation of the latter when these are to be specially studied.

The fact that sewage bacteria are commonly referred to as either aerobic or anaerobic must not be taken to imply that the action in these two classes is entirely independent, these names being merely intended to define the general conditions which are most favourable to each, but since the conditions occurring in practice are seldom ideal or fatal to the whole of either class, there is usually a very considerable amount of overlapping, and even when the surrounding conditions are peculiarly favourable to one class, the other is seldom quite inactive or entirely absent.

In the bacterial purification of sewage, the breaking down of the solids in suspension is mainly effected by anaerobic bacteria having the power of liquefying certain kinds of solid organic matter, and this action is therefore carried on far more rapidly in the absence of air; but there are other so-called "facultative" anærobes, the action of which is not necessarily prohibited by the presence of atmospheric oxygen, but which also possess this power of liquefying to a moderate extent, so that the access of oxygen can only be said to retard liquefaction, and does not at once put a stop to it.

It will thus be seen that the purification of sewage is really effected by different kinds of bacteria in several succeeding stages, the transition from one to another being accompanied by the gradual disappearance of those bacteria whose work is done, and the substitution of others whose function is to continue the work begun by their predecessors; and since the time required for the different particles of sewage to pass through each successive stage of decomposition is exceedingly variable, it is evident that the two processes of liquefying and oxidation may be taking place simultaneously, especially under the conditions naturally existing in the interstices of the soil used for sewage disposal by land treatment, when only partial aeration is possible, and the process of purification is therefore comparatively slow.

The object of artificial sewage disposal works is only to so improve the natural conditions that the activity of the different kinds of bacteria may be developed to the fullest possible extent; but although efforts are still being made to find some method of rapidly effecting the complete purification of sewage in one stage, far greater success has generally been achieved when no attempt has been made to combine the diametrically opposite conditions which are favourable to liquefying and oxidation by anaerobic and aerobic bacteria respectively, but rather to utilise the special powers of each to the best advantage by encouraging their action in two successive stages.

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CHAPTER I.

Alternative Methods of Treatment and Preliminary Considerations affecting the Design and Construction of Works.

Description of alternative processes—Relative efficiency of land treatment and bacteria beds—System of sewage disposal depends on local conditions—Volume and composition of sewage—Conditions to be observed in selecting site—Degree of purification necessary—Selection of materials for constructing works—Local Government Board—Rivers Board and Central Authority—Responsibility of engineers.

The means actually employed for the purpose of encouraging and utilising the action of bacteria have already been referred to in the Introduction, and will be fully described in succeeding chapters, but in order to prevent any misunderstanding or confusion as to the essential features of the different methods of treatment, they may be briefly defined as follows.

Screening is a mechanical means of intercepting and removing sticks, rags, corks, brushes and floating garbage by passing the sewage through fine or coarse screens formed with iron bars, perforated metal sheets or woven wire, so that the larger solids may thus be eliminated to any extent that may be desirable, having regard to the method of purification which follows.

Sedimentation is also a purely mechanical process since it does not involve any chemical change, but it is a simple and effective means of separating a portion of the suspended matter in the sewage by passing it through tanks at such a velocity that the heavier solids naturally settle to the bottom by gravitation in the form of sludge containing most of the road detritus and other inorganic matter which cannot be decomposed by bacterial agency.

Precipitation effects the same object of separating suspended solids from the liquid portion of the sewage by settlement during its passage through tanks after the addition of some chemical reagent which produces a heavy precipitate in combination with water and various substances present in the sewage, so that when the velocity of flow is sufficiently low, nearly all the suspended matter can be removed by this process.

Liquefying is another preparatory process by which the organic solids in suspension may be reduced through the putrefactive action of anaerobic bacteria, but in this case the force of gravity which tends to cause the subsidence of solid matter is not assisted by any precipitant; in fact, its effect is largely counteracted by the buoyancy of gas bubbles (the production of these bubbles shows that a certain proportion of the organic matter is also converted into gas) which are freely given off during the process of anaerobic decomposition, so that a much slower velocity is required in liquefying tanks than for plain sedimentation or precipitation.

Diffusion in water is essentially a natural means of sewage disposal, as it simply involves the discharge of crude or partially purified sewage into the sea or some other large body of water; the bacteria and oxygen contained in the water being relied upon to effect the complete oxidation of the organic matter in the sewage without the aid of any artificial works to facilitate the diffusion or mixing of the sewage and water.

Surface irrigation consists in the distribution of the sewage over the surface of agricultural land on which crops are grown, so that they get the benefit of any manurial value in the sewage by assimilating certain products of decomposition, while the profits derived from their sale may afford the means of recovering the cost of cultivation, but the application of sewage to the land must be suspended while the crops are being planted and harvested.

Land filtration is really a form of irrigation, but distinguished from it by the fact that the area of land used for sewage treatment is exclusively reserved for that purpose, no attempt being made to grow crops upon it, while the aeration of the soil is facilitated by frequent cultivation and the intermittent application of sewage with carefully regulated intervals of rest, so that a much larger quantity can be dealt with per acre by this means than by irrigation.

Contact beds are tanks filled with broken stone or other hard material, the interstices of which are alternately charged with air and sewage, so that the organic matter in the latter is arrested and oxidised by being brought into intimate contact with aerobic bacteria, whose activity is so concentrated by these conditions that artificially constructed contact beds are capable of purifying sewage at a far more rapid rate than a corresponding area of land.

Percolating filters are constructed with similar materials to those used for filling contact beds, but the aeration of the interstices is constant instead of intermittent, the sewage being distributed over the surface in finely divided streams, so that it trickles down through the filter and is rapidly oxidised by the vigorous action of the aerobic bacteria developed by the plentiful supply of atmospheric oxygen, which enables filters of this description to deal with larger quantities of sewage than is usually found possible with contact beds of the same area.

It will be observed from the brief description given above that the relative efficiency of the four alternative methods of purification last referred to practically depends on the extent to which the interstices of the soil or artificial medium can be aerated; and although the following figures will obviously be liable to very wide variations, according to the character and depth of the soil or artificial filtering medium used, they will serve to give an approximate idea of the quantity of sewage which can be dealt with per acre by each of these alternative methods under the conditions usually encountered in English practice.

	Gallons per acre daily.
Surface irrigation	3,000 to 15,000
Land filtration	20,000 to 100,000
Contact beds	400,000 to 800,000
Percolating filters	1,000,000 to 2,000,000

It is evident, however, that even assuming that the above figures are fairly representative, the quantity treated per acre is by no means the only point to be considered in comparing the relative efficiency of these alternative methods, as this also involves the most important question of cost; and when suitable land can be acquired at a reasonable price, its use may be more economical than the construction of artificial bacteria beds, especially when the materials required for the latter cannot be obtained in the neighbourhood of the works, but there can be no question that the efficiency of "intensified bacterial processes" is steadily increasing, whereas the limitations of land treatment are now practically established.

With regard to the preparatory processes it would be equally misleading to compare their efficiency on the basis of cost alone without regard to their effect upon the sewage, and although the popularity of liquefying tanks should continue to increase as their action becomes more perfectly understood, it does not follow that their use is always preferable to the alternative methods of preliminary treatment by sedimentation or precipitation, since every system possesses its peculiar advantages and disadvantages, the importance of which must depend on local conditions rather than abstract theory.

For instance, plain sedimentation may be cheap, but ineffective, whereas precipitation involves very heavy expense in chemicals and sludge disposal, while the advantage of reducing the volume of sludge by liquefying may be largely counterbalanced by the possibility of causing a nuisance through the offensive gases which are produced by the action of anaerobic or putrefactive bacteria in liquefying tanks.

It is therefore quite impossible to lay down any hard-and-fast rule as to what is the best method of sewage disposal regardless of circumstances, and a wide experience of results obtained by different methods under varying conditions is the only really reliable guide in forming a correct conclusion as to the particular process or combination of processes which will best meet the requirements of each individual case.

Before the experience gained elsewhere can be properly applied to a fresh problem, it is first necessary to thoroughly study the local conditions, so that due allowance may be made for the composition and volume of the sewage, the fall and space available at the outfall, configuration of the ground, nature of the soil, and destination of final effluent, as well as the materials to be obtained locally, and endless other points which require the most careful consideration.

In selecting the site for sewage disposal works or the method of treatment to be adopted, the object of an engineer is to meet the needs of the District and the requirements of the Local Government Board or River Authority without incurring unnecessary expense; and although no book can take the place of practical experience, some further consideration of the points above referred to may assist in the attainment of this object by showing the nature of the preliminary investigations which are usually found necessary, and the conditions under which the different processes hereafter described may be most effectually employed.

Sewage may be defined in general terms as the solid and liquid refuse discharged into the public sewers for collection by the water carriage system, and as two of the chief factors governing the design of sewage disposal works are undoubtedly the volume and composition of the sewage to be dealt with they usually form the basis of all preliminary calculations to estimate the extent or capacity of the works required for its purification.

In those cases where the sewage is already collected by an existing system of sewers, its volume and composition might appear to be readily capable of determination by simply taking a gauging and analysing a sample, but in order to obtain reliable data it is of the utmost importance that such observations should extend over a sufficient period to include the variations which occur from day to day and at different hours in the same day, while the results are liable to be very misleading unless the greatest care is exercised in taking the gaugings and samples for analysis in such a way that they will represent a fair average of the sewage which the proposed works will be required to deal with both during dry and wet weather.

Under ordinary circumstances the flow of sewage may be measured with sufficient accuracy by causing it to pass over a weir formed by cutting a rectangular notch in a thin iron plate which is fixed to a temporary dam in the sewer or carrier (with the sill horizontal and the sides vertical), so that the exact depth of sewage passing over the weir may be measured, and when this is known, together with the width of the weir, the corresponding rate of discharge can be easily calculated, either by the tables or formulæ which are fully explained in numerous books dealing with the subject of Hydraulics.

The rate of discharge may sometimes be measured by observing the time required to fill a tank of known capacity, but in any case it is very desirable that such observations should be made systematically at regular intervals of, say, half an hour over a period of sufficient duration to show what is the maximum and minimum dry weather flow as well as the average; and in order to obtain information as to the amount of storm water to be dealt with, as well as the frequency with which a certain degree of dilution is likely to be reached; the gaugings should also be continued during wet weather if possible.

The conditions affecting the volume of storm water discharged by the sewers will be more fully considered in Chapter X., but apart from this it is usually found that although the dry weather sewage flow varies from day to day, its variations follow a fairly uniform cycle each week, the discharge being less on Sundays than week days, and generally greater on one particular day in each week than on other days, while the reduction in waste which results from an intermittent water supply produces a corresponding reduction in sewage flow, when the water is cut off at night.

The fluctuations in dry weather flow are also greater as a rule in small districts with short sewers than in large ones where the mid-day sewage from one part of the district may reach the outfall about the same time as the midnight sewage from another part, thus producing a more uniform rate of discharge; but in the author's experience with watertight sewers, the minimum rate of dry weather flow is seldom less than half or the maximum more than double the average, and where any considerable quantity of subsoil water leaks into the sewers the extreme variations are much less, as the rate of infiltration is approximately constant throughout the twenty-four hours, though it is naturally greater in a wet season than a dry one.

Where it is impracticable to measure the volume of sewage by actual gaugings the consumption of water per head of the population may afford an approximate basis on which to design sewage disposal works when due allowance is made for any water which may reach the sewers from the subsoil or other sources in addition to that derived from the public supply.

It is usually found that when a public water supply is provided, the rate of consumption per head varies to a great extent with the size of the community and density of population, it being quite common in England to find an average consumption of only 10 gallons per head for country villages up to, say, 1,000 population, whereas in towns of 10,000 population it is frequently 30 gallons per head, and in still larger towns it reaches a maximum in some cases of 60 gallons per head per 24 hours, while three or four times this quantity is by no means exceptional in America.

The presence or absence of trade waste is another factor which materially affects the volume and composition of sewage, and when it has the effect of making the sewage strongly acid or alkaline, its purification by bacterial action will be rendered far more difficult, especially when large quantities of trade waste are discharged intermittently, while an excessively high temperature will frequently increase the danger of smell arising from the sewage disposal works.

The design of works for the treatment of sewage containing a large proportion of trade waste will therefore involve a number of special considerations which do not arise in connection with ordinary sewage works, and it is for this reason that a separate chapter has been devoted to their discussion.

As in the case of gaugings, so also in taking samples for analysis it is important that these should fairly represent the average composition of the sewage, but although considerable time and expense may be saved when samples are taken at regular intervals for, say, 24 hours, by mixing them together and analysing a sample of the mixture instead of analysing the original samples independently, the volume taken from each original sample should bear an approximate proportion to the rate of sewage flow at the time, in order that the sample analysed may properly represent the average composition of the sewage, so that it is a good plan to take both gaugings and samples at the same time, and when the gaugings have been calculated, the correct quantity may be taken from each original sample in preparing the mixed sample for analysis.

The difference in composition of sewage at different places may be as great as that between milk and writing ink, yet the complexity of its character and the variations produced by all kinds of local conditions are seldom sufficiently appreciated in their relation to the design of sewage disposal works, the efficiency of which is affected quite as much by the composition of the sewage as the quantity treated; indeed, each of these factors must be very largely dependent on the other, so that it is absurd to expect the production of an equally pure effluent from similar works designed on the same basis as regards volume treated per unit of capacity, but without any allowance for the difference in composition of sewage dealt with.

These variations in composition are not only due to the varying sources from which the sewage is collected, but are also very materially affected by the length of time that it has spent in the sewers, as a considerable amount of decomposition may sometimes take place before it reaches the disposal works, and in large flat districts, where the sewage takes a long time to pass through the sewers, the capacity of tanks required for its preliminary treatment at the outfall may for this reason be reduced, but in those cases where the sewage has to be pumped the stirring up which this involves is far more likely to create a nuisance with stale sewage than with fresh.

Where some parts of the drainage area are much further from the outfall than others, it naturally follows that although some of the sewage may be in the sewers for many hours, and will therefore be largely decomposed, a certain proportion of it will reach the outfall in a comparatively fresh state, so that provision must be made for treating the whole of it in tanks just as if it were all fresh; in fact, such a mixture is really more difficult to treat than fresh sewage, and the liquefying action which takes place in the sewers can only be regarded as a reason for reducing the duration of tank treatment at the outfall when the latter is at a considerable distance from the town.

For the purpose of expressing the relative strength of different sewages various alternative standards of comparison have been suggested, but in considering the analysis of sewage or sewage effluents it would be totally misleading to compare them on the basis of individual figures in the analysis, such as chlorine or ammonia, as the importance of each analytical figure must largely depend on the others, and it by no means follows that a sewage is particularly strong or difficult to treat because one figure in the analysis is unusually high.

The following figures are taken from the first report of the Rivers Pollution Commissioners showing the average composition of samples taken from the sewage of thirty-six different towns, but it will be observed that although these figures may be fairly representative of English sewage, the far larger quantity of water used in America per head of the population produces a much weaker sewage, and dilution by surface or subsoil water may have the same effect in this country with leaky sewers laid on the combined system.

	Parts per 100,000.	
Solids in suspension—		
Organic	20.5	
Mineral	24.1	
		44.6
Solids in solution		72.3
Total solids		116.9
Chlorine		10.6
Free ammonia		6.7
Albuminoid ammonia *		.63

In selecting a site for sewage disposal works its suitability or otherwise will not only depend upon the character, area and level of the land available for irrigation either with sewage or filtered effluent, but also its proximity to the stream into which the final effluent must be discharged, its liability to become flooded or water-logged in wet weather, accessibility from a good road, railway or canal terminus for the delivery of building materials and disposal of crops, as well as its position in relation to the town or outlying houses, having regard to the prevailing winds and the possibility of any smell arising from the works or the annoyance which might be caused by the flies and other insects which are sometimes attracted by the sewage.

All these points require most careful consideration, and

* Estimated by taking $\frac{2}{7}$ of the organic nitrogen.

practical experience is the only safe guide in forming a sound conclusion when deciding between two or more alternative sites, as it will frequently happen that a site which is quite unsuitable for one method of treatment can be very readily adapted for another.

The selection of a site and the method of treatment must therefore be considered together, and this is where very serious mistakes have frequently been made through lack of sufficiently varied experience, with the result that there are numbers of unsuccessful works in this country at the present time which have involved a far greater expenditure than that which was really necessary to secure satisfactory results if the money had been laid out with better judgment in the first instance.

From a purely engineering point of view the level or configuration of the ground and the fall available between the outlets of main sewer and effluent drain are by far the most important considerations, for unless these are fairly favourable no other advantages can counterbalance the difficulty and expense of constructing works on an unsuitable site, as efficiency is the first essential, and it is very false economy to build costly works on a bad site when a better one could be obtained at a reasonable price; but it is owing to the imperfect appreciation of this point that large sums of money continue to be spent on works which are doomed to failure from the commencement through adopting the wrong site or the wrong system of treatment.

The design of sewage disposal works must also depend in many cases on the degree of purification required, and the destination of the final effluent, for whereas simple clarification may be sufficient where a sea outfall is available nothing less than purification can be regarded as entirely satisfactory when the effluent is discharged into a small inland stream in which but little dilution takes place, and which may afterwards be used as a source of domestic water supply by some other community.

No hard and fast rule can therefore be laid down as to the degree of purification which should be attained in all cases regardless of local conditions, and the system of local control by Rivers Boards for each important watershed as recommended by the Royal Commission seems to be the best means of securing the prevention of serious river pollution without unnecessary expense.

There is, however, no justification for the argument that the sewage from inland towns should be converted into drinking water before being discharged into any stream which may be used for domestic supply, since it is in any case necessary that such supplies should be filtered before the water can be considered fit for use, and when sewage effluents are reasonably free from chemical impurities the presence of a few disease germs cannot be considered of vital importance so far as water supplies are concerned when the water is again filtered before use, while the danger arising from the pollution of shell fish in river estuaries could hardly be obviated by sterilising the sewage effluents or storm water discharged into the rivers even if this were practicable.

The importance of correct designing for sewage disposal works is shown by the wide variation in cost of similar plants erected in different parts of the country where the same facilities do not exist for obtaining the materials required for their construction.

For example, the filtering medium used in bacteria beds represents by far the most expensive part of their construction, and an error of judgment in the selection of this may make all the difference between a truly economical plant and an unnecessarily expensive one, for while a considerable saving in first cost may be effected by using a local material this saving may be more than counterbalanced by the cost of its preparation by crushing, screening and washing, apart from the question of maintenance.

There are numbers of schemes involving a large area of artificial bacteria beds which have soon become practically useless through the adoption of improper filtering media, and it sometimes seems to have been considered sufficient to excavate a hole in gravelly soil, line it with brickwork and then replace the excavated material, with little or no attempt to properly prepare it for the purpose.

With a view to affording a clear idea of the many points requiring attention in the selection and preparation of filtering media a separate chapter is devoted to its consideration, but the greatest care is also necessary in designing the structural portion of the work in order to avoid unnecessary expense by using imported materials, when those obtained locally could be utilised with equally satisfactory results by making some slight modification in the design and possibly substituting concrete for brickwork or masonry when good bricks or building stone cannot be obtained without heavy charges for carriage.

Having selected the site and determined the best method of treatment to adopt, as well as the materials to be used in constructing the works, their capacity is the next question to be decided, and in England this is usually expressed as some multiple of the dry weather sewage flow; but in deciding what this multiple should be, there is at present no very definite rule to go upon, except in so far as the usual requirements of the Local Government Board may be regarded as a rule, and these requirements having hitherto been much too inflexible to allow for the variations in local conditions previously referred to, they are sometimes very excessive, while in other cases they may be totally inadequate to prevent river pollution.

However, these requirements constitute by far the most common basis of calculation, for the simple reason that the loans usually required for the purpose of carrying out sewage disposal works in this country can seldom be raised without first obtaining the sanction of the Local Government Board, which implies their approval of the scheme before granting authority to raise money on the security of the rates, so that for the time being at any rate the capacity of sewage disposal works is practically governed by these requirements.

Although each scheme is to some extent considered independently on its merits, and no official statement of their requirements has ever been published by the Board, the conditions which have to be complied with before a loan is sanctioned have recently been subject to very slight variation, at any rate in so far as the capacity of the works is concerned; and as the Author has been jointly responsible with his partner for the preparation of over 100 separate schemes for submission to the Board during the past seven or eight years, he feels qualified to speak with some authority as to what will or will not be likely to meet with their approval in the absence of exceptional circumstances.

With regard to the capacity of tanks for preliminary treatment about one day's dry weather flow has come to be considered a fairly reasonable provision for liquefying tanks, and this will usually include the capacity of small detritus tanks through which the sewage should pass in about one hour before entering the liquefying tanks.

There are undoubtedly many schemes where the tank capacity may be 50 per cent. above or below the dry weather flow, and although the above figure may be taken as a fair average for liquefying tanks in which no chemicals are used, about half this capacity is usually sufficient for precipitation tanks, and about five or six hours is the maximum length of time for which sewage can usefully be retained in plain sedimentation tanks.

In the case of bacteria beds the Board usually avoid making any distinction between percolating filters and contact beds by stipulating that the capacity of each shall be sufficient to treat the volume of sewage to be dealt with at a rate not exceeding 168 gallons per cube yard of media per 24 hours, but double this capacity is generally required when no land is available for the final treatment of effluent from bacteria beds, and although the depth of percolating filters is seldom restricted, the depth of contact beds is usually limited to 3 or 4 feet, and double contact is almost invariably insisted upon.

In addition to making provision for the treatment of the ordinary dry weather sewage flow the English Local Government Board also require in the case of "combined" sewerage schemes that the Sewage Disposal Works shall have a capacity capable of dealing with a total volume of sewage and storm water equal to six times the dry weather flow, half this total quantity to be fully treated as sewage on the basis above described, while the other half may be dealt with on storm water filters at a maximum rate of about 500 gallons per super yard per 24 hours, or upon an area of land specially reserved for the purpose, but when the sewers are laid on the "separate" system, so that surface water is excluded as far as possible, the proportion to be treated as sewage is reduced to one third instead of one half of the total volume.

The area of land provided for the final treatment of effluent from bacteria beds should be not less than 1 acre per

1,000 population wherever possible, but owing to the difficulty of complying with this requirement the Board have sometimes consented to waive it, especially when the character of the land is unsuitable, as in the case of the Staffordshire Potteries, where two schemes with which the Author is personally connected, at Newcastle-under-Lyme and Hanley, were the first instances of sewage disposal works approved by the Local Government Board in which land treatment for the final effluent was entirely dispensed with. The Board had previously refused to make any exceptions to their rule, which is based on the finding of the last Royal Commission, and although land has since been dispensed with at a few other places, a considerable addition to the area of bacteria beds has usually been required as a substitute in such cases.

When the sewage is to be dealt with by land treatment instead of bacteria beds, the area required depends on the character of the subsoil, level of ground water and many other conditions, so that no definite basis can be laid down as universally applicable, but the approximate quantity which is usually treated per acre by irrigation or land filtration has already been roughly indicated in this chapter, and the whole question of land treatment will be referred to again in Chapter III., where the requirements of the Local Government Board regarding it are fully discussed.

The procedure of the English Local Government Board in dealing with applications from Local Authorities for sanction to loans to cover the cost of public works primarily consists in the appointment of an Engineering Inspector to hold a Local Inquiry for the purpose of receiving evidence from all interested parties, and generally investigating the site and local conditions as well as the nature of the works proposed, after which the merits of the scheme are considered by the

Chief Engineer or his deputy, together with the Inspector's report on the result of his Local Inquiry.

The exact nature of these local investigations must depend very largely on the character of the scheme proposed, but it is in any case necessary that all applications should be accompanied by detailed drawings for the whole scheme, together with an estimate of cost on the form supplied for the purpose, showing how the amount of loan to be applied for is made up, as well as a copy of the resolution passed by the Local Authority authorising the application.

When the site of the proposed works does not already belong to the Local Authority it is also necessary that a provisional agreement should be entered into with the owner embodying the terms on which it is to be acquired in the event of the loan being sanctioned, and if any portion of the proposed works is outside the District controlled by the Authority making the application at least three months' notice must be given of their intention to carry out such works in accordance with Section 32 of the Public Health Act, 1875.

In those cases where a site cannot be acquired by agreement, and it therefore becomes necessary to apply to the Local Government Board for a Provisional Order to put in force the compulsory powers to purchase and determine the value of the site required by arbitration under the Lands Clauses Consolidation Act, 1845, notice of such application must be published in a local paper for three consecutive weeks during the month of November as required by Section 176 of the Public Health Act, 1875; and if a Petition is presented to the Local Government Board before the 1st of January following, in accordance with the Parliamentary Standing Orders, the Board will, after holding a Local Inquiry, either dismiss the application or issue a Provisional

Order which will come into force after its formal confirmation by Parliament, but no loan can be sanctioned by the Local Government Board for works to be constructed on lands which do not belong to Local Authorities unless it can be shown that they have power to acquire a suitable site either by agreement or Provisional Order.

There are a great number of other points regarding which the Local Government Board Inspectors usually require information at Inquiries relating to ordinary applications for sanction to loans; and as it is a great advantage to all concerned if this information can be prepared beforehand, the following list will no doubt be of service to anyone who may be called upon to answer such questions, but whose previous experience may not enable him to know exactly what is likely to be required, though it is obviously impossible to give anything like a complete list, as much must depend upon the special circumstances of each particular case.

Particulars required by the Local Government Board in connection with Sewage Disposal Works.

Copies of notices published in accordance with the provisions of the Public Health Act.

Copy of resolution of Local Authority authorising application for a loan.

Will any of the proposed works be outside the district?

Have provisional agreements been entered into for acquiring any land required?

Population provided for by the proposed works, and present population of the district.

Estimated dry weather flow of sewage per head of the population, and data on which this estimate is based.

Particulars of any trade waste discharged into the sewers.

Are sewers laid on separate or combined system?

What proportion, if any, of the dry weather flow is due to infiltration water?

Particulars of storm overflows and degrees of dilution necessary to bring them into operation.

What is source of water supply in the district?

Quantity of water used per head.

Will the sewage be discharged at outfall by gravitation or pumping?

Will the sewage be treated by night as well as day; if not, what will be done with the night flow?

Is there any likelihood of subsidence in the vicinity of the sewage disposal works due to mining operations?

Particulars of trial holes sunk six feet deep on site of disposal works showing nature of subsoil and ground water level.

Area of land reserved for irrigation or treatment of filtered effluent.

Dimensions and capacity of tanks.

Area and depth of bacteria beds.

What chemicals are to be used, if any?

How will the sludge be disposed of?

What is population per acre of land to be irrigated?

Particulars of any waterworks which may possibly be affected by the proposed scheme, and details of geological strata.

Assessable value of District or Parish for sanitary purposes.

Average density of population per acre (in towns).

Is site of proposed works liable to floods, and, if so, how often, and to what depth is it submerged?

Particulars of any observations or investigations regarding tides or currents in the neighbourhood of sea outfalls.

General description of scheme and proposed system of purification, with explanation of drawings and levels of works above ordnance datum of the following points:—

Ground levels on site of works.
Invert of outfall sewer.
Top water level of tanks.
Floor of tanks at shallow end.
Floor of tanks at deep end.
Surface of media in bacteria beds.
Floor level of bacteria beds.
Invert of main effluent drain.
Surface of irrigation area.

In sanctioning a loan the Local Government Board invariably stipulate the period within which it must be paid off, and as the length of time allowed varies according to the purpose for which the loan is required, it is necessary in calculating the annual instalments of capital and interest to bear in mind the time limit usually allowed for their extinction, which is as follows :—land 50 years, structural works 30 years, machinery 15 years and fencing 10 years, these being the four chief headings under which the estimates for most sewage disposal schemes are divided.

In order to equalise the repayments during the whole period of the loan, the proportion of capital paid off each year is generally so arranged that this, combined with the interest on the outstanding amount, makes up a number of equal instalments corresponding with the duration of the loan in years; but as the calculation of these instalments is a somewhat complicated and tedious process, the following abbreviated table has been compiled on the lines originally

AVERAGE ANNUAL INSTALMENT OF PRINCIPAL AND INTEREST.

Period in Years.	3 per cent.	3¼ per cent.	3½ per cent.	3¾ per cent.	4 per cent.
10	·117231	·118731	·120241	·121762	·123291
15	·083767	·085289	·086825	·088376	·089941
20	·067216	·068779	·070361	·071962	·073582
25	·057428	·059040	·060674	062332	·064012
30	·051019	·052682	·054371	·056087	·057830
35	·046539	·048253	·049998	·051773	·053577
40	·043262	·045028	·046827	·048659	·050524
45	·040785	·042602	·044453	·046341	·048263
50	·038965	·040730	·042634	·044574	·046550

adopted by Mr. Baldwin Nathan in his well-known book on "Sewerage," with a view to facilitating such calculations in connection with ordinary loans at from 3 to 4 per cent. interest, and repayable in the periods given in the first column, it being only necessary to multiply the amount of loan by the decimal in the table opposite the time allowed for repayment and under the rate of interest to be paid in order to obtain the amount of each annual instalment required.

Having sanctioned a loan for the purpose of carrying out a scheme of sewage disposal the responsibility of the Local Government Board appears to be at an end, as they do not exercise any control over the actual construction or maintenance of the works on which the money is spent, and so far as the administration of the Rivers Pollution Prevention Act, 1876, is concerned this is usually allowed to remain in abeyance until some action is taken by the County Council as the responsible Local Authority, so that the Board's jurisdiction with respect to sewage disposal is practically limited to the approval or disapproval of new schemes, quite regardless of the results obtained from the works already in operation, although their capacity may be far below that required on paper for new schemes, and little or no attempt may be made to deal with the quantity of storm water which must be provided for in the drawings and estimates for new schemes.

Although County Councils have power to enforce the provisions of the Rivers Pollution Prevention Act, 1876, they are in most cases very reluctant to take action, as they seldom control the whole watershed of any important river, and therefore have no security that other Authorities will do the same, so that even if they take steps to protect rivers in their own county, the rivers may still continue to be polluted when they pass through adjoining counties, and it is on this account, as well as the difficulty of fixing individual responsibility for causing pollution, that the Act has come to be regarded as practically inoperative.

This is strongly emphasised in the following abstracts from the third Report of the Royal Commission appointed in 1898, who confirm the recommendations made by the previous Commissions appointed in 1857, 1865 and 1868, as to the necessity of setting up watershed Boards or otherwise strengthening the machinery for the protection of our rivers :—

"At an early stage of our investigation we were struck by the fact that in many parts of England the pollution of rivers goes on unchecked notwithstanding the fact that the Rivers Pollution Prevention Act has been on the statute book for over a quarter of a century, and in our interim report we deemed it necessary to state that the protection of our rivers is a matter of such grave concern as to demand the creation of a Supreme Rivers Authority."

"We do not, however, consider that the Central Authority should take the place of local bodies in regard to the protection of rivers and other sources of water supply. On the contrary, we think local power should be utilised to the fullest extent possible."

"In our opinion such power can only be fully utilised by the formation of Rivers Boards throughout the country, and we therefore recommend that such Boards be formed."

"We have not sufficient information to enable us to say what precise combinations should be made. Each Rivers Board district should, however, include, as far as practicable, the whole of one or more watersheds, and it should be sufficiently large to justify the permanent appointment of a skilled Chief Inspector at an adequate salary."

"One of the first duties of the Central Authority will be to ascertain what grouping of counties would be most effective, and then to take steps to constitute Rivers Boards for these areas."

"The Central Authority should exercise a general superintendence over the whole country in regard to the prevention of pollution of water. They should direct any inquiries or investigations which they may consider desirable, and generally they should stimulate and encourage Rivers Boards to an active exercise of their powers."

The great advantage of having the whole of a watershed controlled by one Authority is clearly shown by the excellent work already accomplished by the Mersey and Irwell Joint Committee, the Ribble Joint Committee, and the West Riding of Yorkshire Rivers Board, which are the only existing examples of bodies expressly created for enforcing the provisions of the Rivers Pollution Prevention Act, whereas the County Councils are under no obligation to enforce these provisions, and the power which they possess to check river pollution has only been exercised with the greatest reluctance in comparatively rare instances.

The formation of Rivers Boards throughout the country under a Central Authority would therefore seem to be by far the best remedy for the unsatisfactory state of affairs at present existing, and it is to be hoped that the recommendations of Lord Iddesleigh's Commission in this respect will be embodied in an Act of Parliament at no distant date, as their conclusions not only confirm the conclusion of previous Commissions, but also represent the general consensus of opinion expressed by the majority of witnesses who have given evidence before them on this question.

These specially constituted River Authorities would not only have the great advantage of controlling entire watersheds, but the area under their jurisdiction would be sufficiently large to justify the appointment of thoroughly qualified officers to investigate the peculiar conditions obtaining in each district, with a view to determining the nature and extent of the works which may reasonably be required to prevent serious river pollution, after taking all local circumstances into consideration, instead of attempting to enforce any rigid standard regardless of such vital questions as the size or condition of the river or stream into which the waste waters of the district must eventually be discharged.

The contents of this chapter are in the first place intended to show the great number of incidental questions which have to be considered in designing sewage disposal works, but the explanation of these questions will also serve to emphasise the utter fallacy of the idea that such works can be properly designed without a thorough study of each individual case in the light of sufficient experience in dealing with similar problems under a great variety of circumstances, as it is quite unreasonable to expect economy or efficiency from designs which are simply copied from those adopted elsewhere, while it is equally impossible to determine the necessary capacity of such works by any arbitrary formula or standard which does not take the local conditions into consideration.

In the great majority of cases Sewage Disposal is simply a question of money, but no works can be truly economical unless they are efficient, that is, unless they produce the best results obtainable at the least possible expense, and it is for this reason that an Engineer entrusted with the expenditure of ratepayers' money on costly works of this description incurs a very heavy responsibility, for it may very readily happen that an error of judgment on his part may involve the waste of large sums which the District can ill afford to lose, and may render it impossible to carry out much needed improvements afterwards, through all the available funds having been exhausted in carrying out unnecessarily expensive or inefficient works in the first instance.

The danger arising from excessive economy in conducting preliminary investigations, and the disinclination sometimes shown by Local Authorities to pay an adequate remuneration for reliable advice before embarking on expensive schemes of sewage disposal and other public works of a less complicated character, is very forcibly expressed in the annual report of the Local Government Board published in 1903, from which the following abstract is taken, and there can be no doubt that this emphatic condemnation of competitive schemes has been repeatedly justified by the unfortunate experience of many Local Authorities, who have adopted this means of obtaining cheap advice without realising the risks they incur by so doing until it is too late :—

" We have observed an increase in the number of cases in which Local Authorities proposing to carry out works of sewerage, sewage disposal or water supply have adopted the plan of advertising for the best scheme and offering a premium for the one which meets their requirements. It appears to us that there are disadvantages in this which may not have been present to the minds of the authorities concerned.

" In the first place we are advised that the Engineers who have the largest experience in this nature of work will not enter these competitions.

" Secondly, as the acceptance or rejection of a particular scheme by a Local Authority depends to a large extent upon its estimated cost there is a notable tendency to cut down the estimates in connection with these competitive schemes. The consequence of this under-estimating of the expense is seen in the number of cases in which supplemental loans are required to meet excess expenditure, such excess amounting in many cases to 50 per cent. of the whole cost of the works as originally estimated.

"Nor can the competing Engineer be held solely to blame in such cases, for a reliable estimate of cost can only be made after a very careful examination of the locality and some expenditure of money as well as time in examining the subsoil and all the peculiarities of the district.

"The Engineers have no security that they will be reimbursed the preliminary expenses incurred by them in connection with the preparation of these schemes, and, as might be expected in such circumstances, these expenses are often reduced to an extent which is incompatible with the proper examination of the locality for the purpose of preparing the most efficient scheme."

CHAPTER II.

DIFFUSION IN TIDAL WATERS.

Advantages and dangers of sea outfalls—Necessity for studying local conditions in each case—Selecting a site for a sea outfall—Tracing tidal currents by means of floats—Measurement of fresh water in tidal estuaries—Means of sewage purification in sea water—Measurement of sewage pollution by aeration test—Preliminary treatment to remove suspended solids—Storage of sewage during flood tides—Level of outfall in relation to tides—Conditions which necessitate pumping—Nuisance arising from seaweed.

DIFFUSION in large volumes of water as a means of sewage disposal is practically limited in Great Britain, at any rate, to towns and villages situated on the sea coast or tidal estuaries, as nearly all the non-tidal rivers and streams are used to some extent as a source of water supply for domestic purposes, and hardly any of them are long enough or large enough to effect the complete oxidation of the sewage from any considerable part of the population dwelling within their watershed, so that it is only under very exceptional circumstances that the discharge of crude sewage into non-tidal water can be accepted as a satisfactory means of disposal, and even for sea outfalls some form of preliminary treatment is usually necessary to remove at least a portion of the matters in suspension, though it has been estimated that the sewage from over 20 millions of people in the United States is discharged into inland streams and lakes without any treatment whatever.*

* Mr. J. D. Fuller's paper on Sewage Disposal in the United

The various alternative methods of sewage purification for inland towns will be dealt with in the succeeding chapters, but since the solution of the sewage disposal problem is so very much simplified in those cases where an outfall can be obtained direct into tidal water, the various questions arising in connection with this method may be conveniently considered separately.

Although seaside towns may be under no obligation to purify their sewage, it by no means follows that its disposal can be accomplished without difficulty from an engineering point of view, as it frequently happens that the absence of fall along the sea front renders it almost impossible to collect the sewage to one point above sea level without pumping, and the discharge of crude sewage into the sea will frequently involve costly works in order to deliver it at a time and place which will ensure its rapid removal by the tide, and thus prevent the danger of contaminating shell fish and injury to public health.

A sea outfall has, however, the very great advantage of finality, as when the works are once constructed the sewage can be effectually disposed of in this way at infinitely less cost than by any other means, so that any town on or near the sea is well advised in adopting this method whenever it is possible, and the combination of several authorities in the construction of a main trunk sewer to carry their sewage to the sea may sometimes be mutually advantageous by enabling them to undertake joint works of far greater magnitude than would be financially possible for the same authorities individually; the Western Valleys Sewerage Scheme, now being carried out for the joint benefit of six different Urban Districts in South Wales, affords an example of

States, presented at the International Engineering Congress, St. Louis, 1904.

such a combination which is likely to be followed elsewhere.

The risk of danger arising from the contamination of shell fish with the germs of disease discharged with sewage has formed the subject of special investigation by the Royal Commission on Sewage Disposal, now sitting, and the evidence given before them undoubtedly shows that many cases of typhoid fever have been traced to the eating of polluted oysters and other shell fish, while it was also shown that fish may be injuriously affected by the reduction of oxygen in the water which results from the presence of insufficiently diluted sewage.

It appears, however, that the risk of contamination by polluted water cannot be properly estimated by a bacteriological examination either of the water or shell fish, as the danger of disease cannot be indicated by the mere numbers of any particular disease-producing micro-organism that may happen to exist in samples of one or the other, so that for the present, at any rate, topographical observations must be regarded as the only reliable means of detecting objectionable contamination.

With regard to public health the Commission state in their fourth report that :—

"We have also received evidence to show that, apart from cases of specific disease like typhoid fever, offensive emanations from sewage polluted tidal rivers may cause general deterioration of the health of the people living near the river, and more particularly give rise to the prevalence of sore throats; moreover, it would seem that at times the deposit of fæcal matter on foreshores may give rise to serious nuisance."

The presence of floating garbage, such as paper, corks, cabbage stalks, orange peel, and other solid constituents of crude sewage in the neighbourhood of bathing places being so highly objectionable on account of its appearance, is usually intercepted by screening, but this does not materially reduce the danger of bathing in water which is highly polluted with sewage, and only removes the obvious indication of its presence, which is usually well advertised by the flocks of sea gulls attracted by any floating matter of this description.

The general control of sewers and other works below high water mark has hitherto been vested in the Board of Trade as owners of the foreshore in the interests of navigation, and after consultation with the Fisheries Committee, their authority has sometimes been exercised with a view to restricting the discharge of sewage into tidal waters, but the Commissioners have suggested that the local control of all matters relating to the pollution of tidal waters and foreshores should be undertaken by a Rivers Board for each watershed under the supreme authority of a central department of the Local Government Board, the formation of which they recommend in their third report, referred to in the last chapter.

It is further suggested that the Rivers Boards and the Local Government Board would be in a better position than the Board of Trade to consider each individual case on its merits with a view to deciding between the conflicting interests of sewage disposal and shell fish cultivation, since they would have the advantage of skilled advice on these matters.

Under the Rivers Pollution Act of 1876, tidal waters and even portions of the sea can, by order of the Local Government Board, after Inquiry, be declared a stream under the Act; but the uncertainty which at present exists regarding the action of the Local Government Board with respect to schemes for discharging sewage into tidal estuaries certainly does not tend to encourage the prevention of pollution, which is usually ignored until an application is made for sanction to a loan to cover the cost of any new works proposed.

Owing to wide variations in local conditions it is utterly impossible to recommend the best method of discharging sewage into the sea unless the peculiar circumstances of each individual case are carefully studied, and, before selecting a site for the outfall, it is essential that the effect of the prevailing winds and tidal currents should be thoroughly investigated by making a sufficient number of experiments.

Investigations of this description necessarily involve considerable expense, and, in order to afford really reliable information, the observation of tidal currents should extend over as long a time as possible, so that undue hurry or excessive economy in conducting these preliminary studies should be carefully avoided, both on the part of Local Authorities and their Engineers, as any neglect in this respect may result in the outfall being placed in the wrong position and the consequent failure of the whole scheme, when success might have been easily assured if all the local conditions had first been properly understood.

In order that the sewage may be rapidly diffused, it is naturally desirable that it should be discharged at a point where it may at once become mixed with a large volume of sea water, and if the outfall can be placed at the end of a headland it will usually be carried out to sea at almost any state of the tide, as the currents travelling along the coast in either direction are naturally deflected outwards by any projecting headland, but where this ideal condition is not attainable, the outfall should, if possible, be in such a position that under ordinary conditions the sewage is carried away from the town on the ebb tide.

In many cases the same result can be obtained by discharging the sewage into a river estuary at some point where there is a large volume of fresh or tidal water running into the sea, which will carry the sewage with it during the ebb tide to a sufficient distance from the shore to prevent its return when the tide changes.

It is usually found that the tidal currents do not change their direction for some time after high and low water has been reached, but it is seldom desirable to discharge sewage during this period of slack water, or when the tide is rising, as it will not be carried away sufficiently quickly, and may result in solid matter being deposited near the outfall or on some neighbouring foreshore, where its presence would be objectionable and might cause a serious nuisance, especially when large tracts of sand or mud are uncovered at low water

For the purpose of tracing the course of tidal currents, various kinds of floats are employed, but those shown in Fig. 3 illustrate the method of construction usually adopted; a champagne bottle being used for observing surface currents, and a hexagonal piece of pine, about 6 feet long, serving the same purpose for observations below the surface, each being weighted to float in a vertical position and almost completely submerged so that they would not be materially affected by the wind, while the spherical indicators fixed on the top can be easily observed from the shore, and their position checked from time to time by means of a theodolite, the indicators on each float being painted a different colour, or provided with some other distinguishing mark.

It is important to bear in mind that, although float experiments afford the best means of tracing tidal currents, they cannot be relied upon to show the course followed by fresh water or sewage discharged into a tidal estuary, as it is well known that the greater specific gravity of sea water may cause the fresh water to pass over the top of it, and the surface currents may therefore be quite different from those at the bottom, while the mixing of the fresh and salt water is largely affected by the shape of the channel, so that the

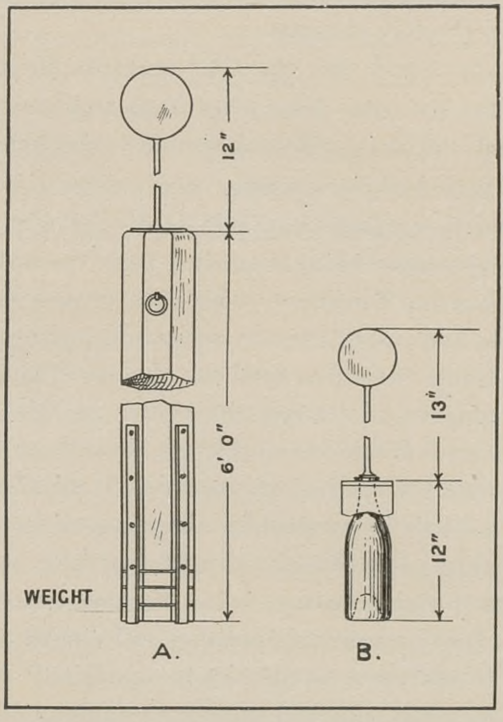

Fig. 3.—Floats for Tracing Tidal Currents.
(Reproduced by permission of Mr. J. W. Brown, Assoc.M.Inst.C.E., West Hartlepool.)

particular stream carrying the float may not represent the course followed by the bulk of the upland water or sewage.

The time required for upland water to pass through an estuary to the sea must also depend to a great extent on the size of the channel and the quantity of salt water which it contains, since it is the average space occupied by the fresh water in the channel at high and low water respectively which governs its rate of progress, and floats afford little information as to how much of the sewage discharged into the estuary is carried away with the most rapid part of the stream, or remains in the comparatively dead water at the sides.

The extent to which any particular section of a river is occupied by sea water can, however, be estimated with great accuracy by taking a series of samples and ascertaining the average quantity of salt which they contain as compared with undiluted sea water, the ordinary chemical formula being as follows :—*

$$X = \frac{A—C}{C—B} \text{ where}$$

X = the number of volumes of B water mixed with one volume of A water.

A = the amount of chlorine in sea water (1961 parts per 100,000).

B = the amount of chlorine in river water, or mixed river water and sewage, being variable and dependent on the volume of upland water in the river. Pure upland water contains about 1·7 parts of chlorine per 100,000, ordinary sewage containing about 10 parts per 100,000.

C = the parts in 100,000 of chlorine found by analysis to exist in the mixed water represented by the samples taken from the river.

The percentage of B water contained in the mixture C can be obtained by the formula

$$X = \frac{100 \text{ A—C}}{\text{A—B}}$$

Having obtained the percentage of upland water or sewage in a river estuary, it is only necessary to estimate the

* Proceedings of the Institution of Civil Engineers, Vol. 78, page 224.

approximate contents of the estuary at high and low water in order to calculate the space actually occupied by fresh water between any two given points, which represents the quantity of fresh water that must be discharged into the estuary in order to completely displace that which is already contained in the particular section under consideration, the time actually required for this being dependent on the rate at which the upland water or sewage enters the estuary.

By applying the above method of calculation to the Thames estuary, it has been found that, although the waterway at Southend is 12 times greater than that at Barking, the upland water actually passes through the wide estuary at Southend more rapidly than the comparatively narrow channel at Barking, owing to the lower part of the estuary being chiefly occupied by sea water, which, by its greater specific gravity, displaces the fresh water and thus very materially assists in its rapid progress to the sea.

The tendency for the salt water to mix with the upland water does not affect the above calculations, since they are based on the relative space occupied by each, whether mixed or separate, but it should be observed that the mixing is a matter of some importance when disposing of sewage by diffusion, and as it is mainly effected by the variable velocity of tidal currents in an irregular channel, it will be understood that the mixing takes place far more rapidly where some parts of an estuary are much deeper than others, the velocity of a tide wave being approximately proportional to the square root of the depth.

This is a very satisfactory method of ascertaining the average velocity of upland water passing through an estuary, but it does not afford any very exact information as to the maximum and minimum velocities of the tidal currents in the estuary, and, in dealing with matters in suspension, it is upon the maximum velocity that their movement or settlement depends, so that it may be worth mentioning that although the average velocity is usually greatest on the flood tide, the maximum velocity is frequently higher on the ebb, and this may explain the apparently contradictory results which are sometimes obtained by float experiments.

Owing to the difference in specific gravity it has already been pointed out that in the absence of disturbance by waves, upland water or sewage has a tendency to float on the surface of the sea water, and may thus preserve its identity for a considerable time, this being the explanation of the dark oily mark which may often be seen near a sewage outfall, and it has been noticed in the estuary of the Severn that the salt water may sometimes be passing under the fresh water with a high velocity on the flood tide when the surface is practically stationary.

Assuming that sewage has become thoroughly diffused and mixed with a large volume of sea water, its purification is effected by the combination of organic matter in the sewage with the oxygen dissolved in the water, and it has been stated in evidence before the Royal Commission on Sewage Disposal that, so long as the sea water is not contaminated with more than 1 per cent. of sewage, there is ample oxygen available in the water to oxidise the whole of the organic matter in the sewage and thus prevent the possibility of any nuisance arising from it.

So long as the water is in motion the heavier solids are held in suspension, but at slack water they are deposited with the sand and mud naturally present in the water with which the sewage is diluted, and so long as this deposit of sewage matter does not take place before it has been sufficiently mixed with sea water, it will bear such a small proportion to the whole as to be practically imperceptible.

The lighter matters in suspension will also be rapidly dispersed by the oscillating motion of the water and rendered harmless so long as the outfall is sufficiently far removed from any foreshore where they may be deposited and become a nuisance.

A method has already been described for estimating the proportion of upland water or sewage to sea water in an estuary, but in order to determine the extent to which any particular sample of water is polluted with sewage, the aeration process is by far the most convenient, since it is based on the fact that unpolluted water when kept out of contact with the air for any length of time remains saturated with atmospheric oxygen, but, when polluted, loses oxygen in direct proportion to the amount of polluting matter which it contains if the quantity is not excessive.

It therefore follows that if a sample of polluted river or sea water is fully aerated at the commencement, a simple determination of the dissolved oxygen and nitrogen after keeping for, say, four hours, will give the data for estimating the degree of pollution in the sample in terms of the volume of the dissolved oxygen consumed during fermentation.

* "The dissolved nitrogen suffers practically no change, hence, since the ratio of the dissolved atmospheric nitrogen to oxygen, in a fully aerated water, is practically constant at different temperatures for both fresh water and sea water, namely, 1·95 to 1, it gives the necessary datum for calculating the volume of oxygen which was dissolved in the sample at the time of its collection. This calculated volume,

* Proceedings of the Institution of Civil Engineers, Vol. 147, page 74.

less that found after keeping the sample, gives the volume of oxygen consumed by the fermentation of the polluting matter in the water."

It will be understood that, although this aeration test affords information as to the total amount of impurity contained in a sample of water, and thus indicates the efficiency of its diffusion, it makes no distinction between dissolved and suspended matter, and even a small proportion of the solid matter in suspension is liable to cause trouble under certain circumstances by being deposited on the bed of the sea or foreshore, where its accumulation may become a danger to navigation or public health, while a procession of sewage matter past bathing places is highly objectionable, so that it is usually found necessary to provide some means of removing most of the suspended matter from the sewage before it can be safely discharged into a river estuary, though under favourable conditions the crude sewage may sometimes be discharged from a well-placed outfall direct into the open sea without any preliminary treatment.

The larger solids and floating garbage may be conveniently removed by passing the sewage through screens, the fineness of which can be arranged according to the nature of the material which it is desired to remove, but where no other treatment is adopted, and it is important to intercept all floating matter which would be noticed near the sea front of a watering place, a wire screen of fine mesh is usually the most efficient, and is briefly described in Chapter IV., though it may be observed that such screens should, if possible, be constructed in duplicate, so that one may always be in use while the other is being cleaned or repaired.

With regard to the finer suspended matter, the heavier particles, which would be most likely to form a deposit near the outfall, can be separated by passing the sewage through sedimentation tanks; but in order to intercept all the matters in suspension, some form of chemical precipitation or bacteria treatment must be resorted to, which necessarily involves far greater expense, but is undoubtedly the proper course to adopt in all cases where there is any risk of a nuisance arising from the deposit of solid matter on or near the foreshore.

In the works quite recently completed for Dublin, provision is made for treating the whole of the sewage with lime in precipitation tanks having a capacity which approximately corresponds with the average daily dry weather flow, the deposited sludge being pumped into tank steamers and carried some eight miles out to sea.

A similar system has been followed for many years by London, Glasgow, and Manchester, but owing to the great quantity of sludge produced by lime precipitation, and the cost of transporting it out to sea, bacteria treatment in septic tanks is now rapidly gaining popularity, with a view to liquefying as much of the solid matter as possible, and this method of treatment has lately been adopted at a considerable number of places in preference to the older system of preliminary treatment by precipitation.

In order to apply any system of tank treatment it is necessary to find a suitable site for the plant, and as this should, if possible, be placed in such a position that the sewage may be brought into the tanks by gravitation, the limited fall available, as well as the objection to placing such works near the sea front, will frequently make it extremely difficult to find a site even large enough for a screening chamber which will not be open to some objection, either from an engineering or sentimental point of view.

The objection to placing such works in a prominent position may, however, be largely avoided if the tanks are covered, and thus hidden from view, this means of overcoming the difficulty having been adopted for at least one well-known watering place, where the tanks are under the promenade, quite unsuspected by the thousands of visitors who pass over them during the summer; but the location of screening chambers may sometimes present even greater difficulties than the tanks, owing to the constant attention they require, whereas the tanks will only have to be emptied occasionally for the removal of sludge.

It has been suggested that subsoil water may be advantageously admitted to the sewers at seaside towns, but when any system of preliminary treatment is necessary, the adoption of this course would necessitate larger works, and would therefore be a direct disadvantage, though where a sea outfall is obtainable for crude sewage there is of course no objection to discharging both subsoil and surface water into one combined system of sewers, which may also receive trade waste, as the disposal of this does not usually involve any special attention or expense in the case of a sea outfall.

Since the fall available for sewers at sea coast towns is usually very limited, it is important to observe that if precipitation tanks are used they will require emptying much more frequently than septic tanks, and if pumping is to be avoided the bottom of tanks should be high enough for the contents to be removed by gravitation, so that the sewers must discharge into the tanks at a height above the outlet equal to the depth of sewage which they are intended to contain when full.

In the absence of exceptionally favourable circumstances, or some kind of preliminary treatment to remove the solid floating matter which might be washed back on to the shore, it is seldom possible to discharge crude sewage into the sea during any part of the flood tide, and in order that it may be carried well out to sea before the tide begins to turn, it is usually necessary to suspend the discharge during the latter part of the ebb tide as well, so that the level of the outfall must sometimes be kept at a considerable height above low water, thus restricting the fall available for the sewers, and possibly making it necessary to empty some of them by pumping, in spite of the fact that they are actually above low water level, and might consequently be emptied by gravitation if the discharge could be continued right down to low water.

Unless the sewers are allowed to become surcharged, which is most undesirable, this suspension of sewage discharge necessitates the provision of storage tanks to hold at least the dry weather sewage flow during the time that the outfall is closed, but owing to the heavy expense involved by providing storage for the large volumes of storm water brought down in wet weather, this is generally allowed to escape into the sea by storm overflows regardless of the state of the tide, or in case it cannot be discharged by gravitation at high tide, it is generally cheaper to provide plant for pumping it rather than attempt to store it in tanks, though both pumping and storage are in some cases unavoidable.

Owing to the heavy cost of storage tanks for crude sewage and the impracticability of deferring the discharge of storm water, it is generally preferable to provide some form of preliminary treatment for removing the suspended matter, so that the difficulties arising with a limited period of discharge may be reduced or avoided, except in so far as this may be required in order to obtain an outlet for any sewers which are below high water level, the contents of which must in any case be stored or pumped so long as the sea level is above them during a part of each tide.

Even when the suspended solids are removed, it is still necessary that the outfall sewer should terminate in such a position that the outlet will always remain submerged at low tide, but when crude sewage is discharged it should extend much further below the low water than would be necessary when all floating garbage has been carefully removed by screening, and the other suspended matter has been reduced to a minimum by previous sedimentation, precipitation, or liquefying.

The saving thus effected by reducing the length of outfall sewer may be very considerable, especially where the foreshore is comparatively flat, or where costly works are required for anchoring and protecting the pipes, so that the extra expense involved by the construction of tanks for preliminary treatment will be counterbalanced in many cases by the reduced cost of outfall sewer, together with the omission of storage tanks, or at all events a large reduction in their capacity.

The construction of tanks either for the storage or clarification of sewage in sea coast towns will frequently present a number of difficulties owing to the position in which they may have to be placed, and the necessity for constructing such works below the level of the sewers, which may involve deep excavations in treacherous ground, but in all cases where the outlet is tide locked for a number of hours each day it is of the utmost importance that provision should be made for the escape of any foul gases so confined in the sewers or tanks in such a way that they may not cause a nuisance, and the ventilation of such works will therefore require very careful attention.

Where storage tanks or sewers have to be constructed below high water level it is necessary to prevent the entrance of sea water by providing a tide flap at the outlet which will close whenever the pressure of the sea water on the outside

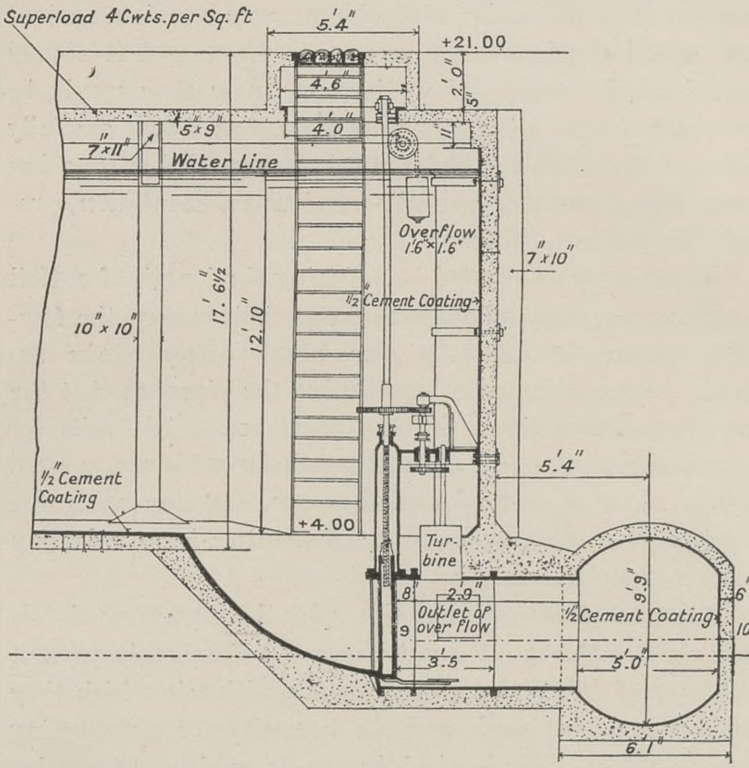

Fig. 4.—Section of Tidal Outlet Valve, Portsmouth Main Sewerage.
(Reproduced by permission of Mr. Philip Murch, Portsmouth.)

becomes greater than that of the sewage inside, but when the discharge has to be suspended during the flood tide or before low water is reached on the ebb tide, it is also necessary that the outlet should be controlled by valves which can be opened and closed by hand at the proper time.

Fig. 4 shows the arrangement of tidal outlet valve employed at Portsmouth for controlling the discharge of sewage from storage tanks in which it is retained during the flood tide; the labour of operating the valve by hand is in this case very materially reduced by using a small turbine, which is worked by the sewage itself, and under favourable conditions there seems to be no reason why such an arrangement should not be made entirely automatic.

In order to avoid the necessity for attending to these valves at all hours of the night and day, according to the state of the tide, they may sometimes be controlled by automatic syphons actuated by the rise and fall of the tide itself, and in several cases the Board of Trade have required the provision of an indicator showing when the outlet is closed or open, so that its proper regulation may be observed and checked from a distance.

In those cases where it is necessary to pump the sewage in addition to providing storage tanks, it will generally be found economical, where a suitable site is available, to construct the latter well above the required level of the outlet into the sea, and to discharge the sewage into them by continuous pumping, thus avoiding the necessity for large low level storage tanks, the construction and cleaning of which below the level of the sewers would cost far more than tanks built at ground level with the same capacity, though where such works have to be placed in an exposed position, an underground tank may be preferable on the principle that out of sight is out of mind.

With regard to the capacity of storage tanks and other works in connection with the discharge of sewage into tidal water, it would seem that these may in most cases be conveniently based on the usual requirements of the Local Government Board in dealing with the disposal of sewage from inland towns, provision being made for screening and storing or partially clarifying a volume of sewage equal to twice the daily dry weather flow, which should always be discharged at a point below low water level during the time when the set of the tidal currents away from the town or beach is sufficiently strong to carry the whole of the sewage out to sea.

Any excess over this quantity up to six times the daily dry weather flow should also be discharged by an overflow at the same point, but no storage or preliminary treatment is usually required for this, except the removal of floating garbage by screening, while anything beyond this quantity can be discharged by ordinary storm overflows wherever a convenient outlet may be available.

It is, however, very apparent in many places that the storm overflows come into action long before the above rate of dilution is reached, and this is not infrequently due to the insufficient capacity of outfall sewers, as well as the absence of adequate storage, and in this connection it may be well to observe that in calculating the actual discharging capacity of a submerged outfall sewer due allowance must not only be made for the relative water level inside and outside, but also for the difference between the specific gravity of fresh water and salt water.

In dealing with the various questions arising in connection with sea outfalls, it should not be too readily assumed that, so long as the suspended solids are first removed from the sewage, it can always be discharged into the sea with impunity, or that a sea coast town will necessarily be relieved of the obligations falling upon inland towns to remove the dissolved impurities in its sewage as well as the suspended matter, since it is sometimes found that the former may indirectly cause a very serious nuisance by developing the growth of certain kinds of sea-weed which, when dead, may drift on to the shore, where they undergo gradual decomposition, and are liable to become highly offensive during hot weather.

This difficulty is undoubtedly exceptional and unlikely to arise when the outfall discharges into the open sea, but Belfast Lough may be mentioned as an instance where sea-weeds, chiefly Ulva latissima, or sea-lettuce, have developed in extraordinary quantities on the large tract of sand and mud which is uncovered at low water, and, drifting ashore in layers often two or three feet thick, become rotten in the summer and autumn months, giving rise to a nuisance surpassing anything which could have been caused by the sewage itself.

In this case the sewage is discharged in a crude state, but in the opinion of Dr. Letts, who has examined the whole subject very closely, its purification cannot be expected to entirely do away with the nuisance, inasmuch as while rendering the sewage inoffensive it will simply bring its polluting constituents into a form more readily assimilated by plant life.

Chichester is another place where the same difficulty was encountered, but, in that case, it has apparently been overcome by treating the sewage in bacteria beds, and it is, therefore, possible that a similar course may have to be adopted at Belfast with a view to at any rate mitigating the present evil, and it should be observed that this would simply mean that the oxygen required for the purification of the sewage matter would be absorbed from the atmosphere instead of the sea water, in which the process is necessarily slower, owing to the comparatively small quantity of free oxygen which it contains, though it is now recognised that when the supply of dissolved oxygen in water is depleted by sewage contamination, a further supply is rapidly absorbed from the atmosphere, so that the rate at which organic matter is oxidised does not exactly depend on the quantity of oxygen originally present in the water with which it is mixed.

The grave responsibility incurred by Local Authorities who discharge their sewage into the sea without proper precautions is well illustrated by the Emsworth oyster case, decided by the Court of Appeal in May, 1906 (Foster *v.* Warblington Urban District Council), in which the Court held that, although a prescriptive right to drain on to the foreshore existed, and although the inhabitants had a right to connect their drains with the public sewer, there was no right to commit a public nuisance; and since it was proved by float observations that the sewage had been carried over the oyster beds in the neighbourhood, with the result that they had to be abandoned, it was held that the Local Authority was liable for damages.*

It has been suggested that the danger of spreading infection by the contamination of shell fish and public water supplies with the germs of disease carried into the streams or estuaries by sewage, might be materially mitigated if all sewage effluents were sterilised,† but in order to render such a system really effective, it would no doubt be necessary to sterilise the whole of the storm water which passes through the sewers as well as the ordinary sewage flow, and in that case the cost would be practically prohibitive under ordinary conditions, where the volume of storm water is frequently far greater than that of the sewage proper.

* Paper on "Sewage Outfalls," read by Prof. Henry Robinson before the Manchester Branch of the Association of Managers of Sewage Disposal Works, September, 1906.

† "Prevention of Bacterial Contamination of Streams and Oyster Beds," by W. P. Digby and H. C. H. Shenton.

It would, therefore, seem to be a very much simpler matter to sterilise the shell fish or water supplies than to deal with sewage effluents in this way, as no such system could be relied upon to remove all danger of contamination, and the consumers would still have to rely for protection on those who supply them with water or shell fish as the persons directly responsible for their freedom from contamination.

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CHAPTER III.

Irrigation and Land Filtration.

Development of original methods of disposal—Difficulty of obtaining sufficient suitable land—Volume of sewage treated per acre of land—Relative merits of different kinds of land—Underdrainage of irrigation areas—Carriers and pipes for distribution—Preparation of land filtration areas—Distribution on land filtration areas—Cultivation and cropping of land—Effect of overworking irrigation areas.

When it first became necessary to provide some systematic means of preventing the nuisance arising from the accumulation of liquid refuse in the vicinity of populous communities, or the pollution of inland water courses, the method of sewage disposal which naturally suggested itself was by distribution over the surface of the land, and as this original method is still employed with success at a very large number of places throughout Great Britain, it is desirable to define its possibilities and limitations before proceeding to study the application of the various alternative means of purification by bacteria beds, although these merely consist in an artificial substitute for land in which the same natural agencies are concentrated to achieve the same result in a more confined space.

Although land treatment is still so extensively employed in this country as the most effective means of sewage purification under favourable conditions, its popularity is no longer due to any hope of deriving a profit from the manurial value of the organic matter contained in the sewage, as the complete futility of this idea has been long since recognised, owing to the fact that the organic matter can only reach the land in combination with many hundred times its volume of water, and the manurial value of the sewage in proportion to its bulk is therefore so exceedingly small that its profitable extraction is impracticable.

The reports published by the Royal Commissions appointed to consider the question of sewage disposal in 1857, 1868, and 1898 very clearly illustrate the remarkable changes of opinion which have taken place during the past 30 or 40 years in regard to the reliability of land treatment as a means of purification, for it is not only described in 1857 as the right way to dispose of town sewage, and the only means of preventing the pollution of rivers, but in 1868 the Commission reported that, "Irrigation is the only process of cleansing sewage which has stood the test of experience, and, unless it is extensively adopted, there is but little hope of any substantial improvement in our sewage polluted rivers"; whereas the conclusions of the Commission now sitting are expressed in their Interim report, published in 1901, as follows :—

"We are, however. forced to conclude that peat and stiff clay lands are generally unsuitable for the purification of sewage, that their use for this purpose is always attended with difficulty, and that when the depth of top soil is very small, say six inches or less, the area of such lands which would be required for efficient purification would in certain cases be so great as to render land treatment impracticable."

"We are satisfied that it is practicable to produce by artificial processes alone effluents which will not putrefy, which would be classed as good according to ordinary chemical standards, and which might be discharged into a stream without fear of creating a nuisance."

It will, therefore, be seen that the disposal of sewage by irrigation on land was formerly regarded as the ideal method of treatment under all circumstances, whereas we now know that the local conditions may frequently be far more favourable to some other system of purification, but when a sufficient area of suitable land is readily available, as in the case of small communities surrounded by agricultural districts, disposal on land may still be effective and practicable.

"In the case of great cities, however, and of the smaller communities so often gathering around them, with only small intervening agricultural areas, the treatment of sewage on land becomes an increasingly difficult problem. Indeed, land treatment in these cases usually becomes quite impracticable, when we remember how the areas suitable for the purpose are restricted by the question of levels; how, when a certain area is available, it often proves of unsuitable quality, so that it can only deal efficiently with a very small volume per acre, and how we are now called upon to deal, not only with the dry weather flow, but also at times with the first five dilutions by rain, which are often fouler than the normal sewage." *

In estimating the area of land required for treating a given volume of sewage it is not only necessary to consider the quality of the land and the composition of the sewage, but very much must also depend on the particular method to be adopted for the actual application of the sewage to the land as well as the kind of crops to be grown upon it, and the time required for agricultural operations, which may necessitate the temporary suspension of sewage treatment on a large proportion of the total area at different seasons of the

* Report by Col. T. W. Harding and W. H. Harrison, M.Sc., on Sewage Disposal Experiments at Leeds, 1905, p. 125. Colonel Harding is a member of the Royal Commission.

year, not more than about one quarter of the total area being usually under irrigation at any one time.

The following table was prepared by Mr. R. A. Tatton to roughly indicate the relative merits of different kinds of arable land for the treatment of sewage by the two alterna-

APPROXIMATE AREAS OF ARABLE LAND REQUIRED UNDER VARYING CONDITIONS.

—		Direct to Land.		After Precipitation or Mechanical Settlement.		After Filtration on Bacteria Beds.	
		Ratio of Population per acre.	Acres per 1,000 Persons.	Ratio of Population per acre.	Acres per 1,000 Persons.	Ratio of Population per acre.	Acres per 1,000 Persons.
Surface Irrigation.	Gravel	100	10	500	2	1,000	1
	Light Loam ...	100	10	500	2	750	1⅓
	Heavy Loam ...	75	13⅓	200	5	400	2½
	Peat	Unsuitable.		Unsuitable.		Unsuitable.	
	Clay	50	20	100	10	300	3⅓
Land Filtration.	Gravel	150	6⅔	500	2	1,000	1
	Light Loam ...	150	6⅔	500	2	1,000	1
	Heavy Loam ...	75	13⅓	300	3⅓	500	2
	Peat	75	13⅓	200	5	400	2½
	Clay	Unsuitable.		Unsuitable.		Unsuitable.	

tive methods usually adopted, regarding which he gave evidence before the Royal Commission; but it is, of course, obvious that no hard-and-fast rule can be laid down, owing to the impossibility of drawing any definite line of distinction between one kind of land and another, for, even assuming that all other conditions are equal, the infinite variations in quality of land and its capacity for sewage treatment are entirely a matter of degree between the two extremes represented by the lightest sandy loam and the most impervious clay.

The above figures show very clearly that, even assuming the most favourable conditions, it has become totally impracticable to treat the sewage from our great cities on land alone, owing to the vast area required, especially when due allowance is made for the rapid increase of population, which has to be provided for in a district such as that in the immediate neighbourhood of Birmingham, draining to the existing farm of the Tame and Rea Drainage Board, where over 3,000 acres are already in use, and where an additional area of nearly two acres per week would be necessary to keep pace with the increase of population within the district of the Drainage Board, if the whole of the sewage were to be dealt with by irrigation.

It may further be observed in regard to this particular Sewage Farm that, although it is now the largest in the world, the population draining to it is so great that there is only one acre of land available for the treatment of sewage from a population of 400 persons, which approximately represents 15,000 gallons per acre per day, whereas it has been stated by Mr. Watson, the Engineer to the Drainage Board, that in his opinion the land cannot be safely relied upon to deal with the sewage from more than 300 persons per acre, taking an average for the whole farm, which is generally well suited to the purpose, but includes land of very variable quality.

Referring once more to the relative merits of different kinds of land for the purification of sewage, it is now pretty generally agreed, by the best authorities, that the most suitable soil is the light alluvium found in most river valleys which, in spite of its extreme fineness, is sufficiently porous to let the sewage soak slowly through it, and so long as the quantity put upon it is not so great as to cause waterlogging, excellent results are obtained owing to the very rapid oxidation of organic matter which takes place when the air in the soil becomes intimately mixed with the sewage passing through it.

It should be understood, however, that this tendency to waterlogging is not always due to the excessive quantity of sewage discharged over the surface of the land, but may sometimes be accounted for by the absence of a sufficiently porous subsoil to carry off the purified effluent after its passage through the surface layers, in which the work of purification chiefly takes place.

The best land should, therefore, consist in a fine surface layer of alluvium overlying a subsoil of gravel, chalk or other porous material, but the land which effects the greatest amount of purification is not, as a rule, that through which it is possible to pass the largest volume of sewage; the characteristics which make for efficiency in point of quality of effluent being, to some extent, opposed to those which confer the power of treating larger quantities on a given area.

A porous subsoil may, however, be of little or no advantage unless it is provided with adequate means of draining to prevent the accumulation of subsoil water, and by keeping down the level of saturation to permit the penetration of air to a depth of, say, 4 or 5 feet from the surface.

Even where the subsoil is sufficiently porous and naturally well drained for ordinary agricultural purposes it may frequently happen that when large volumes of sewage are being constantly discharged on to it, a considerable amount of waterlogging takes place, owing to the rise in ground water level, and, in the case of the more impervious soils, this is inevitable unless some artificial means of drainage are provided, either by open ditches or covered pipes at fairly frequent intervals.

The use of open drainage ditches is generally undesirable on a sewage farm owing to the difficulty of preventing the passage of the sewage into them by merely flowing over the surface instead of soaking through the soil; but when their adoption is unavoidable, owing to the fall being insufficient to permit the use of ordinary underdrainage, it is important that the distributing carriers should be kept far enough away from the drainage ditches so that the sewage cannot pass from one to the other without undergoing a fair amount of lateral filtration as a substitute for the more efficient method of vertical filtration, which would be relied upon under more favourable conditions when the levels would permit of pipe drains being laid at a proper depth below the surface.

From the conclusions of the Royal Commission, referred to at the end of this chapter, and the tabulated figures already given, it will be observed that clay land is usually of very little value for sewage purification, but when its use is unavoidable, as in the case of the Leicester sewage farm, the results may be much improved by irrigating the lower portion of the land with the effluent from the higher portions, thus securing the benefit of double filtration.

In cases where the available fall is insufficient to permit of this, it is highly undesirable to drain clay land at all, since it is quite impracticable to make such soil more porous by putting in underdrains at intervals of even half a chain, and drains simply have the effect of increasing the natural tendency of clay land to crack, thus facilitating the escape of unpurified sewage, which readily passes down the cracks direct to the drains without undergoing any purification whatever.

In every other kind of soil except clay it is, however, almost invariably necessary to provide some artificial system of underdrainage in order to keep down the ground water level, as, unless this is done, the most suitable land is liable to become waterlogged and therefore useless owing to the obvious impossibility of securing adequate aeration, on which the oxidation of the sewage depends.

The proper determination of the depth, number, size, and gradient of land drains must always be a matter of judgment based on practical experience and knowledge of local conditions, as it is quite impossible to lay down any definite rule which could be universally applicable, but there are certain general principles which it is very important to bear in mind in order to draw a correct conclusion after carefully considering the peculiar circumstances of each particular case.

Although land drains are intended to keep down subsoil water, and thus increase the volume of aerated soil available for filtration purposes, it does not follow that any advantage is gained by laying them at a greater depth than about 4 or 5 feet (except in the case of main pick-up drains, which must sometimes be deeper), for it has been repeatedly proved by careful observation that most of the oxidising action takes place near the surface, and the quality of effluent is seldom improved by increasing the depth of underdrains beyond 5 feet, unless this is necessary for the purpose of securing a satisfactory gradient or some other engineering reason.

Since land drains are almost invariably laid in approximately parallel lines the total length or number required per acre must depend upon the average distance between them, and the usual distance being from half a chain to one chain apart, it may be useful to observe that 660 agricultural pipes (12 inches long) are required to drain one acre with drains one chain apart, or double this number when the drains are half a chain apart, excluding the main pick-up drains which run transversely to the others.

The size and gradient of pipes must to some extent be interdependent, since a larger pipe is required to discharge the same quantity of water with a flat gradient than a steep one, but, however good the gradient may be, it is seldom found advisable to use anything less than 3-inch pipes for ordinary branch drains, as a smaller size costs very little less, and is not only much more liable to become blocked with sediment, but is also much more difficult to ventilate, and in order to obtain the best results, it is essential that any system of drainage should be so arranged that air may escape freely from all the main pipes when they become suddenly charged with water, one simple method of accomplishing this object being shown in Fig. 5.

The size of main drains must naturally depend upon their gradient and the quantity of water they may be required to take from the branch drains connected with them, but the smallest size is seldom less than 6-inch, and in those cases where only a small amount of fall is available for the main drains, it is frequently desirable to use socket pipes instead of the ordinary agricultural pipes in order to obtain a true invert with a uniform gradient in the right direction, as it is very prejudicial to efficiency if any portion of the pipes fall the wrong way, and therefore remain charged with water even when not in use.

In order to ensure that the sewage filters through the land before reaching the underdrains, it is a good plan to surround the pipes with fine ashes, screened gravel, or surface soil before filling in the trenches, and when large pipes are necessarily laid at a shallow depth for main drains, they should be made watertight with cement joints, at any rate

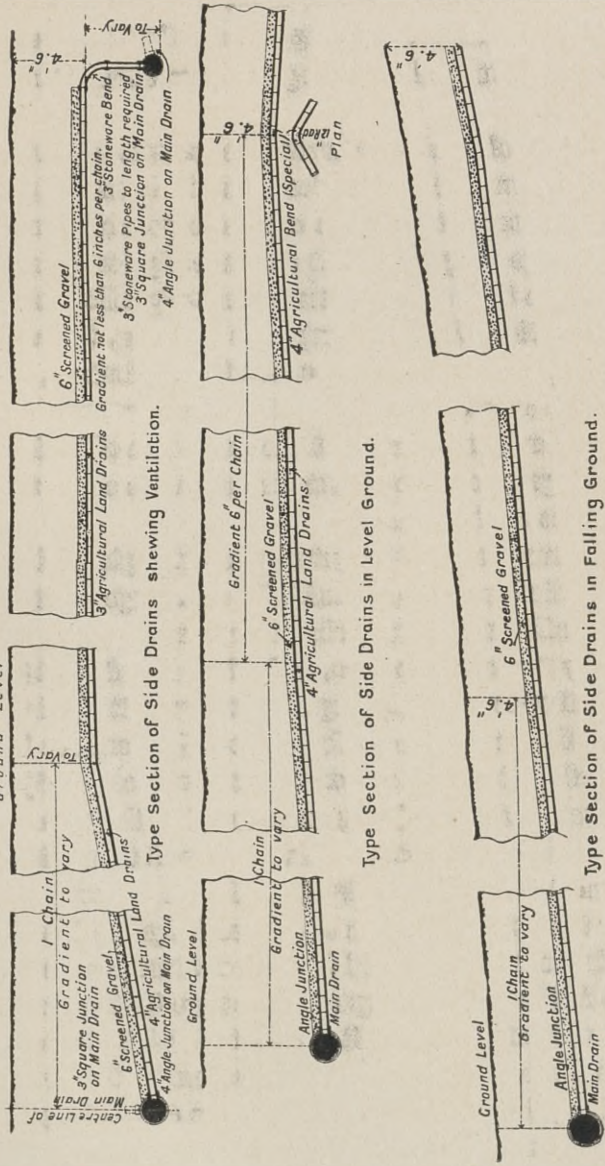

Fig. 5.—Laying Out Lands for Sewage Purification. Type Sections of Side Drains at Birmingham.

(Reproduced by permission of Mr. J D. Watson, Birmingham) on the upper side, while it is also important that moles and rats should be systematically trapped, for the same reason as their burrows may allow sewage to pass direct into the effluent drains.

In all forms of land treatment the process of sewage purification is practically identical, but it is nevertheless important to observe that when crops are grown upon the land, the sewage is applied to it continuously for considerable periods at a time on the system commonly called surface or broad irrigation while the crops are growing, but while the agricultural operations of cultivating, planting, and harvesting are in progress, the application of sewage must be completely suspended, so that the same area of land can seldom be irrigated on this system for more than about three or four months in the year.

As an alternative to this system the principle of intermittent filtration may be adopted with advantage when the soil is of a sufficiently porous character to receive a dose of sewage every two or three days, and when it is desirable to work the land up to its utmost capacity without attempting to grow crops, this method is preferable to irrigation, the land filtration beds being laid out on fallow land, as nearly as possible level, each plot being surrounded with low earth banks so that it can be flooded at intervals and then allowed to rest until it is sufficiently dry to again receive sewage.

In order to apply the system of surface irrigation the land is usually laid out in ridges and furrows as illustrated in Fig. 6, so as to facilitate the absorption of sewage by the roots of the crops without bringing it in contact with the crops themselves more than is absolutely necessary, the sewage being discharged into the furrows while the crops are grown on the ridges, but as this method is only applicable to certain kinds of root crops the more usual method is to form shallow earth carriers in the direction of greatest fall, so that the sewage can be readily distributed over the surface of the land by the use of stop boards on semicircular pieces of sheet iron stiffened by an angle iron along the straight side, and pro-

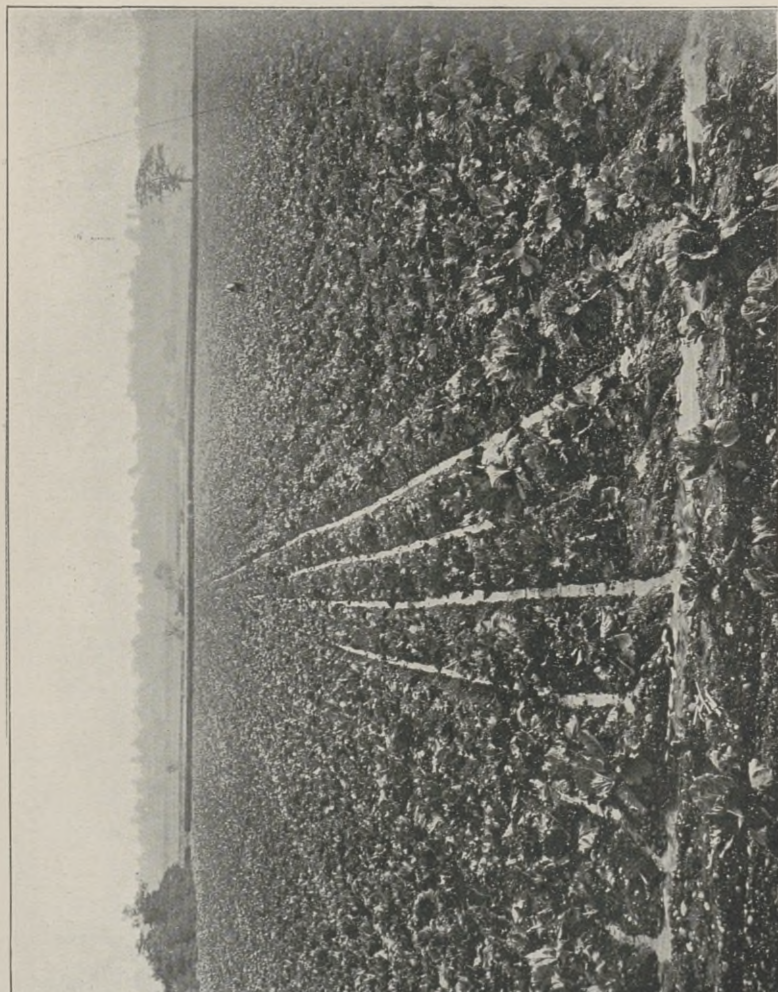

Fig. 6.—Method of Laying Out Land for Irrigation.
(Reproduced by permission of Mr. J. D. Watson, Birmingham.)

vided with a handle at the centre, so that they can be pressed into the soil and thus used for repeatedly damming the sewage at different points until it flows over the sides of the carrier.

The main permanent carriers required for bringing the sewage to the highest part of each plot are usually constructed of concrete or brickwork for the larger sizes, and stoneware pipes for the smaller ones, but it is important that all main carriers should be laid with a slight fall, and provided with emptying valves so that they need not be left full of stagnant sewage when not in use, while they should also have sluices or valves at intervals for regulating the flow of sewage on to the land.

On the older sewage farms the carriers were usually constructed in the form of open channels, but the more modern system of covered carriers is preferable, as the exposure of the sewage to the atmosphere in open carriers not only tends to cause a smell in hot weather, but in very cold weather it is an advantage to maintain the high temperature of the sewage until it is actually discharged on to the land, as this is the best means of keeping the land free from ice, which would otherwise form an impervious covering all over the surface, and thus prevent the passage of any sewage through it.

Fig. 7 shows various alternative methods of construction for carriers of different sizes, together with the arrangement of sluice outlets and syphons for crossing under roads as adopted for the new works on the Birmingham Sewage Farm.

Whatever system of distribution is adopted, it is very necessary that all depressions in the surface of the land shall be carefully filled up, as the sewage will otherwise be concentrated in any hollow places instead of being equally dis-

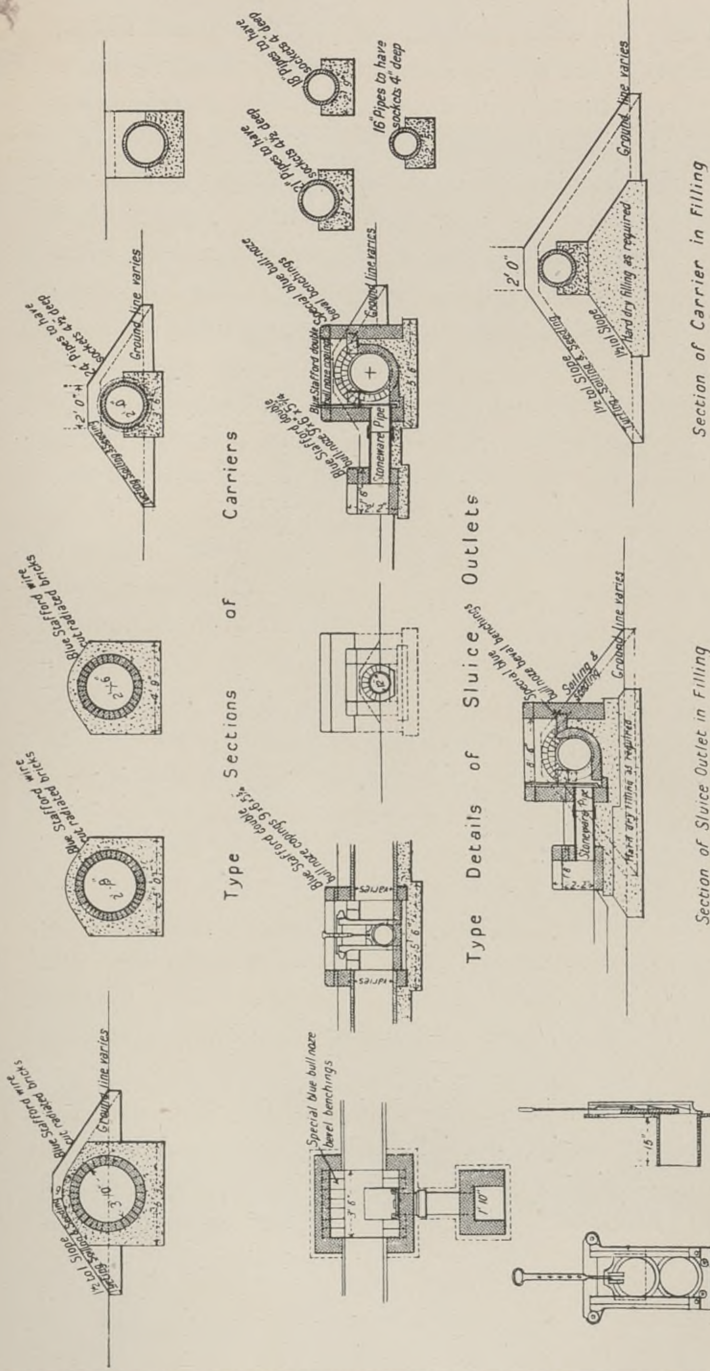

Fig. 7.—Laying Out Lands for Sewage Purification. Details of Carriers and Sluice Outlets at Birmingham.

(Reproduced by permission of Mr. J. D. Watson, Birmingham.)

tributed over the whole surface, and in forming land filters, it is necessary that the whole of each plot should be made perfectly level; the method of levelling usually adopted being well illustrated in Fig. 8.

It will also be observed that the preparation of land for this method of treatment involves far more expense than laying it out for ordinary surface irrigation, especially when there is a considerable slope in the ground, so that the filtration areas have to be formed in terraces contouring the hill; and in order to ensure a sufficiently rapid rate of filtration and aeration, it is usually found necessary to strip the surface soil to a depth of about 1 foot, leaving nothing but the coarse sandy subsoil, which is essential to the success of this system.

Land filtration is sometimes defined as surface irrigation intensified, and when both systems consist in the application of sewage to growing crops, there can be little distinction between them; but in order to avoid the confusion which results from the use of two different terms to describe practically the same method, it is far better to reserve the term "filtration" for any system in which the land is used exclusively for the filtration of sewage, without any attempt to make use of it at the same time for growing crops, and it is in this sense that land filtration is understood in America, where it is almost universally adopted in preference to irrigation, though it is interesting to observe that this system of land treatment was first suggested by the English Rivers Pollution Commissioners in their report of 1868.

This preference is, no doubt, due to the fact that very porous sandy soil is essential for its success, and this can usually be obtained with less difficulty in the United States than in England; also, owing to the enormous consumption of water per head of the population, the sewage is so dilute that very much larger quantities

Fig. 8.—Levelling and Cultivation of Land Filtration Area.
(Reproduced by permission of Mr. J. D. Watson, Birmingham.)

can be purified per acre than would be possible in England, where most of the land is comparatively impervious, so that it very readily becomes waterlogged, especially during wet weather, when it is required to receive large volumes of rain water from the whole drainage area, in addition to the sewage itself and the rain actually falling on the land filters (1 inch of rain representing about 22,000 gallons per acre).

Land filtration areas not only require far more careful levelling and more numerous underdrains than land used for irrigation, but in order that the sewage may be quickly and uniformly distributed over each filter at frequent intervals without the necessity for constant attention, it is also desirable to provide some form of automatic dosing apparatus with artificial distributing channels, the total area being divided up into plots of about one acre or less, according to the size of the scheme, each of which is supplied by a central carrier.

These carriers may be economically constructed with a concrete bottom and wooden sides, the latter being held in position by iron bars set in the concrete, extending across the entire width of the carrier and turned up at the ends, while each outlet can be conveniently regulated by a hinged wooden gate, as on the new works recently completed at Saratoga Springs, U.S.A., where provision is made for dealing with the sewage from a population of 40,000 at an average rate of about 60,000 gallons per acre per day.

The sewage is applied to each bed on alternate days in doses of about 35,000 gallons four times a day, the discharge being automatically regulated by means of an 18-inch syphon, shown in Fig. 9, which ends in a 24-inch vertical cylinder provided with four equi-distant circular openings, 12 inches diameter, which connect with pipes enlarging to

24 inches diameter, each extending to serve a separate group of filters.

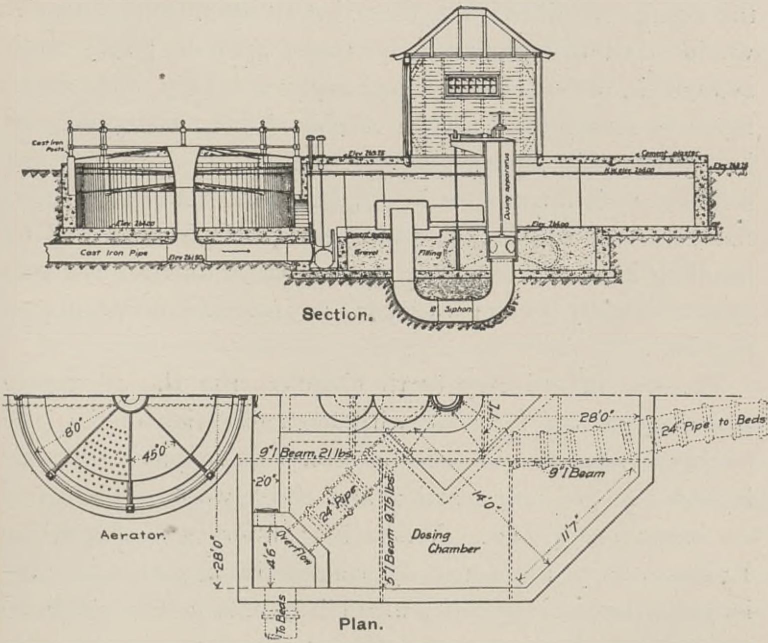

Fig. 9.—Intermittent Application of Sewage on to Land Filters. Dosing Tank and Aerator at Saratoga Springs, U.S.A.

(Reproduced by permission of Mr. F. A. Barbour, Boston, U.S.A., and the *Engineering News*, N.Y.)

Inside the four-way cylinder another cylinder with one opening is made to revolve by the rise of a float, so arranged that each rise of the float causes the inside cylinder, or revolving gate, to turn one quarter of a revolution by means of a ratchet, thus making the position of the inner opening correspond with each of the four outer ones in succession, and discharging the contents of measuring chamber on to a fresh filter each time.

As regards capacity, Mr. L. P. Kinnicutt, of the Worcester Polytechnic Institute, U.S.A., states that, after preliminary tank treatment, one acre of filter surface may receive the sewage from 1,000 to 1,500 persons, and from the results obtained from these intermittent sand filters it would seem that they can be relied upon to purify weak sewage in a satisfactory manner where the albuminoid figure is something between .2 and .4 per million gallons; but when this figure reaches from 1.0 to 1.9 parts per million, as it often does in England, the rate of filtration must be very much less, and the expenditure involved by levelling land and constructing permanent carriers becomes proportionately greater owing to the increased filtration area required.

The use of ordinary earth channels has the advantage that they do not interfere with the cultivation of the land by horse labour, which is necessary at frequent intervals in order to promote aeration and check weeds, even when no crops are grown. When land filters are adopted in England they more usually consist in a portion of the irrigation area temporarily utilised for this method of treatment for a year or two and then replaced by a fresh area, while the original one is again employed for irrigation and growing crops, and the use of temporary carriers is therefore preferable to permanent ones.

The duties of a manager in connection with the maintenance and control of sewage disposal works are fully dealt with in Chapter XII.; but since the method of laying out an irrigation area must to some extent depend upon the kind of crops which it is intended to grow upon it, the question of cultivation and cropping may be briefly considered here; for although it is impossible to summarise the general knowledge of agriculture which every sewage farm manager should possess, it is desirable to emphasise some of the chief points which should be well observed by anyone who wishes to compare the merits of sewage disposal on land with the more modern methods of bacteria treatment, to be considered in succeeding chapters.

The first point to be observed is the absolute necessity for keeping the land thoroughly clean and free from weeds, as the rapidity and luxuriance with which weeds grow and flourish on sewage farms can only be appreciated by those who have had personal experience of their management. In fact, they constitute a perpetual plague, which if allowed to spread unchecked will rapidly cover the whole ground, and by excluding light and air will prevent the purification of sewage discharged on to it.

It is, therefore, of the utmost importance that all land which is required to treat the greatest possible quantity of sewage should be constantly broken up and cultivated so that the soil may be kept well aerated, and although where crops are grown they should always be a secondary consideration as compared to sewage purification, they represent a valuable asset with which to balance at least a portion of the working expenses; and since the cultivation is necessary in any case, the crops should produce a good return for the expenditure involved by planting and harvesting them.

The most efficient form of cultivation is undoubtedly hand trenching or double digging with a fork, so that all squitch, docks, and other strong growing weeds may be shaken out on the top and burnt in heaps; but as manual labour is far too expensive for adoption on a large scale, most of the cultivation is usually done by horses, though far better results can be obtained by the use of steam power wherever this is practicable, owing to the greater depth to which the ground can be ploughed and turned over.

The latter method can only be applied on very large works, which should be specially laid out for the purpose in approximately square plots, with roads between them, not more than, say, 400 yards apart, for the use of the traction engines required for driving the wire ropes by which the large ploughs and other implements are drawn backwards and forwards, as shown in Fig. 10, it being quite possible to cultivate the ground in this way to a depth of 15 inches.

With regard to the best kind of crops for a sewage farm, this must largely depend on the nature of the soil; but since land treatment is now very seldom attempted, except on fairly light land, the conditions are usually favourable to various kinds of root crops, such as mangolds, swedes, and turnips, while cabbage and rhubarb can also be grown with success, but by far the most popular crop is Italian rye-grass, as it absorbs an enormous quantity of moisture, and a good crop may usually be cut about four times a year, while its strong growth also has the advantage of keeping down the weeds.

It will, however, be understood that, no matter what crops are grown, there must be certain seasons during which sewage cannot be advantageously applied to them, and it is on this account that the great difficulty of combining successful sewage purification with profitable agriculture arises, and as satisfactory results can only be obtained by rendering the latter subservient to the former, it is highly undesirable to accentuate this natural conflict of interests by letting a sewage farm to a tenant.

When land is worked up to its fullest capacity, occasional signs of sewage sickness are inevitable, even under the most skilful management; but this sickness only becomes serious when allowed to become chronic through neglect, and although the land will, under ordinary circumstances, recover its normal condition after a short period of rest, it is sometimes necessary to apply a more drastic remedy in

Fig. 10.—Steam Cultivation at the Sewage Farm of the Birmingham, Tame and Rea Drainage Board.

(Reproduced by permission of Mr. J. D. Watson, Birmingham.)

cases of chronic sickness, either by growing a grain crop on the land without any sewage, or in some cases the use of lime may prove effective when this can be obtained at a reasonable cost; but in a very great number of cases the failure of sewage farms may be accounted for by improper management.

The whole question of land treatment has been very fully investigated by the Royal Commission now sitting, and the following summary of their observations is taken from their Fourth Report, Volume IV., Part I.

"To summarize all our results within the limits of a few sentences is impossible; but we may say, in conclusion, and speaking in general terms, that we doubt whether even the most suitable kind of soil worked as a filtration farm should be called upon to treat more than 30,000 to 60,000 gallons per acre per 24 hours at a given time (750 to 1,500 persons per acre), or more than 10,000 to 20,000 gallons per acre per 24 hours, calculated on the total irrigable area (250 to 500 persons per acre). Further, that soil not well suited for purification purposes, worked as a surface irrigation or as a combined surface irrigation and filtration farm, should not be called upon to treat more than 5,000 to 10,000 gallons per acre per 24 hours at a given time (125 to 250 persons per acre), or more than 1,000 to 2,000 gallons per acre per 24 hours, calculated on the total irrigable area (25 to 50 persons per acre). It is doubtful if the very worst kinds of soil are capable of dealing quite satisfactorily even with this relatively small volume of sewage. The population per acre is calculated on 40 gallons of sewage per head per day. It is here assumed that the sewage is of medium strength and is mechanically settled before going on to the land.

"Comparing the above figures with the volume of sewage capable of being treated by artificial processes, we note that the witnesses examined by the Commission generally expressed the following opinion :—

"Contact Beds. 750,000 gallons per acre per 24 hours, allowing for periods of rest, but not for secondary treatment. Allowing one acre of secondary bed for every two acres of primary bed, about 500,000 gallons per acre per 24 hours could, according to this view, be finally treated. It is assumed always that the sewage has been previously treated either by chemical precipitation, or by subsidence in settling tanks, or in a septic tank.

"Continuous Filters. About 484,000 to 2,904,000 (4,840,000 according to one witness) gallons per acre per 24 hours. Previous treatment by chemical precipitation or subsidence in settling tanks, or in a septic tank, is assumed.

"Apart from the question of the quality of the effluents, it is obvious that, generally speaking, a larger volume of sewage can be treated by artificial bacteria bed processes than by land.

"It is impossible to lay down any hard and fast rule as regards the proper proportions between the area actually being irrigated at one time and the surplus ('resting') irrigable area. Each case must be judged on its own merits; but, broadly speaking, the tentative assertion that at least (a) four-fifths of a surface irrigation farm and (b) two-thirds of a filtration farm respectively should be at rest, is probably not remote from the truth, it being assumed that (a) one-fifth and (b) one-third are capable of effectively purifying the sewage until such time as the next one-fifth and one-third respectively of the surplus irrigable area due in rotation have been sufficiently rested. The above is subject to the reservation that the whole question of intermittency is but little understood, and as we have said before, whether or not rapid or slow alternations of working and rest are advisable we are unable to say."

Although the popularity of land treatment as a means of sewage purification has considerably decreased since the introduction of the more scientific methods of treatment in artificial bacteria beds, it is well to remember that land still possesses certain advantages as compared with these more modern systems, and is, indeed, preferable to any other system under really favourable conditions.

For instance, the rate at which sewage can pass through the land is limited by the porosity of the soil, and the quality of sewage farm effluents is, therefore, seldom liable to sudden variations, while the straining action of fine sandy soil naturally has a far greater effect in removing dangerous pathogenic bacteria than the comparatively coarse-grained media used in artificial beds.

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CHAPTER IV.

Removal of Matters in Suspension by Screening and Treatment in Tanks.

Screens for removing floating garbage from crude sewage—Tank treatment by sedimentation, precipitation and liquefying—Principles governing the size and shape of tanks—Methods of admitting sewage and withdrawing effluent—Utility of scum on sewage and covering liquefying tanks—Construction of tanks with concrete or masonry—Object and construction of circular tanks—Hydrolytic tank; construction and method of working—Separation of colloidal matter.

It has already been explained in the Introduction that the purification of sewage practically consists in the oxidation of the putrescible organic matter which it contains either in suspension or solution, but although many attempts have been made to accomplish this in a single process by treating crude sewage on land or bacteria beds, it has seldom been carried out successfully as the suspended matter tends to accumulate on the surface, where it forms a comparatively impervious coating, which prevents thorough aeration and consequently renders the rapid oxidation of organic matter impossible, with the result that bad effluents are produced and the interstices of the land or bacteria beds soon become completely clogged.

It is therefore generally considered essential that any system of purification should include some kind of preliminary treatment to separate the suspended matter from the liquid as far as possible, and for this purpose it is found advisable to first pass the sewage through screens to remove sticks, rags, corks, brushes, and other floating garbage which might cause trouble by blocking pipes and valves if allowed to pass into the works, and then to reduce the other suspended matter by subsidence or liquefying in tanks, so that the quantity remaining in the effluent is so small and finely divided that it may be readily decomposed and oxidised by bacterial action without risk of clogging the surface and interstices of any land or artificial bacteria beds on to which it may be discharged.

Under ordinary conditions sewage screens consist of a series of flat or slightly tapered steel bars, fixed side by side in a frame, with spaces between them about $\frac{1}{2}$ in. to $\frac{3}{4}$ in. wide, and arranged so that the garbage which they intercept may be conveniently removed by a rake drawn up the bars from bottom to top, the screen being inclined at an angle of about 30 degs. with the vertical to facilitate this, and having the top turned over to allow the rake to pass without catching the frame.

In small works the cleaning of the screens is usually done with a hand-rake used by a man standing on a platform immediately above the screen, but unless this is done at frequent intervals, both by night and day, the matter collected soon blocks the passage of sewage through the screen, and many instances might be mentioned where this has resulted in backing up the sewage in the main outfall sewer until the storm overflow came into action, so that any neglect on the part of the man responsible for cleaning the screens is not only liable to cause the discharge of crude sewage into a water course even in perfectly dry weather, but may also result in damage to the sewer by placing it under pressure, besides checking the velocity of flow, so that a sewer that is self-cleansing when it has a free outlet

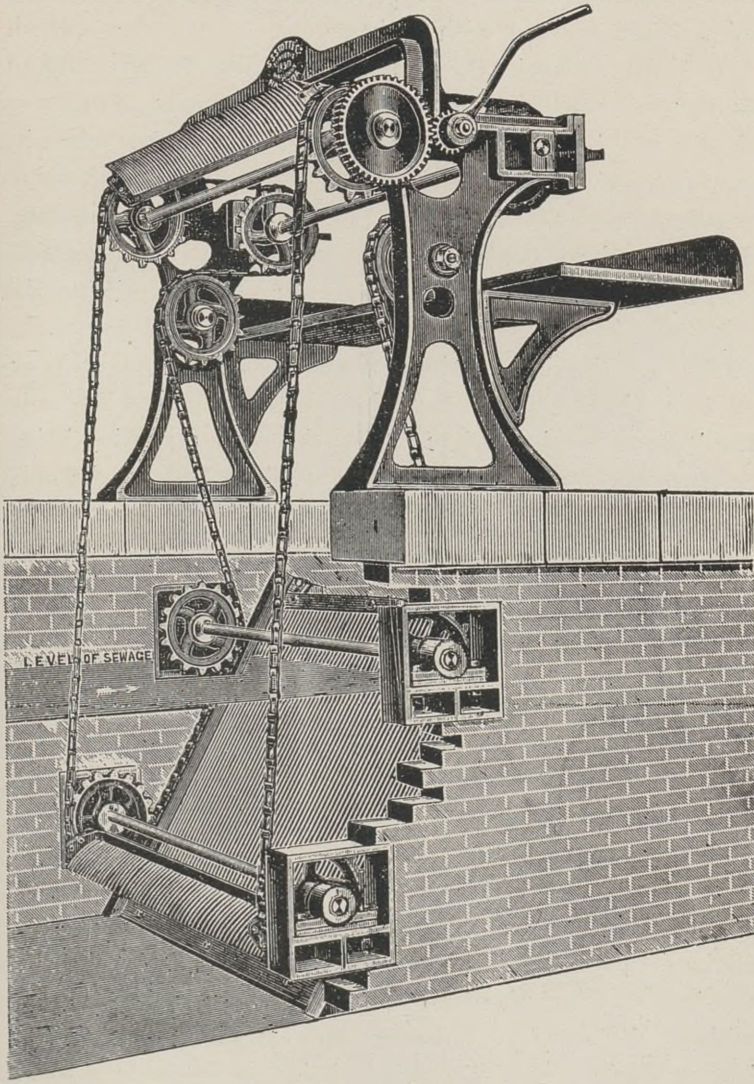

Fig. 11.—Mechanical Means of Cleaning Sewage Screens with Rakes Attached to an Endless Chain.

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may become a sewer of deposit when the outlet is blocked by a screen covered with garbage.

In order to avoid this danger, and also for the sake of economy in working, the screens for large works at any rate should not be dependent on manual labour, but may be more effectively cleaned by a series of power-driven rakes attached to an endless chain, so that they are constantly drawn up along the front of the screen, and by a suitable arrangement of the pulley wheels carrying the chains the rakes may be deflected downwards on passing the top of the screen, so that the garbage they have collected falls off on to a platform, and the rakes then pass down again to the bottom, as shown in Fig. 11, the same operation being thus constantly repeated so long as the rakes are kept in motion.

This screening apparatus includes an arrangement of spikes attached to a revolving spindle which pass between the teeth of the rakes, as shown in Fig. 12, and prevent rags, string, and other similar matter from sticking to them, means being also provided for tightening the chains when they become slack, while they should be made specially strong to resist the hard wear and heavy strains that sometimes come upon them when anything becomes wedged in the screen or when the pulley bearings become obstructed.

It will also be observed that in the case illustrated in Fig. 13 the screening apparatus is driven from the pumping engines by means of an underground shaft with suitable gearing, and in order that the screenings may be removed without difficulty or nuisance they are discharged direct into a tumbler cart, the whole being enclosed in a brick house ventilated by a shaft, in which a gas jet is kept burning to consume any foul gas given off by the sewage or screenings, which are in this case unusually offensive owing to the large quantity of brewery waste in the sewage.

This system of screening is similar to that adopted at

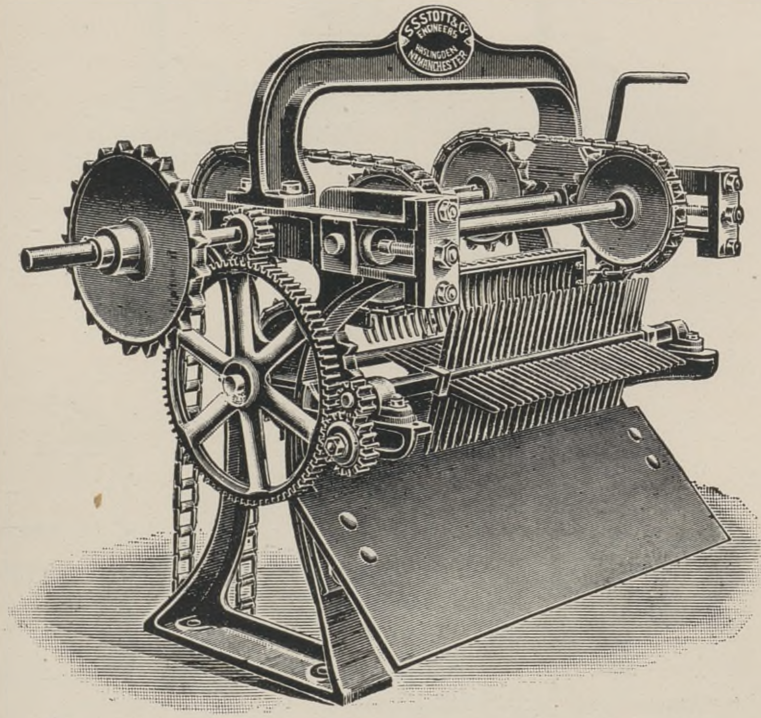

Fig. 12.—Mechanical Means of Cleaning Rakes Used for Removing Garbage from Sewage Screens as shown in Fig. 11.

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Davyhulme for the Manchester sewage; but the Manchester works being on a very much larger scale, the length of screens required is correspondingly increased, and a travelling belt conveyor is provided for the purpose of carrying the screenings to a small wagon, in which they are removed for disposal, while the screening chambers are arranged in

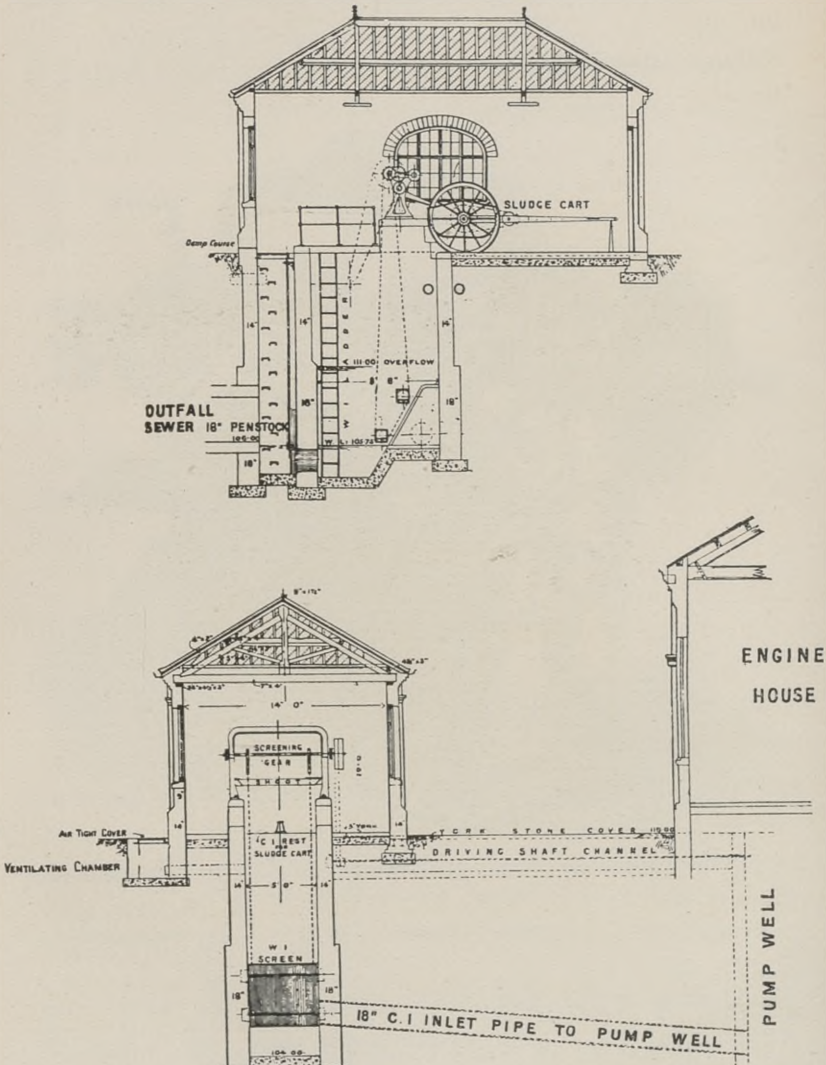

Fig. 13.—Sections of Screen House at Stratford-on-Avon, Showing Method of Enclosing Screens and Sludge Cart.

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duplicate, so that whenever it is necessary to empty them for repairs to bearings, etc., the sewage can be readily diverted from one to the other or can be temporarily turned through the bye-pass direct to the tanks, and if (as in this

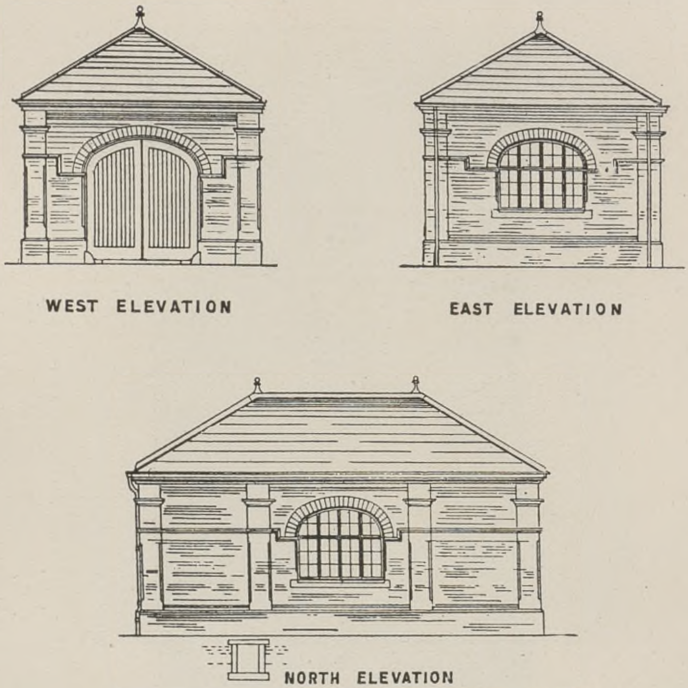

Fig. 13A.—Elevations of Screen House at Stratford-on-Avon.
(Reproduced by permission of Messrs. Willcox & Raikes, Birmingham.)

case) suitable watertight gates are provided at each end of the screening chambers, their arrangement in duplicate is a great advantage.

In the case of small works, where the cost of power-driven rakes is prohibitive, and where the screens are at such a depth below ground that they cannot be conveniently cleaned by hand, the arrangement shown in Figs. 14 and 14A is frequently adopted, the screens being arranged in duplicate to slide up and down in guide channels fixed to the side walls, so that they can be alternately raised to the surface

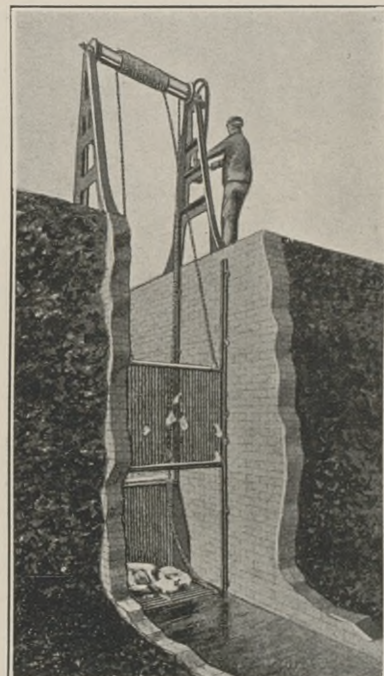

Fig. 14.—Duplicate Screens Showing Method of Raising Same Alternately for Cleaning.

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by means of a small winch, and while each is so raised for cleaning the sewage passes through the other.

As an alternative to fixed screens with travelling rakes, it has in some cases been found preferable to use travelling screens formed of fine copper wire netting and cleaned by revolving brushes, as shown in Fig. 15; but under ordinary conditions these very fine screens remove from the sewage a large quantity of highly putrescible organic matter which can be more conveniently dealt with in tanks, it being frequently found, in fact, that no screening is necessary

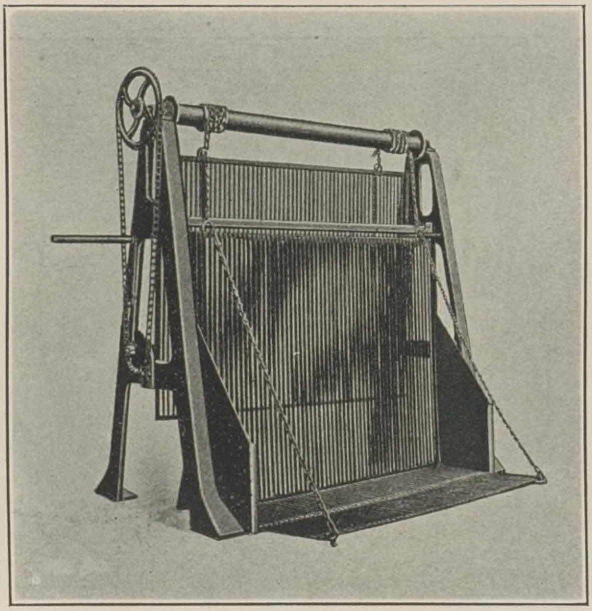

Fig. 14A.—Screen Fitted with Hinged Flap at Bottom and Hand-Winch for Raising.

(Reproduced by permission of Messrs. Adams' Hydraulics, Ltd., York.)

when the sewage can be discharged direct into liquefying tanks without pumping, as most of the material removed by any kind of screens can be decomposed by septic action.

It will, however, be observed from Fig. 14 that the power required for working this screen is developed by a small water-wheel driven by the sewage itself, and this arrangement not only has the advantage of economy, but since the speed of the water-wheel is approximately proportional to the volume of sewage, any fluctuation of this automatically effects a corresponding variation in the speed at which the screen travels.

The width of screens should be roughly proportional to the volume of sewage to be screened, and with bar screens

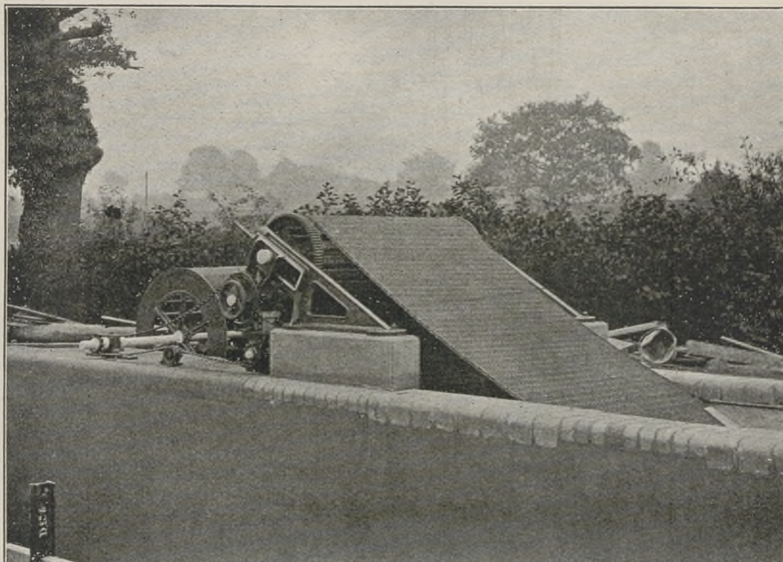

Fig. 15.—Wire Screen Driven by Water Wheel and Cleaned by Revolving Brushes.

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of the type referred to above, a width of 9 ins. per 1,000 population is about the usual basis of calculation for large works, though much must depend on the nature of the sewage, the fineness of the screen, and the quantity of storm water which may sometimes have to be dealt with as well as sewage.

With regard to the disposal of garbage removed by the screens, one simple and effective method is that adopted at Manchester, where the sediment from detritus tanks contains such a large proportion of combustible material, that by mixing it with the screenings, these can be readily burnt in a destructor, and in any town where the sewage works are near a destructor with forced draught this method can be adopted with advantage if a small quantity of coal dust is added as fuel, but as it more commonly happens on smaller works that a destructor is not available, the more usual method of disposal is by burying in trenches excavated in the ground, where the organic matter gradually becomes decomposed and oxidised without offence.

Since the particular kind of preliminary tank treatment to be adopted must very largely depend upon the nature of the sewage, it may be well to first define the different systems and the conditions under which each may be applied with advantage, as well as the principles governing the design of all sewage tanks, before proceeding to explain the actual construction of the tanks themselves or the alternative methods of operating them.

Sedimentation, or mechanical subsidence, is really a process common, more or less, to any system of preliminary treatment when the sewage is passed through the tanks with such a slow velocity that the solid suspended matter naturally gravitates to the bottom; but although this system was formerly used to some considerable extent for removing both organic and mineral matter, when little or no further purification was attempted, its application is now practically limited in England to what are more commonly called detritus tanks of comparatively small capacity, so that the velocity is only reduced sufficiently to permit the settlement of heavy mineral matter, while the organic solids can be more conveniently dealt with afterwards by bacteria treatment.

The mineral matter in ordinary sewage being chiefly composed of road detritus and sand, which is naturally incapable of decomposition by bacterial action, the importance of providing properly-constructed detritus or sedimentation tanks as a preliminary to any kind of bacteria treatment cannot be over-estimated, as the admission of such indestructible materials to septic tanks or bacteria beds must destroy their efficiency by rapidly reducing their water capacity; but although sedimentation is thus recognised as an independent process, it must also be included, to some extent, with both the alternative methods of tank treatment next referred to.

Precipitation consists in the artificial acceleration of natural or mechanical subsidence by the addition to the sewage of certain chemicals to form a precipitate, which, in settling to the bottom of the tanks, entangles the solid matter in suspension, and carries this down with it, so that it is possible by this means to remove nearly all the suspended matter from the sewage and to produce a comparatively clear tank effluent, which in the early days of sewage purification was freely discharged into inland water courses, and which may still be considered unobjectionable when it can be readily diluted with a sufficiently large volume of water, as in the case of an outfall into the sea.

It has, however, been estimated by Sir Edward Frankland that the suspended solids in sewage only represent about one-seventh of the total polluting matter which it contains, the remaining six-sevenths being in solution; so that even if the whole of the suspended solids are removed, this only represents one step in the direction of purification, and the organic matter retained in solution by the effluent from precipitation tanks being liable to decomposition, it constitutes a most serious source of pollution in any inland water course into which it may be discharged without further treatment.

For this reason it is very important to observe that precipitation can seldom be relied upon to do more than clarify the sewage, and should therefore be only considered as a preliminary to the further treatment necessary for its final purification by the agency of bacteria, either under natural or artificial conditions; but although the more economical methods of accomplishing the same results now available have caused the former popularity of chemical precipitation to rapidly decline during recent years, this process is still applied with advantage in some places where it is only necessary to clarify the sewage, and in cases where exceptional quantities of acid or alkaline trade waste are met with which may require to be neutralized by the addition of chemicals before it can be effectually purified by bacterial treatment.

Liquefying is another means of partially clarifying the crude sewage in order to facilitate its final purification, and since this result is accomplished by the septic action of anærobic bacteria without the use of expensive chemicals which are required for precipitation, it is rapidly replacing the latter process, and is now almost universally adopted for new works where complete purification is required, unless there is some exceptional reason for using chemicals in order to counteract the effect of trade wastes.

This process not only has the advantage over precipitation in that it saves the cost of chemicals, but it also effects a still more important saving in reducing the volume of sludge to be dealt with by eliminating the chemicals, which of themselves represent a considerable quantity of sludge when combined with more than twenty times their weight of water and also by gasifying or liquefying a certain proportion of the solid suspended matter in the sewage, so that it can be readily dealt with by oxidation on land or bacteria beds, instead of its having to be disposed of separately by pressing or otherwise as described in the next chapter.

In liquefying tanks having a capacity equal to one day's dry weather flow, the quantity of solid suspended matter in the effluent usually amounts to from 5 to 15 parts per 100,000, but although this quantity would be considered excessive in the case of precipitation tanks, its presence in the effluent from liquefying tanks is seldom objectionable, as it is in a condition to be more readily oxidised by bacterial action.

Having thus briefly defined the three chief systems of tank treatment, the main factors governing the design of the tanks themselves may next be considered, and since it has already been explained that the efficiency of their action depends chiefly upon the time occupied by the sewage in passing through them, it obviously follows that the correct determination of their shape and capacity is of the first importance.

With regard to the best shape, very little variation is possible, and (although two notable exceptions will be described later) they are almost invariably rectangular both in plan and section, this being the form in which tanks of a given capacity can be most economically constructed, since it only involves a horizontal or slightly inclined plane for the floor with straight walls which can be readily constructed in concrete or masonry.

The dimensions representing their depth, width, and length are, however, of even greater importance than the shape of the tanks, so far as results are concerned, since it is only by having these properly proportioned that a given cubic capacity can be utilised with the greatest effect or a given effect can be secured without incurring extra expense for unnecessarily large tanks.

The depth of tanks is usually limited in the first place by the fall available or the level of land on to which it may be desired to empty them by gravitation, but apart from these special considerations it is seldom found desirable to make them less than 4 feet, or more than 8 feet, deep if it can be avoided, and an average of 6 or 7 feet usually seems to give the best results, a greater depth rendering it difficult to prevent a considerable part of their contents remaining practically stagnant, so that the full benefit of their capacity cannot be obtained, while shallower tanks, on the other hand, are not only more costly to construct, but they occupy more space and expose a larger area of sewage to the atmosphere than deeper tanks of the same capacity, while it is also difficult to prevent the disturbance of solids deposited at the bottom of very shallow tanks by any slight variation in the velocity of the sewage passing over them during periods of maximum flow.

Assuming that the depth and required cubic capacity of a tank are fixed, the relation of length to width still has to be settled, and although it is certainly not economical to make the length more than three or four times the width, owing to the greatly increased length of walls required, long narrow tanks are always likely to be more effective than wide ones of the same capacity, especially for small works, when the sewage in taking, say, twenty-four hours to pass through a very short tank would necessarily move at a much slower velocity than when passing through a long tank in the same time, and an excessively slow velocity is undesirable as it usually means imperfect circulation and is consequently detrimental to efficiency.

The importance of this point will be particularly apparent when the sewage is admitted to small tanks by means of a weir extending across their full width, as in such cases the depth of sewage passing over the weir is so exceedingly slight that it is difficult to ensure a uniform flow over its whole length, and without this the full capacity of a tank cannot be utilised owing to a portion of its contents remaining stagnant.

It is therefore obvious that for small works narrow tanks afford the means of securing a more uniform flow than wide ones of the same capacity owing to the increased depth of sewage passing over the inlet and outlet weirs, while the proportionately increased length of a narrow tank also tends to prevent any part of its liquid contents passing through more quickly than the rest.

The number of units into which the total tank capacity should be divided is the next question which naturally arises, and, in considering it, the first point to bear in mind is that when the volume of sewage to be dealt with varies considerably at different times, it is impossible to maintain an even approximately uniform velocity through a single tank, but if there are several tanks the number brought into operation may be roughly proportioned to the sewage flow, and although it may not be practicable to have more than two or three tanks in very small works, there should never be less than two if it can be avoided, so that one can always be kept in use while the other is being periodically emptied for the removal of sludge.

In large works it is usually convenient to adopt an even number of tanks so that they can, if necessary, be worked in pairs, and it is seldom desirable to reduce the number below four so long as the capacity of each is not less than, say, 100,000 gallons, though the exact number must in all cases depend to some extent upon the quantity of storm water to be dealt with and the consequent fluctuations in sewage flow.

The total capacity of tanks in proportion to the volume of sewage to be treated necessarily varies according to the method of treatment and the time required for its effective application, for whereas a detritus or sedimentation tank, with a capacity equal to, say, one hour's flow, is usually quite effective in removing heavy mineral matter, a much larger tank capacity is required for the deposit of the organic matter in suspension which is so nearly the same specific gravity as the liquid in which it is suspended, and when this is to be accomplished as far as possible by simple sedimentation the tanks should hold at least half the dry weather flow, while by the use of chemical precipitants a greater degree of clarification can be obtained with tanks holding, say, one third of the daily dry weather flow; but if bacterial action is to be relied upon, the liquefying tanks should have a capacity under ordinary conditions of about one day's dry weather flow.

Although the above figures represent the general result of the Author's experience, it is impossible to fix any arbitrary standard which would be applicable to all cases regardless of local conditions; and with a view to indicating the circumstances under which the above capacities may be varied with advantage, it may be well to point out that in the case of sedimentation tanks, the capacity should be greater when the mineral matter to be deposited is particularly fine, and therefore takes longer to settle, as in the case of waste from pottery works known as slip, which is so fine that when dry it forms an impalpable powder, while, on the other hand, coarse sand, ashes, and road detritus will settle so quickly that most of it can be separated in tanks holding a much smaller proportion of the daily flow, and through which the sewage may pass in half an hour or less.

In the case of precipitation tanks their capacity must largely depend on the quantity and efficiency of the precipitants used as well as the composition of the sewage and the degree of clarification required; a considerable space must also be allowed for the accumulation of sludge, or it will be necessary to empty the tanks very frequently, which is undesirable especially when their contents cannot be discharged by gravitation, and it is naturally impossible to obtain good results from any tanks when an excessive proportion of their capacity is occupied by sludge, or in liquefying tanks which have to be frequently emptied, and whose efficiency is thereby destroyed until the bacteria and septic action have again had time to develop.

Liquefying tanks are perhaps more difficult to design than either sedimentation or precipitation tanks, owing to the greater uncertainty of the bacterial action on which they depend, but it is safe to assume that a greater capacity is required in proportion to the dry weather flow when the sewage is received in sudden flushes or in a fresh state than when it is already partially septicised during its passage through a long length of sewer, as in the case of a large town, and it is therefore desirable to increase their capacity up to, say, one and a half times or twice the normal daily flow, when designing tanks for the treatment of sewage from private houses or public institutions, while about one and a quarter times the dry weather flow is usually found sufficient for small villages, and good results are obtained in many large towns with tanks holding three quarters of the dry weather flow or less; but much must in all cases depend upon the strength of the sewage or volume per head, and no general rule can be laid down regardless of these and other local conditions.

Apart from the correct determination of their shape and capacity, the efficiency of sewage tanks must chiefly depend upon the details of their construction, including the method of admitting and withdrawing the sewage, as well as the means of removing the sludge and securing a proper circulation of the liquid contents without unduly stirring up the solid matter when it has once settled to the bottom or accumulated on the surface in the form of scum.

With regard to the method of admitting and withdrawing the sewage, mention has already been made of inlet and outlet weirs at opposite ends of rectangular tanks, which being constructed with perfectly level crests the sewage flows over them at a uniform rate throughout their length, and as this system combines simplicity with efficiency, it is almost universally adopted for all kinds of sedimentation and precipitation tanks.

The same method is also very generally applied to septic or liquefying tanks, being usually preferable to any other as a means of securing uniform circulation, but since it is, in this case, necessary that the sewage should be admitted and drawn off at some distance below the surface in order to avoid disturbing the scum (which serves a useful purpose to be considered later), the use of weirs also necessitates the provision of scum boards or iron plates extending into the sewage for a distance equal to about one quarter the depth of the tank and fixed about three inches from the end walls parallel to the weirs, so that the sewage on entering the tank is deflected downwards by the first scum board, and by passing under the second before reaching the outlet weir any tendency to form a current along the surface is prevented.

The usual arrangement of iron scum plates is to support them on small corbels projecting from the end walls, but when wooden scum boards are used, they are generally arranged to float on the sewage, the ends being kept in place by vertical iron channels fixed in the side walls, so that when the tank is emptied the boards sink to the floor, and therefore require no supports, though in order to keep them sufficiently submerged when the tank is full, a stop or peg is placed near the top of the channel to keep the boards down to the required depth.

In order to obviate the use of wood or iron, which are both liable to deteriorate rapidly when partly immersed in sewage and partly exposed to the atmosphere, the end walls are sometimes carried up above the surface of the sewage, which passes through a series of apertures formed in the walls at the required depth below the surface into a channel outside, from which it can either be drawn off by a pipe at one point, or preferably may pass over a long weir into a second channel in order to prevent the concentration of current which results from the omission of a weir, though in the case of very small works a weir extending across the whole width of a tank is sometimes unsuitable for reasons already explained.

For the purpose of facilitating the removal of sludge from rectangular sedimentation or precipitation tanks, it is customary to form the bottom with a fall or gradient of from about 1 in 50 to 1 in 100 towards the inlet end, as the bulk of the sludge accumulates near the inlet, and this end should therefore be the deepest, but where liquefying tanks are preceded by detritus tanks to remove mineral matter, the organic solids undergoing decomposition being very nearly the same specific gravity as the liquid are repeatedly raised to the surface by the temporary buoyancy due to gas bubbles, so that when these escape the solids again sink to the bottom at a point somewhat nearer to the outlet, and this process being constantly repeated, the tendency for sludge to accumulate near the inlet is thereby counteracted, and it may sometimes be found convenient to make the floor fall towards the effluent outlet instead of the inlet.

It will, however, be understood that no matter which way the floor falls, it is seldom practicable to give it a sufficiently steep gradient (about 1 in 15) to discharge the whole of the contents by gravitation, and it is almost invariably necessary to push the sludge down towards the outlet by hand with wooden squeegees, or flat boards attached to handles.

In the case of large tanks it is sometimes desirable to form the floor in a series of narrow bays separated by dwarf walls about six or eight inches high, extending from one end of the tank to the other, so that where several squeegees are used in one bay at a time, the dwarf walls prevent the sludge running round the ends.

As it becomes necessary to empty sewage tanks long before they are completely filled with sludge, a large part of their contents consists in supernatant water which contains a comparatively small amount of suspended matter, and which can be dealt with by the same treatment as the sewage or tank effluent, so that considerable economy is effected by keeping it separate from the sludge, especially in the case of precipitation tanks, which require emptying at frequent intervals, even if worked on the continuous flow principle, and with the old absolute rest or quiescent system of alternate filling and emptying, the means of drawing off supernatant water is of still greater importance.

The ordinary means of accomplishing this in precipitation tanks is by the use of floating arms on outlet pipe, which are so constructed that the open end is held up by floats within a few inches of the surface, the movable arm being attached to the outlet pipe by a swivel joint and sluice valve, which can be closed when the sludge is reached, and the main penstock valve can then be opened at the bottom of the tank, so that the remainder of its contents can be discharged to sludge lagoons, or to a pump well in cases where it cannot be dealt with by gravitation.

Owing to the scum which collects on the surface of sewage in liquefying tanks, it is not desirable to use floating arms, and the Author has found it convenient to substitute the arrangement shown in Fig. 16, which consists in a vertical standpipe divided by horizontal joints into a number of sections about a foot long, each of which is attached by lugs to a long screwed spindle passing down the centre of the pipe, and which is provided with a hand-wheel at the top, so that the different sections of the pipe can be raised in succession from the top downwards, the sewage thus being drawn off at a depth of one or more feet below the surface according to the number of sections raised, and allowing the scum and sludge to remain undisturbed.

Where the sewage contains large quantities of heavy road detritus, a large proportion of this may be collected in small deep rectangular tanks formed with the floor sloping steeply from all four sides towards the centre, from which the detritus can be raised by a series of perforated iron buckets attached to an endless chain, as shown in Fig. 17, and arranged so that the buckets travel continuously up and down, and in passing over pulleys at the top of an iron frame they are automatically turned over so that their contents are discharged into a sludge cart or other suitable receptacle by means of a shoot, or for large works a belt conveyor may be substituted for a fixed shoot, as in the Manchester works at Davyhulme already referred to.

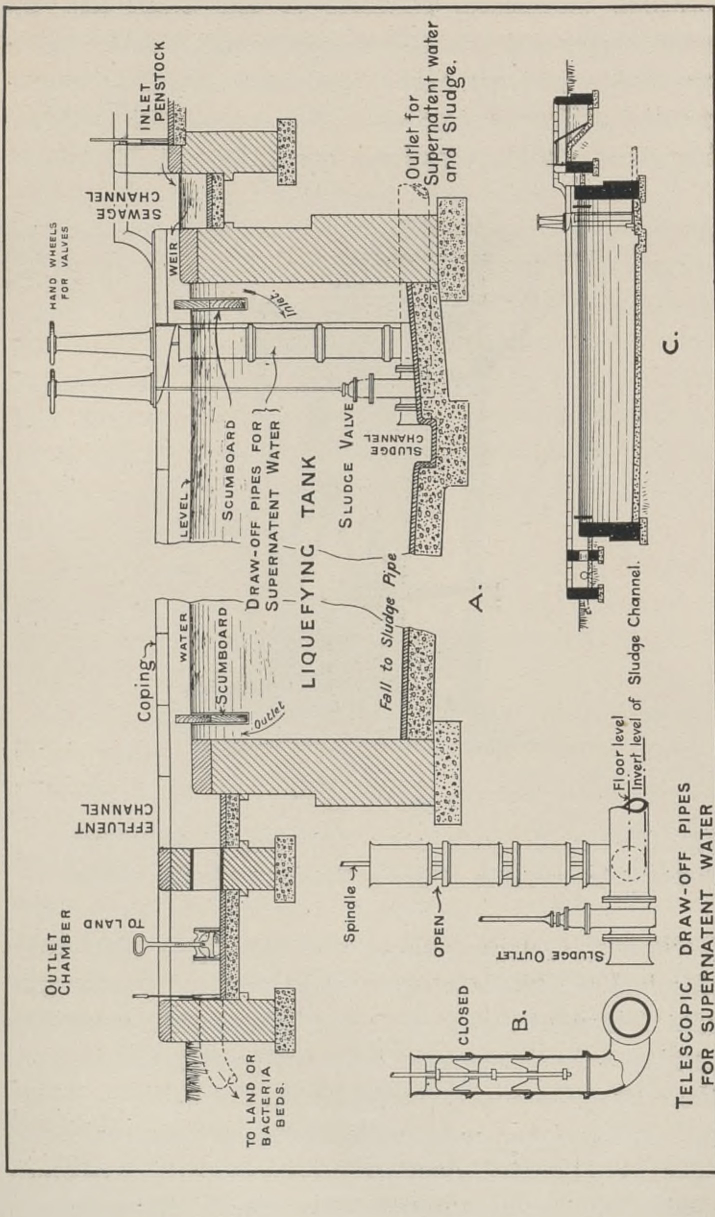

Fig. 16.—Typical Section and Details of Liquefying Tank.

(Reproduced by permission of Messrs. Willcox & Raikes, Westminster and Birmingham.)

Although mechanical elevators of this description are sometimes operated by hand in very small works, this is impracticable for large works, and some kind of an engine is essential so that the detritus may be continuously removed during storms, when very large quantities may have to be

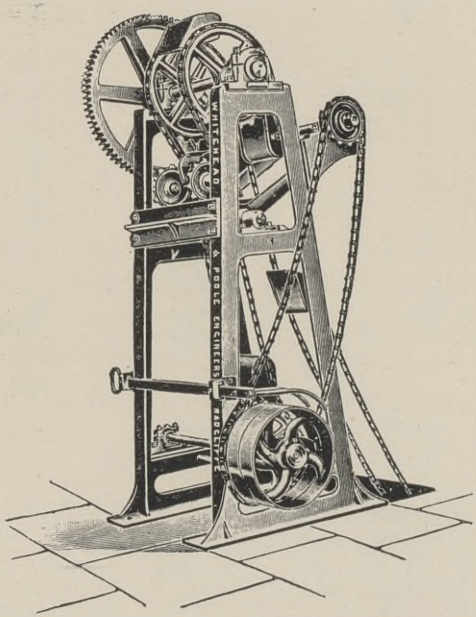

Fig. 17.—Elevator for Removing Sludge from Detritus Tanks.
(Reproduced by permission of Messrs. Whitehead & Poole, Manchester.)

dealt with in a short time, and thus prevented from passing into the tanks or other works provided for the subsequent treatment of the sewage. Power may sometimes be developed for this purpose by a small water-wheel driven by the sewage itself when sufficient fall is available.

The utility of the scum which forms on the surface of the sewage in liquefying tanks has been the subject of much discussion, and in the Author's experience the quality of tank effluent does not seem to be affected by it; but as a means of checking the escape of foul gases rising to the surface in the form of bubbles, it certainly seems to be useful, and may be encouraged by floating light wooden trellis work on the sewage, though it is better to provide a substantial roof to the tanks when they have to be placed in close proximity to houses or the public highway, as it is impossible to prevent some slight smell arising from the surface of sewage when exposed to a hot sun, and even a light iron roof may in some cases answer the purpose by protecting the sewage from the sun and disturbance by wind or rain, so that the scum will more readily form a natural coating than when exposed, and when kept dry there is less risk of the nuisance which is sometimes caused by the rapid evaporation from a moist surface.

When an air-tight roof is required this may be conveniently constructed of concrete reinforced by expanded metal or iron rods and supported by steel joists with brick or cast-iron piers, though it is important that all metal should be protected from corrosion by being incased in concrete or brickwork.

Nothing has yet been said about the building of tank walls and floors, but the use of concrete is almost universal for the latter, as it can be readily worked up to a smooth surface, and as it is seldom necessary to make it more than 9 inches or a foot thick in order to secure a watertight covering for the earth bottom, its homogeneous character is a great advantage, while its cost is much less than masonry or brickwork, and where there is any risk of uneven settlement it can be strengthened by the use of metal reinforcement as suggested for the roof.

The construction of tank walls is subject to very wide variation according to circumstances, as although they must always be watertight, the thickness necessarily depends very much on their length as well as their height, and whether the tanks are constructed above or below ground, also the nature of the subsoil; but where they are entirely above ground and the walls have to support water pressure up to within, say, 1 foot of their full height, their thickness at the base should certainly not be less than a quarter of the height under ordinary conditions; and where a solid foundation cannot be secured, the thickness of base may have to be increased to one-third the height in order to distribute the weight sufficiently to prevent undue pressure and settlement, which might endanger the whole wall by rendering it liable to failure by overturning; but with good brickwork or masonry there is seldom any danger of failure at the joints of short walls of the above thickness, owing to the very large factor of safety represented by the tensile strength of such materials, especially where the foundation of the wall forms part of the floor.

In the case of small tanks, the side walls derive considerable support from the ends, and *vice versâ*, so that the thickness required is not governed by the height or pressure alone; and it by no means follows that walls which are perfectly safe for a small tank would be thick enough if they formed part of a larger one of the same depth, and practical experience is therefore of far more value than theoretical calculations alone in designing the walls for sewage tanks so as to secure sufficient stability and watertightness without unnecessary expense, and it is the absence of such experience which frequently results in great waste of public money in badly proportioned or excessively thick walls.

The walls of tanks being frequently used as a path by the men looking after them it is unsafe to form the coping with slippery material, freestone being preferable to brick or terra-cotta for this reason; and where the walls are built above ground the top width should not be less than about

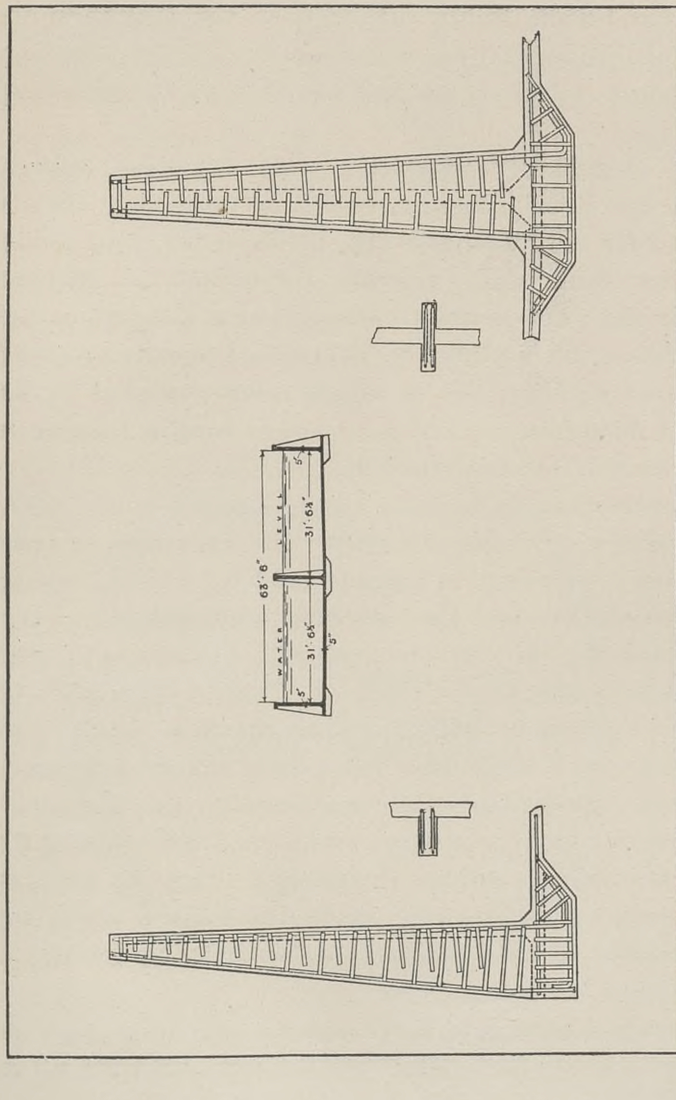

Fig. 18.—Section of Sewage Tanks at Great Malvern and Details of Reinforced Concrete Walls.

(Reproduced by permission of The Hennebique Ferro Concrete Co., Ltd., Liverpool.)

18 inches, though the exact dimensions of coping for brick walls must depend on the size of bricks used, $22\frac{1}{2}$ inches being a convenient top width for walls built with the 9-inch bricks commonly used in the Midlands, where the blue and brindle bricks obtainable in the district to the West of Birmingham are of such excellent quality that they are almost exclusively adopted for all kinds of engineering work.

The method of construction with reinforced concrete which has already been suggested for roofs may also be adopted for the walls, and Fig. 18 shows the cross section of some tank walls recently constructed at Malvern in this way; but it will be observed that although a considerable saving is effected by the reduced thickness required to ensure stability, this is largely counterbalanced by the cost of reinforcement, and very perfect work is required to make such thin walls watertight.

Attention has so far been chiefly directed to the essential features of rectangular tanks; but since circular tanks have been somewhat extensively used for treating sewage by precipitation, and they are now being adopted at Birmingham and elsewhere for removing the humus or solid suspended matter from septic tank effluents, it may be well to give a few notes regarding the principles of their construction where these differ from those already considered.

Circular sewage tanks were first introduced at Dortmund, in Germany, many years ago, with a view to facilitating the removal of sludge without emptying the tanks by utilising the pressure of the sewage itself, and Fig. 19 shows the construction of tanks designed on this principle by Mr. J. D. Watson, of Birmingham.

The upper portion of these tanks is cylindrical, and the bottom is in the form of an inverted cone, with the silt or

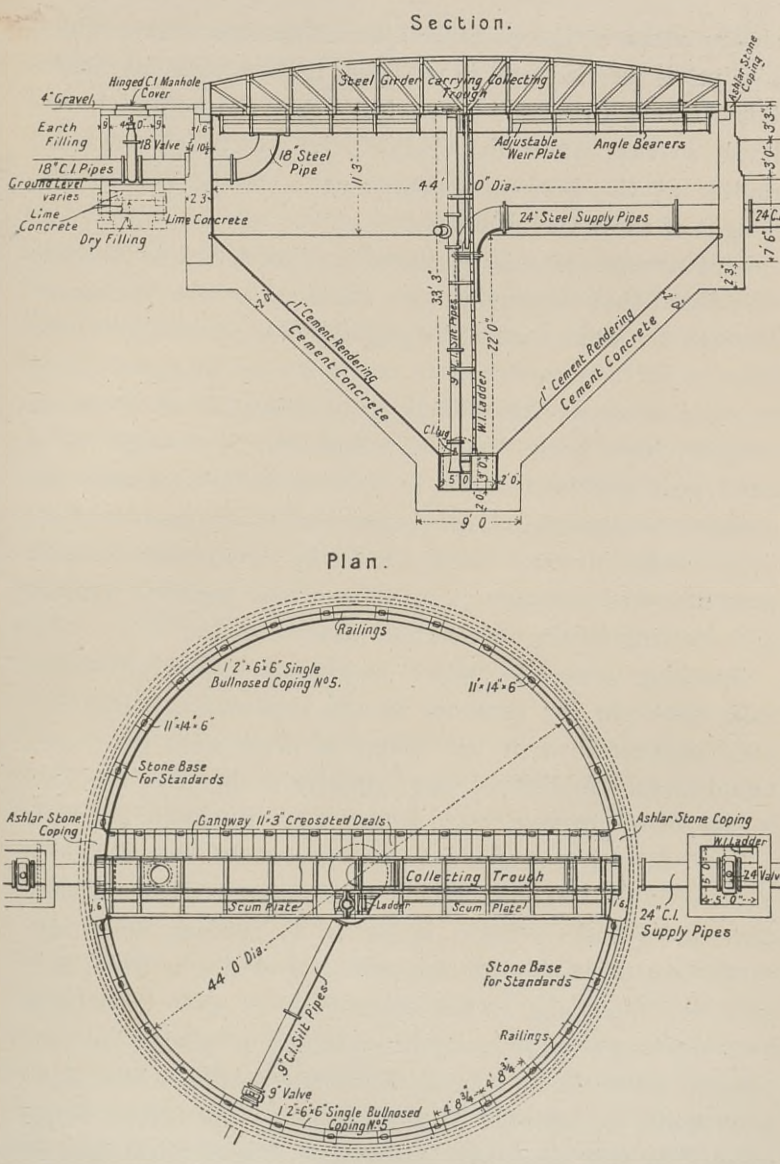

Fig. 19.—Circular Upward Flow Tanks at Birmingham for Removing Suspended Matter in Effluent from Liquefying Tanks.

(Reproduced by permission of Mr. J. D. Watson, Birmingham.)

sludge outlet at the point or apex of the cone, from which a pipe is carried up inside the tanks, with its outlet taken through the wall a few feet below the normal water-level, so that when the sludge valve is opened the solid matter at the bottom of the cone is forced out by the weight of the water above it.

This arrangement is excellent in theory, but in practice it is found that the liquid has a tendency to force a channel through the solid matter, leaving the sludge sticking to the sides of the cone unless it is removed very frequently, and in order to obviate this difficulty various kinds of revolving scrapers have been designed which can be rotated by a bevel gear and hand-wheel at the top so as to detach the sludge from the bottom and sides; but in any case the bulk of the sludge is very much increased by the excessively large percentage of moisture it contains when removed without first drawing off the supernatant water.

Speaking generally, most devices for removing sludge from tanks in the presence of the supernatant water are only successful when the sludge is dealt with in a very liquid state. Additional tank capacity is therefore required for its further concentration before it can be finally handled.

With careful management there is usually little difficulty in removing a large proportion of the sludge from ordinary rectangular tanks while in operation by opening the sludge valve for a short time at intervals, and closing it when it is seen that the sludge in the neighbourhood of the outlet has been discharged until a further quantity of sludge has had time to settle down behind the outlet valves, when these may again be opened, a great economy of labour being effected by this means at Manchester, where 3,000 tons of sludge have sometimes been removed from the tanks in a few days without drawing off the supernatant liquid.

In the tank shown in Fig. 19 the sewage is admitted by passing down a vertical pipe at the centre, with its open end near the bottom, so that the sewage on escaping from the pipe rises slowly upwards and is drawn off by overflowing into the open trough fixed across the centre of the tank, the effect being that the suspended flocculent matter forms a kind of natural strainer, through which the liquid rises to the surface while the solids gradually sink to the bottom, when they become sufficiently dense for the force of gravity to counteract the effect of the very slow current of sewage and gas bubbles passing up in the opposite direction.

Although some advantage was claimed for tanks of this shape for precipitation, their great depth involves greater expense in construction than ordinary rectangular tanks, especially when they have to be built in a waterlogged subsoil; and in large tanks the method of admitting the sewage makes it difficult to secure the uniform circulation which is of such great importance, so that they have recently gone very much out of favour for their original purpose. But, as already mentioned, circular tanks of a somewhat similar design have been put down at Birmingham for the further clarification of septic tank effluent, which is found to contain an excessive quantity of flocculent matter, their construction being shown in section by Fig. 19.

Since the general adoption of bacterial treatment the Author only knows one place of any importance where liquefying tanks have been constructed on this principle, and the results obtained from them do not seem to justify a repetition of the experiment, it being apparently found impossible to secure a satisfactory tank effluent, even when it is strained through small coal placed on iron gratings about a foot below the water level.

Another special form of liquefying tank has, however, been in use for about two years at Hampton-on-Thames under the name of a Hydrolytic Tank, and as it differs materially from both the rectangular and circular tanks hitherto described, while introducing a number of novel principles, its construction and method of working deserve some consideration.

Owing to the great difficulties experienced at Hampton through the bacteria beds becoming constantly clogged with solid matter, a series of experiments have been carried out there, under the direction of Dr. W. Owen Travis, with a view to devising a means of overcoming this difficulty, and as a result of these experiments the tank shown in Fig. 20 was specially designed with the object of securing the most efficient clarification of the sewage in the shortest possible time.

The original experiments were made in a small glass model of a liquefying tank, in which the movement of the sewage and solid matter could be carefully observed; and from the information so obtained, Dr. Travis has come to the conclusion that in order to maintain the working efficiency of liquefying tanks the regular and systematic withdrawal of the sludge is essential for the following reasons :—

1. Its accumulation restricts the liquid capacity of the tanks, and consequently accelerates the passage of the sewage through them, so that it has not time to become properly clarified.

2. The bubbles of gas produced in the decomposing sludge reduce its specific gravity, so that portions of it are constantly rising to the surface through the fresh sewage, and particles of solid matter thus become mixed with the tank effluent.

3. The formation of thick scum on the surface is mainly due to the solid matter raised and supported by small bubbles of gas which cannot escape, but if the scum is not

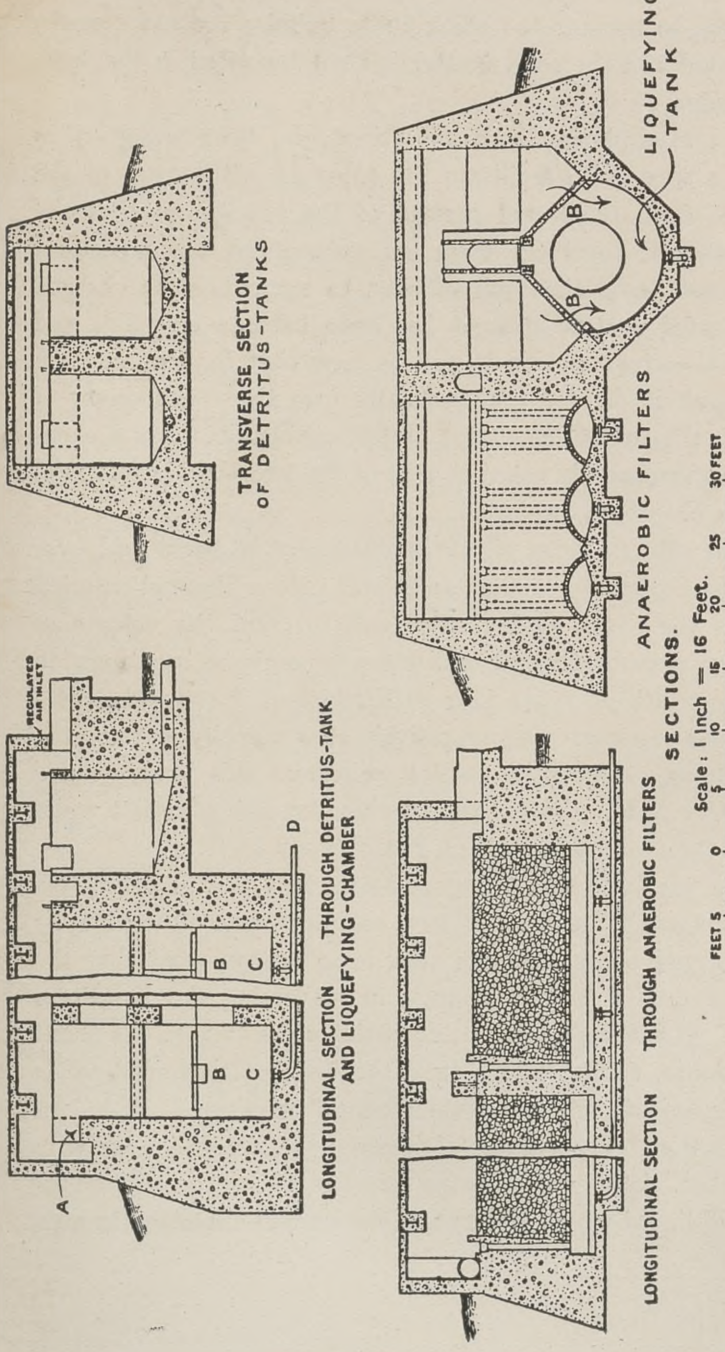

Fig. 20.—Sections of Hydrolytic Tank at Hampton-on-Thames.

(Reproduced by permission of Dr. W. Owen Travis, Hampton-on-Thames, and the Institution of Civil Engineers.)

allowed to become too thick these bubbles are more easily liberated and the solid matter is then deposited in the form of sludge.

The Hydrolytic Tank has, therefore, been designed in such a way as to facilitate the constant withdrawal of the sludge from the liquid portion of the sewage, so that the disturbance resulting from its subsequent decomposition may not cause the tank effluent to again become charged with solid matter after it has once become clarified, and from the cross section it will be seen that for this purpose the tank is divided longitudinally into three chambers, of which the central or sludge liquefying chamber has a capacity approximately equal to that of the two outside sedimentation chambers combined.

The effluent from all three chambers is discharged over different portions of the same weir into a channel running across the outlet end of the tank, so that the volume of sewage passing through each chamber must be in proportion to the width of outlet weir with which it is connected, and in order to secure a comparatively slow velocity through the liquefying chamber the outlet weir from this is only made two feet wide, whereas the combined width of outlet weirs from the two sedimentation chambers is 14 ft.

The whole of the sewage, having first passed through a detritus tank, enters the two sedimentation chambers by submerged inlets, and the tank is so proportioned that the time occupied by the sewage in traversing the length of these outside chambers to the outlet weirs "A.A." is about five hours, during which time the heavier suspended solids are deposited, and gravitate through openings "B.B." at the bottom of dividing walls into the central liquefying chamber, their passage being accelerated by the slight current of liquid which also enters the central chamber through these openings, but which escapes on the central portion of outlet weir above referred to, leaving the solid matter to accumulate as sludge in the bottom of the liquefying chamber, where a considerable part of it gradually becomes hydrolysed or liquefied.

When the sludge has been sufficiently hydrolysed, or when its level approaches that of the openings " B.B.," the outlet valves " C.C. " in the bottom of the chamber are successively opened, and the lowest portion of the sludge is forced out through the sludge pipe " D." by the head or pressure of the liquid in the tank.

Since the sludge only accumulates in the lower portion of the central chamber, it remains practically undisturbed by the liquid, which, after entering by the openings "B.B.," traverses the upper portion to the outlet, the capacity of this upper portion being such that the liquid takes about 15 hours to pass through it.

The results obtained with this tank, as given by Dr. Travis in a paper which he recently read before the Institution of Civil Engineers,* seem to be so far successful as at any rate to justify a continuation of his investigations, but although he has found that there is little difficulty in separating the heavier solids, which readily settle to the bottom, the sewage also contains a considerable quantity of very finely divided matter in suspension whose specific gravity differs little from the liquid, and which is therefore less readily deposited in the sedimentation chambers, especially when the capacity of these is only equal to five hours' flow, as in the case of the Hampton tank.

It also appears from these experiments, as well as those carried out by Dr. Fowler and others, that, in addition to

* "Proceedings of the Institution of Civil Engineers," Volume 64.

the suspended matter which passes through liquefying tanks, the effluent contains matter in a state of emulsion, or, to be more chemically exact, colloidal matter which is invisible and but little affected by sedimentation, but which is slowly deposited after the sewage or effluent stands and becomes oxidised, when, under certain conditions, it may give rise to troublesome putrefaction.

The exact nature of colloidal matter has formed the subject of much discussion and considerable difference of opinion, but the following abstracts from some notes recently published by Mr. A. Vincent Elsden, B.Sc.,* regarding the properties of colloids, will serve to show some of the more important characteristics by which they are distinguished.

"The terms 'crystalloid' or 'colloid' were first used by Graham to distinguish between bodies of definite crystalline form, such as minerals and most inorganic salts, and amorphous substances, such as albumen and jelly.

"Colloids appear to be extremely unstable bodies. A solution of a colloid is in general readily coagulated, i.e., the colloid easily assumes an insoluble form, and even in this condition there appears to be a tendency to further change to a crystalline condition. Thus glass, which is usually considered a typical colloid, may become crystalline with lapse of time.

"In aqueous solutions colloids diffuse at a much slower rate than do crystalline bodies, and whereas crystalloids will diffuse through various animal and vegetable membranes, colloids will not, and this forms a means of separating the two classes of substances, the process being known as dialysis."

This process practically consists in a system of straining

* "Some Properties of Colloids," by A. Vincent Elsden, B.Sc., etc. Paper published in "Water," February, 1906.

through parchment, by which the colloids may be gathered and examined, with a view to ascertaining what proportion of them can be decomposed and oxidised by bacterial agency, and the amount of residue which will accumulate in bacteria beds and may therefore have to be removed, either by washing and screening the media or the adoption of some self-cleansing hydrolysing chamber, as already described.

It has been shown by Zsigmandy and Siedentopf that although colloidal bodies will pass through filter paper, and may appear in the analysis of filtrate as soluble solids, they are, strictly speaking, in suspension rather than solution, but in such an exceedingly finely divided state that the particles can only be observed through a microscope when the liquid is illuminated by two beams of light at right angles to each other.

It is estimated that in the case of Hampton sewage 50 per cent. of the dissolved organic matter is in the colloidal state and is not removed by passing through filter paper, but it has been observed that when brought into contact with other substances the fluid colloid will, in course of time, become curdled and insoluble without combining with these substances, so that the action of filtering material in separating such matter is apparently mechanical rather than chemical or biological, though its subsequent oxidation is, no doubt, effected by bacterial agency.

Assuming that the deposit of this colloidal matter is due to surface attraction, it seems fair to conclude that the largest possible number of surfaces should be presented to the liquid, and in order to secure this condition at Hampton the effluent from the hydrolytic tank is passed through a series of four hydrolysing chambers or anaerobic filters arranged in sequence and filled with broken flints.

The sewage is conducted to the bottom of each chamber through vertical stoneware pipes, from which it is discharged under the false bottom, formed with brick arches having 2½ ins. openings between the bricks, through which the liquid passes upwards into the filtering material which rests upon them.

After passing up through the interstices of the flints to the surface of the first bed, the liquid flows over a weir and is again conducted through the second and succeeding beds in the same way, the time occupied in the process being about three hours, and the effluent is then discharged on to contact beds for final purification.

May–August, 1905. (Average of eight series of samples.)	Parts per 100,000.							
	Solids.		Chlorine.	Nitrogen.		Oxygen absorption in four hours.	Settled.	
	In Suspension.	In Solution.		Ammoniacal.	Albuminoid.		Albuminoid Nitrogen.	Oxygen absorption four hours.
Crude sewage . .	20·7	91·3	13·5	7·09	1·09	8·9	0·50	5·7
Hydrolytic tank .	1·2	92·0	9·7	6·21	0·46	5·8	0·42	5·2
Hydrolysing chambers . .	6·0	90·0	10·5	7·29	0·37	8·1	0·31	7·4

NOTE.—The increase in the oxygen absorption of the effluent from the hydrolysing chambers is due to the formation of hydrogen sulphide.

The above table, prepared by Dr. J. H. Johnson,* the chemist and bacteriologist to the Hampton Urban District Council, shows the work done by the hydrolytic tank and hydrolysing chambers, but in considering these figures it may be well to bear in mind that before the sewage reaches the outfall it has no doubt undergone considerable septic

* "Proceedings of the Institution of Civil Engineers," Volume 164, page 92.

action in the long rising main, which has a capacity equal to about 21 hours' dry weather flow, and it does not seem to have been proved that the colloidal matter in septic tank effluents cannot be separated and oxidised equally well by the ordinary method of treatment in properly constructed bacteria beds, while recent experience has shown that the bubbles of gas rising through the flints disturb the solid matter deposited in their interstices, as happens with the sludge in ordinary tanks.

During the progress of these Hampton experiments it has also been observed that the solid matter was deposited almost entirely on the upper surfaces of the flints used for straining the tank effluent, and in the glass model a large amount of deposit also accumulated on the vertical sides until it became detached by its own weight, when it slipped down to the bottom of the tank, thus leaving the glass clean and ready to receive a fresh accumulation.

These observations suggested the advisability of using plates set parallel to each other at a slight angle with the perpendicular in place of the flints previously employed to intercept the very finely divided matter in suspension, and by providing the means of drawing off the sludge below the plates, the difficulty formerly experienced has been practically overcome.

In each space between the plates, three distinct areas are clearly discernible, viz. :—

1. An area immediately adjacent to the under surface of a plate where gas bubbles are continually ascending in large numbers.

2. An area adjoining the upper surface of the next plate occupied by the deposited solids, from which accumulation small masses are constantly becoming detached and rolling downwards to the sludge accumulation at the bottom.

3. An intermediate quiescent layer of liquid in which small particles can be seen slowly ascending or descending.

The character of the sludge deposited in this chamber is entirely different from that arrested in the tank, both as regards colour and texture, and it seems to contain a larger proportion of organic matter than ordinary sludge.

Although Dr. Travis's observations and conclusions are most instructive as indicating the ideal to be aimed at in designing liquefying tanks, the best method of carrying them into effect appears necessarily to involve many practical considerations, and there is therefore ample scope for further investigations as to the means of overcoming the difficulties encountered in determining the most efficient type of tank for continuously producing a uniformly clear tank effluent which can be safely discharged on to bacteria beds without risk of clogging them.

The idea of separating the sludge by simple sedimentation in tanks of a comparatively small capacity has also been developed in a different way at Skegness, where an ordinary cylindrical tank is so arranged that while the bulk of the liquid is drawn off at the top, and dealt with in bacteria beds, the heavier solids are continuously decanted into another tank for further treatment, by means of a sludge pipe at the bottom, the proportion of the total flow separated in this way being about 20 per cent.

The use of tanks filled with slate has also been tried with success for removing suspended matter by Mr. Dibdin at Devizes and elsewhere, the slates being laid as shown in Fig. 30, Chapter VI. These tanks are really worked as contact beds rather than ordinary liquefying tanks, the crude sewage remaining in contact with the slates for a given period, and after discharge they stand empty for aeration. By this means liquefaction is obtained under aerobic conditions, and thus the sewage does not reach the state of putrefaction which is necessary in anaerobic or septic tanks, so that the effluent is practically odourless, which is a very important feature; but they entail some loss of fall, as the outlets must be at the bottom, whereas in ordinary septic liquefying tanks it is but slightly below the inlet, and the cost of the slates involves considerable additional expense.

CHAPTER V.

Chemical Precipitants and the Disposal of Sewage Sludge.

Chemicals most commonly used for precipitation—Cost of precipitants and quantity used—Machinery for preparing precipitants—Reduction of sludge in liquefying tanks—Quantity and composition of sludge—Alternative methods of sludge disposal—Barging out to sea—Mechanical filter pressing—Air drying in lagoons—Air drying on land—Burying in trenches.

Having dealt with the works necessary for the clarification of sewage in the last chapter, this one is devoted to the chemicals used for the precipitation of the solid suspended matter, together with the alternative methods adopted for the disposal of the sludge which is produced by this and other systems of tank treatment.

Precipitation consists in producing an artificial precipitate or coagulum in the sewage by which the suspended matter may be entangled and weighted so that it is carried down with the precipitate to form the deposit commonly known as sludge, which is separated from the liquid by natural subsidence when the sewage is brought to rest in a suitable sized tank as already explained.

The different chemicals which have been suggested for the purpose of sewage precipitation form the subject of innumerable patents, but as lime, copperas, and alum have for many years been far more extensively used than any others, it seems reasonable to assume that their popularity is due to their having proved effective under all ordinary conditions, and their simplicity having been found advantageous when compared with the more complicated processes against which they have competed, it will be sufficient to briefly indicate the chief points to be observed in connection with these three kinds of precipitant, though it is impossible to lay down any definite rule as to their application without knowing the chemical composition and peculiar characteristics of the sewage to be dealt with in each case.

Lime has, in England at any rate, been far more widely adopted than any other precipitant owing chiefly to its comparatively low cost combined with the rapidity of its action, but as it can only be applied successfully in the form of a concentrated solution or milk of lime, the preparation of which necessitates the use of machinery for first reducing the lime to a fine powder and then mixing it with about twenty times its weight of water (or sewage), its adoption for small works is practically limited to those cases where sufficient power can be developed from the sewage itself by means of a water wheel, or where power must in any case be provided for pumping, though the lime may be prepared in a very much less efficient manner by merely slaking it without grinding, it being usually found that when a bushel of lime is slaked with about two gallons of water, its original bulk is increased by from 50 to 100 per cent.

Having regard to the cost of providing and operating machinery for its preparation, and the greatly increased quantity of sludge which it produces, it does not by any means follow that because lime is cheap in first cost it is therefore the most economical precipitant to use in all cases, and as its efficiency depends on the percentage of pure lime which it contains, it is very false economy to use any but the best quality even if the price is considerably higher, as by using lime containing, say, 30 per cent. of impurities instead of 10 per cent. the quantity required to achieve the same result is correspondingly increased, while considerable extra expense is also involved by the greater difficulty of grinding and mixing it, together with the increased quantity of sludge produced.

As the effect of lime depends on its combination with the carbonic acid in the sewage to produce a precipitant which serves as a weighting material to assist the deposition of the lighter flocculent matters, it is of the utmost importance that the lime should be added in such a form as to facilitate its rapid combination with the acid, and since any solid particles of lime are only attacked on the outside, a great loss of efficiency results from imperfect grinding, so that the best results can only be obtained when the lime is first reduced to an impalpable powder before mixing with water or sewage to form the milk of lime previously referred to.

Fig. 21 shows a type of machine commonly used foı grinding and mixing the lime, consisting of a cylindrical iron vessel furnished with internal stirring arms. At the top of the rim of this cylinder there is a flange planed true which forms the bottom surface for grinding, and on this the cover or lid of the machine is made to rotate by means of a vertical shaft and bevel wheels, the underside of lid being also furnished with a flange planed true to form the upper rubbing surface.

Both the lid and agitators are driven by the same bevel gear, and the lime is introduced by means of a hopper at the back of the machine, while a constant stream of water is at the same time added through the pipe near the bottom from a tank in which the water level is kept slightly above that of the rubbing surfaces, the head of water thus causing the finer portions of lime carried upwards through the mixer by the water to wash over and to pass between the rubbing surfaces into an outer trough not shown, from which the milk of lime is discharged into the sewage.

In passing through the flanges the hard particles are reduced by attrition to an impalpable powder, and as only the finest particles floating near the top of the vessel can escape over the lip, the uniform character of the cream or

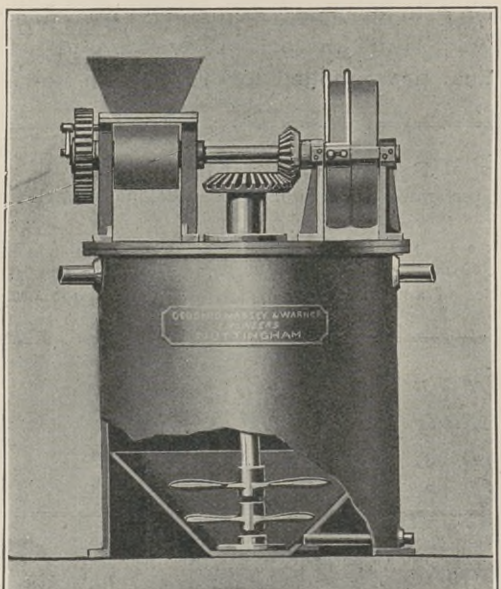

Fig. 21.—Lime Mixer, Showing Grinding Mill and Agitators.

(Reproduced by permission of Messrs. Goddard, Massey & Warner, Ltd., Nottingham.)

milk of lime is insured, but before use the lime should be slaked and hand-picked free from stones.

Some advantage is claimed for the particular type of machine above described, as the mixing and grinding is combined in one operation, but the lime is sometimes ground in a small mill before being admitted to the mixer itself, and in order to prevent the deposit of lime at the bottom, this is made to slope towards the centre in the form of a cone; the agitators, consisting of propeller blades, are fixed to a vertical shaft, so that their revolution propels the chemicals upwards, and thus maintains a continuous agitation.

The quantity of lime required varies according to the variations in the nature of the sewage and the amount of acid which it contains, so that the best results can only be obtained by properly regulating the supply to suit the changes which are constantly taking place, especially in large towns, where the sewage is affected from hour to hour by the different kinds of trade wastes discharged into it.

The importance of using the correct quantity of lime required is not only due to the waste involved by the addition of too much and the incomplete precipitation of solid matter produced by an insufficient quantity, but if the amount needed to neutralise the acids in the sewage is exceeded, an alkaline effluent results, which is liable to undergo secondary putrefaction of a most offensive nature if discharged into any water course, and an excess of lime in the effluent may cause it to act as a precipitant if any suspended organic matter is present in the river water, thus producing deposits which in hot weather become exceedingly offensive, while the presence of free lime is likely to clog the interstices of any land or bacteria beds on to which it may be discharged, besides being prejudicial to nitrification and most destructive to fish when turned into a natural water course without further treatment.

The proper quantity must therefore be determined in each case by careful experiment, but the usual dose is about

$\frac{3}{4}$ ton of lime per million gallons of sewage, which represents about 12 grains per gallon, and as one ton of lime water (milk of lime) contains about one cwt. of lime, it is sufficient to treat 330 tons of sewage, or about 75,000 gallons, at the rate of 12 grains per gallon, or about 16 parts per 100,000.

In order to ensure the thorough mixing of the lime water with the sewage, it is usually made to flow through a carrier in which baffle plates are fixed on alternate sides like a fish ladder, or, in cases where the power for driving the mixer is developed by a water wheel driven by the sewage, its passage under, or over, the wheel immediately after the addition of the chemicals will have the same effect in thoroughly stirring it up.

Copperas or proto-sulphate of iron is a green salt readily soluble in water, and its acid reaction renders its use as a precipitant very convenient in conjunction with lime, when large quantities of the latter alone would produce an excessively alkaline effluent, and although the copperas costs more per ton than lime, it has the effect of so far reducing the quantity of lime required that its adoption frequently results in a considerable saving in the total cost of chemicals necessary to obtain satisfactory precipitation of the sewage.

Copperas is applied to the sewage in the form of a concentrated solution immediately after the addition of lime water, the copperas solution being usually prepared of a standard strength by dissolving a certain weight of the green crystals in a tank of water heated by a steam coil.

The usual proportion of lime and copperas used is about $3\frac{1}{2}$ and $1\frac{1}{2}$ grains per gallon of sewage respectively, but in many large manufacturing towns the sewage already contains abundance of acid salts, while in others it is naturally alkaline, so that the quantity of copperas that can be used with advantage varies from nil up to 10 grains per gallon, according to circumstances.

Alum in the form of alumino-ferric or sulphate of alumina is usually supplied in blocks about 30 ins. by 20 ins. by 3½ ins. thick, of a brownish-white colour, somewhat resembling large pieces of hard soap, and although it is much more expensive than lime or copperas, it is very generally used on small works where precipitation is necessary, but where power is not available to drive lime mixing machinery. It is very conveniently applied to the sewage by placing several blocks in an iron cage fixed in the sewage carrier, as shown in Fig. 22.

This method is, however, not very exact or economical, and it is better to use a saturated solution, which can be readily prepared by immersing the blocks in a box lined with lead and provided with a false bottom, so that the water can circulate all round the blocks, the solution being drawn off at the bottom and mixed with the sewage in any proportions desired. Each gallon of saturated solution contains about 7½ lbs. of the alumino-ferric and has a specific gravity of 1.33.

Sulphate of alumina is also sometimes used with advantage in conjunction with lime and copperas, especially when the sewage contains the waste from dye works, as the alumina is very effective in producing a colourless effluent, but the quantity of copperas used should not be sufficient to quite destroy the alkalinity produced by the lime, as it is by this that the alumina is precipitated.

The usual quantity of alumina sulphate, when used alone, is about 20 grains per gallon, or from 5 to 10 grains when used in conjunction with lime and copperas, but it should be observed that, whereas in the case of lime nothing is gained by adding more than a certain quantity, the effect produced by copperas and alumina is increased by the use of a larger quantity of chemical (though a definite amount of lime must be mixed with the sewage first in the case of copperas), and it is therefore quite possible to remove prac-

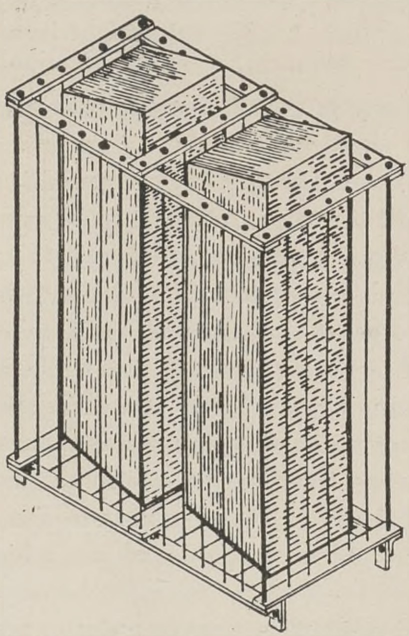

Fig. 22.—Cage for Holding Blocks of Alumino-Ferric to be Dissolved in Sewage as a Precipitant.

(Reproduced by permission of Messrs. Peter Spence & Sons, Ltd., Manchester.)

tically all the suspended matter from the sewage if sufficient quantities of these chemicals are employed, but the effect of precipitants in reducing the matters in solution is seldom appreciable; indeed, lime has the opposite effect by dissolving suspended matter when excessive quantities are used.

The prices of chemicals are naturally liable to considerable fluctuations, and depend largely on the cost of carriage in different districts, but the following approximate figures may be taken as fairly representative of the cost of each delivered in Birmingham :—

Lime containing	70	per cent.	oxide of calcium,	35s.	per	ton.
Copperas ,,	50	,, ,,	sulphate of iron,	45s.	,,	,,
Alum ,,	45	,, ,,	,, alumina,	60s.	,,	,,

For the purpose of calculating the price per pound represented by the above figures, the Author has often found it convenient to remember that 1d. per pound is approximately equivalent to £9 per ton (£9 6s. 8d. to be exact).

Before leaving the question of chemicals and passing on to consider the disposal of the sludge which they are employed to separate, it may be well to emphasise the importance of applying precipitants while the sewage is fresh, and passing it through the tanks as quickly as possible without more agitation than is necessary for the purpose of mixing, as directly putrefaction sets in the sewage becomes much more difficult to clarify owing to the constant disturbance of the sludge by bubbles of gas, which cause large masses to rise to the surface and again become partly mixed with the liquid effluent, so that in order to prevent this the sludge should be removed from precipitation tanks at frequent intervals.

It has frequently been stated that the problem of dealing with the enormous quantities of sludge produced by chemical precipitation presented greater difficulties than any other question connected with the disposal of sewage; and when it was claimed for the newer system of bacteria treatment that the whole of the organic solids could be liquefied, it was very readily assumed that the sludge difficulty was at an end.

Further experience seems to show, however, that although the quantity of sludge which accumulates in septic tanks is usually less than half that produced from the same sewage by precipitation, there must always be a certain proportion of indestructible mineral matter and also a further quantity of organic matter in suspension which cannot be decomposed by bacterial action within a reasonable time, and which must therefore either accumulate in the tanks as scum and sludge, or must be discharged with the tank effluent in a highly comminuted and partially decomposed form.

From the evidence given by a number of witnesses before the Royal Commission, it appears that of the reduction in solid suspended matter effected by the passage of sewage through septic tanks, not more than about 50 per cent. is usually liquefied, gasified, or digested, while there is also abundant evidence to show that the actual proportion is subject to very wide variation according to local circumstances and the capacity of tanks, it being in some cases unnecessary to empty the tanks for a number of years, while in others where there is a considerable quantity of mineral matter in the sewage the reduction is only about 18 or 20 per cent.

The amount of solid matter liquefied or retained in septic tanks does not, however, represent the full measure of their efficiency, owing to the fact that septic sludge only contains about 90 per cent. of moisture, whereas ordinary precipitated sludge usually contains about 95 per cent.; so that more than double the quantity of solid matter is concentrated into a given volume of septic sludge, which means that even if there were no liquefying action at all the bulk of wet sludge would be reduced by quite 50 per cent.; and where this effect is combined with an actual reduction of, say, 50 per cent. in the quantity of suspended solids by liquefying, it represents a total reduction in volume of

L 2

sludge to be dealt with of over 75 per cent., in addition to the elimination of sludge actually produced by the chemicals used for precipitation, which in the case of lime would be equal in bulk to at least 20 times the bulk of dry lime used.

In addition to the reduction in quantity of sludge and the consequent saving of expense in dealing with it, the action of septic tanks also has an important effect upon the liquid effluent as well as the suspended matter discharged with it, which seems to be susceptible to rapid oxidation, and the work of oxidising bacteria is greatly facilitated in consequence, so that they will work more rapidly and more efficiently, while the thorough mixture of the sewage during its passage through the tanks produces an effluent of fairly uniform quality in spite of the natural variations constantly taking place in the composition of the sewage.

With regard to the weight of wet sludge produced by precipitation, about 40 tons per million gallons, or a little over one gallon of sludge per cube yard of sewage, is usually considered a fair average when it contains about 90 per cent. of moisture; but the quantity varies from 20 to 60 tons in individual cases, and the comparison of weight alone without considering the percentage of moisture at the same time is apt to be very misleading.

The following table shows the reduction in weight effected by drying 100 tons of wet sludge containing 95 per cent. of moisture, with a view to clearly indicating the very marked reduction in bulk and weight represented by a comparatively small reduction in percentage of moisture, which might at first sight appear to be insignificant, but which is really of the greatest importance, as the effect of reducing moisture from 95 per cent. to 90 per cent. is to save practically half the cost of disposal, which is roughly in proportion to the bulk of sludge to be dealt with.

100 tons of sludge containing 95 per cent. of moisture
= 50.00 tons when moisture is reduced to 90 per cent.
= 25.00 ,, ,, ,, ,, ,, ,, 80 ,, ,,
= 16.33 ,, ,, ,, ,, ,, ,, 70 ,, ,,
= 12.50 ,, ,, ,, ,, ,, ,, 60 ,, ,,
= 10.00 ,, ,, ,, ,, ,, ,, 50 ,, ,,
= 8.33 ,, ,, ,, ,, ,, ,, 40 ,, ,,
= 7.14 ,, ,, ,, ,, ,, ,, 30 ,, ,,
= 6.33 ,, ,, ,, ,, ,, ,, 20 ,, ,,
= 5.55 ,, ,, ,, ,, ,, ,, 10 ,, ,,

The above figures are calculated by the following simple rule :—

Let X = weight of sludge after drying.
S = weight of solids in 100 tons of sludge before drying.
P = percentage of moisture in the sludge after drying.

Then:— $X = \frac{S \times 100}{100 - P}$.

For instance, to ascertain the weight to which 100 tons of sludge containing 95 per cent. of moisture would be reduced when the percentage of moisture is reduced to 50 per cent. :—

S = 5 tons. P = 50 per cent. $X = \frac{5 \times 100}{100 - 50} = \frac{500}{50} = 10$ tons.

The specific gravity of sludge being so nearly the same as the liquid from which it is deposited, it is somewhat difficult to measure the quantity which has accumulated in a tank without disturbing it and so rendering the measurements misleading, and it may therefore be of interest to describe a convenient method of taking such measurements.

* The apparatus used for measuring the deposit in a septic tank while in operation consists of a glass tube about 2 ft.

* Report on Sewage Purification at Columbus, Ohio, U.S.A. By George A. Johnson, Engineer in Charge. 1905.

6 ins. long and $\frac{1}{2}$ in. diameter, open at both ends, and fastened parallel to the side of a wooden rod long enough to conveniently reach the bottom of the tank. Through the glass tube a fine wire is drawn, at the lower end of which a flexible rubber stopper is fastened, the smaller end uppermost, the wire being carried up to the top of the rod through small screw eyes or staples.

In making a measurement the rod is slowly lowered vertically into the sewage and through the deposit to the bottom. By pulling the wire the stopper is then drawn into the bottom of the tube, so that when raised to the surface it contains an accurate section of the deposit, which can thus be correctly measured.

A cubic yard of wet sludge usually weighs about 16 cwt., so to convert cubic yards into tons, it is only necessary to deduct one-fifth, and, conversely, to convert tons into cubic yards, add one-fourth.

The particular method of sludge disposal to be adopted must in every case depend to a great extent on the local conditions, but the alternative systems most commonly followed at the present time may be distinguished as follows :—

1. Taking the whole of it out to sea in barges and discharging it in deep water.

2. Pressing it by mechanical means into a solid cake resembling damp peat.

3. Air drying in specially prepared lagoons and then transferring it to land.

4. Air drying on the surface of land and afterwards digging it in.

5. Discharging it into narrow trenches in which it may at once be buried with soil.

The first of these methods is only suitable for those large seaport towns such as London, Glasgow, and Manchester, where the sewage cannot be discharged into tidal water in a crude state, but which are so near to the sea that the cost of dealing with the sludge in this way is less than that involved by the other alternatives, but it necessitates a constant service of specially constructed steamers for carrying the sludge in all weathers to a point where it can be safely discharged without risk of polluting any foreshore or oyster beds.

The steamers used for carrying the London and Manchester sludge take about 1,000 tons each trip, and are so arranged that when the tanks are empty the bottom is about 6 inches above the light load line, as also is the top of the sludge when the vessel is fully loaded, and they can thus be emptied by gravity in about 17 minutes, the discharge being regulated by means of large valves controlled from the deck, but as a rule the load is spread over a course taking an hour at a speed of about ten knots.

Fig. 23 shows the type of vessel used at Manchester.

The cost of these vessels is from £24,000 to £26.000 each, and in the case of London each trip involves an expense of about £15, which represents about 3½d. per ton of sludge disposed of, in addition to the cost of precipitation and pumping into the barges.

This method of disposal is undoubtedly simple and effective, as it is found that although the London steamers discharge about two million tons annually, there is no trace of pollution, either in the sea or on the shore, the whole of it being apparently consumed by the organic life in the sea.

Pressing by means of mechanical filter presses is adopted by many inland towns when land treatment is impracticable owing to its unsuitable character, the limited area available or the proximity of works to houses render-

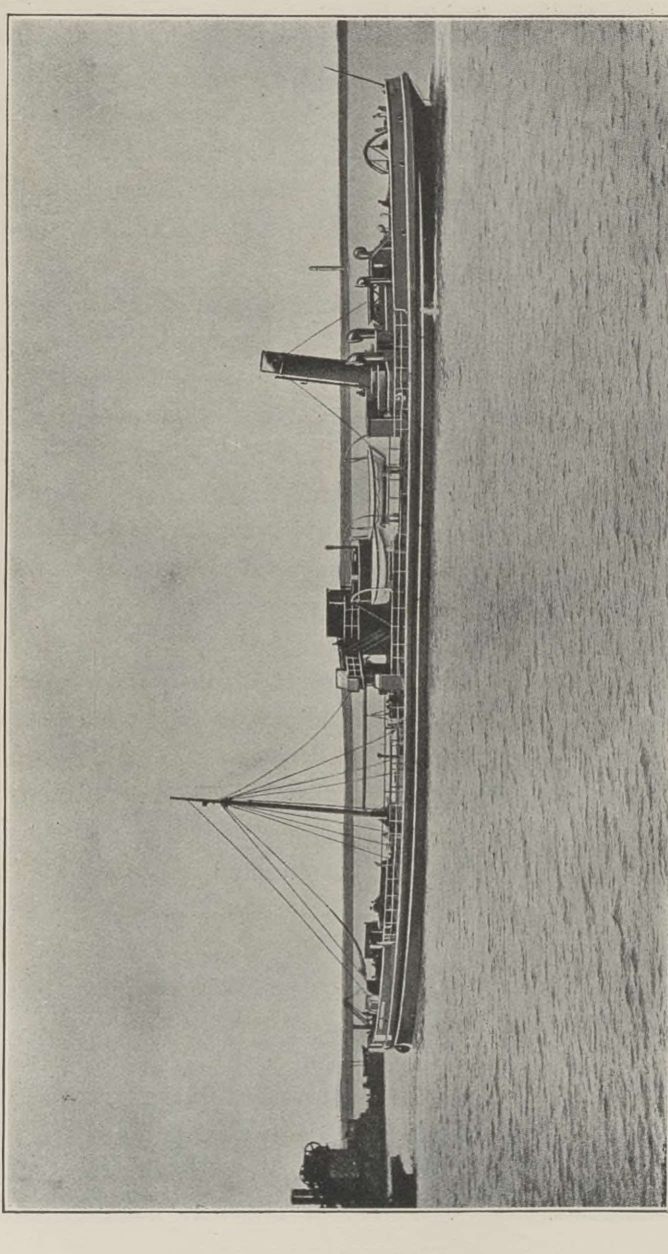

Fig. 23.—Manchester Sludge Steamer Going Out to Sea Loaded.
(Reproduced by permission of Mr. J. P. Wilkinson, Manchester.)

ing it important to avoid the possibility of nuisance that might arise from air drying.

The principle of a filter press is that the wet sludge is compressed between sheets of strong hemp, canvas, or sack-cloth, so that most of the moisture it contains is forced through the cloths, leaving the solid residue in the form of a comparatively dry cake about 1½ inches thick, and containing about 50 per cent. of moisture, so that if the wet sludge contained 90 per cent. of moisture, the cake represents about one-fifth of its original bulk, and when broken up as it comes from the press, it weighs about 12 cwt. per cube yard as compared with 16 cwt. per cube yard for wet sludge.

There are many different patterns of filter presses, but those most commonly used consist of about 40 cast iron plates of varying shape, but usually equivalent in area to about 3 ft. by 3 ft., placed side by side in a frame, as shown in Fig. 24, each plate having a series of corrugations formed on both faces, with a hole about 6 inches diameter in the centre, and a projecting rim round the edge, planed true to form a watertight joint and maintain a space or cell about 1½ to 2 inches wide between the body of each plate when the edges are tightly pressed together.

Double sheets of sack-cloth about 3 ft. 6 ins. by 3 ft. 6 ins. are placed flat between the plates, so that they are tightly held in position by the projecting rims all round the edge, and each cloth having a hole about 4 inches diameter in the centre to correspond with the hole in the plates, there is a clear passage for the admission of sludge right through the whole press, but in order to prevent the sludge getting between the cloths and the plates the two sheets adjoining each plate are securely clamped or sewn together round the 4 in. hole in the centre, where they project slightly beyond the edge of the 6 in. hole in the plates.

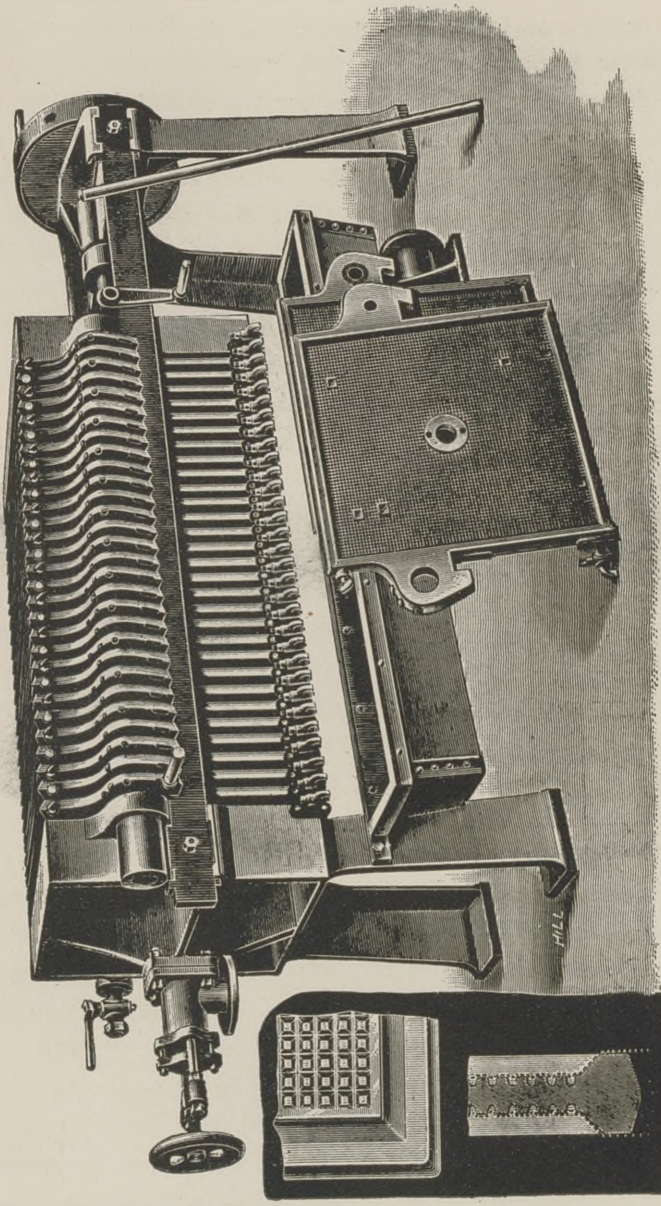

Fig. 24.—Filter Press for Abstracting Moisture from Sewage Sludge, Showing Details of Recessed Plates.

(Reproduced by permission of Messrs. S. A. Johnson & Co., Ltd., London.)

When the sludge is admitted under pressure it fills the space between the cloths, and the liquid squeezed through them is drained away by means of the small channels formed by the corrugations on the surface of the plates already referred to, which lead to a small outlet pipe at the bottom of each plate, where the liquid pressed out of the sludge escapes into an open trough from which it is usually discharged into the sewer, to again undergo treatment as crude sewage, being of a highly concentrated and offensive character.

Each plate is supported and held in position at the top or sides by the very strong tie bolts required for holding the two ends of the press together, and the sewage is admitted through a pipe in the centre of one end controlled by a screw down valve as shown in illustration, while the plates are held tightly together by a screw or hydraulic piston at the other, arranged so that when the spaces between the plates become completely filled with solid cake so that no more liquid can be pressed out of it, the plates can be released and forced apart with an iron bar, and the cake then drops out into a truck placed below to receive it.

Fig. 25 shows the general arrangement of a complete sludge pressing plant where the sludge is forced into the presses by compressed air, the method of operation being as follows :—

The sludge is first delivered into a small storage tank, where it is thoroughly mixed with lime, the quantity used varying from 3½ to 5 per cent. of the weight of pressed sludge, but with slimy septic sludge a larger quantity is required in order to prevent the filter cloths becoming clogged with glutinous matter, which adheres to them instead of sticking to the pressed cake when it is removed, though one cwt. of lime per ton of cake produced may perhaps be taken as a fair average.

From the storage tank the sludge gravitates into iron

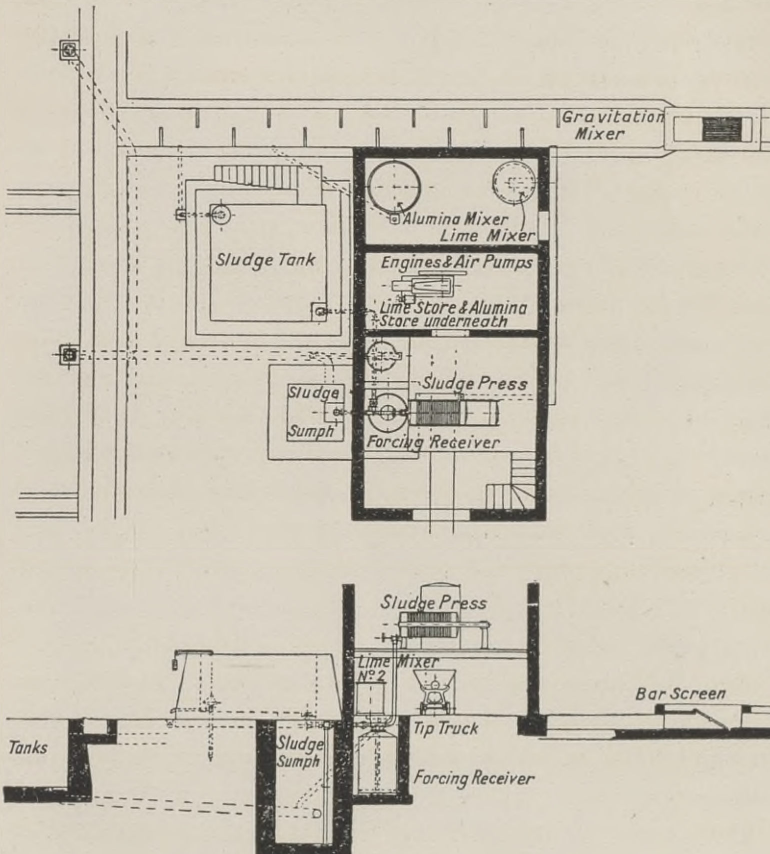

Fig. 25.—Plan and Section of a Typical Sludge Pressing Plant for a Small Town.

(Reproduced by permission of Messrs. S. A. Johnson & Co., Ltd., London.)

receivers, from which it is slowly forced into the presses by compressed air applied to the surface, so that the sludge passes out through a pipe with an open end dipping down inside the receiver nearly to the bottom, and as the liquid escapes from between the plates, more and more wet sludge is forced in under a pressure gradually increasing up to about 60 lbs. per square inch until the whole press is completely filled with solid cake, when the inlet valve is closed so that the press can be opened and the cake removed.

Although the cake still contains from 50 per cent. to 60 per cent. of moisture, this can be further reduced by air drying, and as it is not liable to subsequent fermentation it can be allowed to accumulate without risk of nuisance until it can be disposed of as manure, burnt in a destructor, or utilised for filling up waste land.

In order to facilitate the charging of presses, the capacity of forcing cylinders or ejectors is made equal to that of a single press, viz., about 1,340 gallons, or, say, 6 tons of wet sludge, and as each press is usually charged about five times a day, producing about 25 cwt. of pressed cake each time, the total quantity of wet sludge which can be dealt with by a single press is about 30 tons, or 6,700 gallons per day.

The cost of sludge pressing varies considerably between large and small plants, but it usually works out between 4d. and 6d. per ton of wet sludge pressed, which is equivalent to from 2s. to 2s. 6d. per ton of cake, including lime and the whole expense of operation; the capital outlay involved by a complete plant for treating, say, 30 tons per day being about £800, including air compressors, forcing cylinders, and filter presses in duplicate with all necessary pipes and fittings.

Air drying in specially prepared lagoons must not be taken to imply that the whole of the moisture is carried off by evaporation alone, as a large proportion of it is also removed by a system of underdrains laid under the bottom of the lagoon.

These underdrains are usually ordinary 4-inch agricultural pipes laid about three yards apart, and covered to a depth of about 18 inches with fine engine ashes or coarse sand, through which the liquid from the sludge soaks away, and when the residue is sufficiently dried it can be readily handled with a spade and removed without difficulty to an area of land on which it may be spread and ploughed in.

The lagoons are formed with earth banks or walls high enough to contain the liquid sludge discharged into them to a depth of about 18 inches, and under favourable conditions it will usually become sufficiently dry for removal in about six weeks, when the moisture in the residue is reduced to about 75 per cent., and its volume is about half its original volume.

This system is obviously very much cheaper than pressing, in fact, it necessitates practically no expense beyond the cost of removing the dry sludge and occasionally renewing the ashes or sand forming the floor of the lagoon, some of which are unavoidably taken away with the sludge each time the bed is emptied; it is therefore a method of disposal that is very generally adopted in small places where the lagoons can be constructed on a much smaller area of land than that required when the sludge is dealt with by either of the following methods, and the dry sludge being readily handled and so much reduced in bulk can be carted away and disposed of far more easily than it could be in its original liquid state.

The process of air drying on the surface of land is very similar to the above in many respects, but as the land cannot be so thoroughly drained as the permanent lagoons, and the depth of sludge must not exceed that which can be effectually dug in when dry, the area required is very much greater, and the increased surface exposed to the sun in hot weather necessarily involves increased risk of a nuisance while the process of drying is in progress, so that it cannot be recommended for adoption in populous districts or where sufficient area of fresh land is not always available, and it is, of course, essential that the subsoil should be of a porous, open character in order to facilitate drainage.

The above system was in use on the Birmingham Sewage Farm for about 30 years, when the sludge was conveyed to the land by elevated wooden troughs carried on trestles, but owing to the cost of constantly moving these temporary carriers, and the comparatively small area of land which they could command having become practically clogged up, a new method was adopted in 1902, on the advice of Mr. J. D. Watson, the Engineer to the Tame and Rea Drainage Board, by which the sludge can be discharged, under pressure from an ejector, through underground pipes to any portion of the large area available for the purpose.

The main pipe is about 3½ miles in length, and is provided with branches controlled by valves at intervals of 200 yards, by which portable steel distributing pipes may be supplied from the main, the connection being made with a 9 ft. length of armoured rubber hose, and the portable pipes, shown in Fig. 26, having flanged and bolted joints, can be readily laid down on the surface of the ground as required with but little expense or delay.

The sludge is delivered through the portable pipes into head trenches connecting with a series of parallel trenches 3 feet wide, cut 18 inches deep below the ground surface, but with the excavated material thrown up on either side so as to allow the trenches to be filled with sludge to a depth of 24

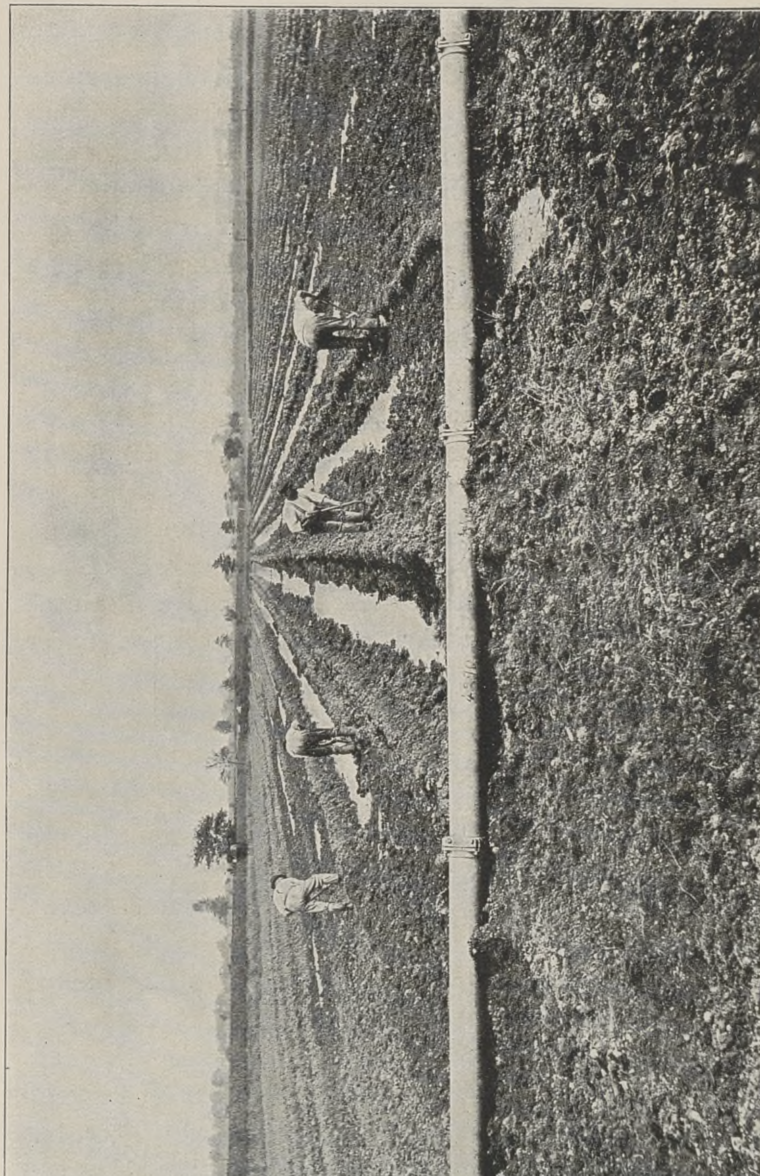

Fig. 26.—Method of Burying Sewage Sludge in Trenches, Showing Portable Distributing Pipes.

(Reproduced by permission of Mr. J. D. Watson, Birmingham.)

to 30 inches, which may afterwards be covered over with soil as soon as convenient.

In the summer the sludge is sometimes covered within 24 hours from the time of taking it from the tanks, but a week is usually allowed to elapse before covering, and rye is sown on the sludged area in the following autumn, the mixture of sludge and earth being deeply cultivated and broken up by steam power after the rye is harvested.

The action of the winter frosts and rain apparently restores the land to its original porous condition by the second spring, when sludge may be again applied to it.

This method reduces the risk of a nuisance from the sludge to a minimum, and where a large area of land is available it seems to be preferable to the other systems of land treatment above described, at any rate under conditions similar to those existing on the Birmingham Sewage Farm, though the cost of preparing the land is very considerable. It is also found that the septic sludge at Birmingham is far less offensive than the sludge from ordinary settling tanks, in fact it has been discharged on to about 8 acres of land to a depth of 18 inches without creating any nuisance during the 7 months allowed for drying before ploughing in.

It will be observed that, with all these alternative means of sludge disposal, attention is chiefly directed to the solid matter which it contains, but as the composition of sludge includes about 90 per cent. of water, the disposal of the foul liquid draining from it in the process of drying also requires careful treatment, and although this can be generally provided for, where presses are used, by draining the liquor back into the outfall sewer, it sometimes results in considerable difficulty when the sludge is dealt with on land unless the underdrains can be made to discharge on to a lower area, where the liquid may be purified by irrigation before being discharged into any river or water course in which it might otherwise cause serious pollution.

For the purpose of deodorising sludge a number of experiments have been tried by Mr. Watson, at Birmingham, with soot, lime, and paraffin, but though the best results have been obtained with a solution of bleaching powder containing hypochlorite of calcium having 36.35 available chlorine, which was mixed with the sludge as it was pumped from the tanks in the proportion of 35 lbs. by weight of powder to 20,000 gallons of sludge, it has been found that its effect shown by laboratory experiments is not quite confirmed by practical tests under working conditions.

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CHAPTER VI.

FILTERING MEDIA FOR BACTERIA BEDS.

Comparison with land—Percolating and contact beds—Disintegration — Aeration — Drainage — Sizes —Weight— Cost—Crushing — Screening—Washing—Burnt clay—Coal—Coke—Gravel — Bricks — Clinker — Granite— Sandstone — Slag — Saggars—Slate.

NO matter what method or system of purification is adopted, the final oxidation of the organic matter in sewage is mainly due to the action of bacteria, and the object to be attained in designing artificial bacteria beds is to secure those conditions under which the growth of these bacteria can be cultivated, and their activity developed to the fullest possible extent.

In describing bacteria beds as artificial, it is only intended to distinguish them from land treatment in which the soil is utilised for the same purpose in its natural state, whereas in bacteria beds some kind of artificially prepared material is adopted in which the decomposition of organic matter can be accomplished at a far more rapid rate than is possible in ordinary soil, though the results must in both cases depend upon bacterial action.

It is, however, very important to bear in mind, when comparing the efficiency of land and artificially prepared bacteria beds, that although the purification of sewage is in both cases affected by similar agencies, it by no means follows that a fair comparison can be based on the cost of purifying an average quantity of sewage per day by either method, unless due allowance is made for the relative facility afforded by each for dealing with large volumes of storm water during a short time.

The average rate of filtration through bacteria beds may be 100 times greater than the quantity which could be regularly dealt with on an equal area of land, but there is nothing to prevent a far larger quantity being discharged on to the land for a few hours during a period of maximum flow, as the rate at which it passes through the land to the under drains is dependent on the natural porosity of the subsoil, and the tendency to surface clogging which results from temporary overwork can be more easily remedied by a period of rest and cultivation over a considerable area of land than when a similar quantity of solid matter is concentrated in the interstices of a much smaller area of bacteria beds.

The maximum rate of treatment is thus of more importance than the average in most cases, when it is not only necessary to provide for treating the average dry weather sewage flow, but possibly a maximum of six times this quantity during storms, and it would be very misleading to suggest that because the average rate of treatment on land and bacteria beds may be 10,000 gallons and 1,000,000 gallons per acre per day respectively, it is therefore more economical to use bacteria beds at a cost of, say, £5,000 per acre whenever 100 acres of suitable land cannot be acquired and laid out for less than this sum.

This point is particularly emphasised here, as unless it is taken into consideration the relative advantages of bacteria beds and land treatment cannot be properly compared, and it also follows that the greater efficiency of bacteria beds must depend on the suitability of media employed, so that its careful selection and proper preparation is absolutely essential to their success, and it is for this reason that the special questions relating to filtering media are dealt with separately in this chapter.

The actual construction of bacteria beds will be fully considered in the succeeding chapters, but it may be observed that the term bacteria bed is intended to include both percolating filters and contact beds, for although these two types have many distinguishing features, both as regards their construction and operation, they are both designed for the purpose of developing the growth of bacteria for sewage purification, and involve the use of artificially prepared filtering media in which the organic matter may be decomposed by biological action in the presence of atmospheric oxygen.

It is now generally recognised that in order to secure the best results from bacteria beds, the filtering media should be as fine as possible consistent with the proper drainage and aeration of the interstices; it is necessary, however, that this condition should not only be fulfilled with the new material when first placed in the bed, but must be maintained permanently in actual operation.

It will therefore be realised that any material which contains dust, or which is liable to disintegrate or fall to pieces when constantly exposed in a more or less damp state to the weathering action of the atmosphere, is unsuitable for use as a filtering medium, since the process of disintegration must inevitably tend to the gradual consolidation of the bed as a result of small particles breaking off the larger ones and filling up the interstices between them. The underdrains also become obstructed by the accumulation of any dust or fine material that gets washed into them, and the proper aeration of the bed being thus impeded, the interstices of the media soon become water-logged and clogged with solid organic matter which cannot be properly decomposed without a good supply of oxygen.

Having selected a material free from dust and that will not disintegrate, it is still necessary to exercise the greatest care in determining the proper sizes for the particular kind of medium adopted, and providing adequate means of drainage and ventilation, without which it is impossible to obtain the highest efficiency for the beds, for when the interstices are too small, the liquid is held up by capillarity, so that the bed does not drain quickly enough and thorough aeration is thus impeded, while the use of too large a size results in a great reduction of surface area on which the bacteria may find lodgment.

It will, however, be understood that although it is usual to define the sizes of media by the mesh of screens by which they are passed and retained, this is only done as a matter of convenience, the real object being to fix the size and capacity of the interstices, and the same result may possibly be secured by having particles of various sizes mixed together instead of using media of a uniform size, though this is not so satisfactory as regular grading.

In order to prevent the media undergoing a gradual process of settling together or consolidation, it is important that the largest particles in any particular part of the bed should not be more than twice the size of those immediately above them, as the latter may be displaced when the bed is in operation if they are not individually larger than the interstices between the particles below them.

The most efficient size depends to a great extent upon the nature of the medium used and its natural inclination to break into cubical or flat flaky pieces, but for first contact beds the average size is rarely less than 1 in., and larger sizes are generally used to facilitate rapid drainage and aeration, but more of the organic matter in suspension is then carried down into the body of the bed in the process of filling, and retained in the interstices, where it is only gradually decomposed when the bed is again charged with air after being emptied, whereas with fine grain media the greater part of the purification is more rapidly effected in the surface layers, where the aeration is naturally more perfect, and for second contact, at any rate, it is undoubtedly better to use comparatively fine material throughout.

To prevent the drainage being unduly impeded by capillary attraction it is not desirable to use such fine material even for percolating filters that it will pass through a $\frac{1}{4}$ in. screen unless it is exceptionally uniform in size, while anything that will not pass a $\frac{3}{4}$ in. mesh should, as a rule, be rejected except for a thin layer of larger size at the bottom, which is useful to facilitate the rapid removal of the purified effluent when the under-drains are placed some distance apart, and a finer layer on the top to retain the matters in suspension is sometimes desirable. It being assumed that most of the suspended matter is removed by preliminary treatment.

In some experiments conducted at Hanley, in Staffordshire, under the supervision of the Author and his partner, for the purpose of determining the most suitable size of media to use in the nine acres of percolating filters now being constructed there, two $\frac{1}{4}$ area beds were filled in sections with crushed saggars (described later) of sizes varying from $\frac{1}{8}$ in. to $1\frac{1}{2}$ ins., and kept in regular work under practically identical conditions for two years, during which time the whole area was supplied with septic tank effluent at the rate of about 200 gallons per super yard per 24 hours, perfectly uniform distribution being secured by the mechanically driven distributors described at the end of Chapter VIII.

The following table shows the average analysis of filtered effluent from each section of the beds as published in a report to the Staffordshire County Council by Dr. George Reid, the County Medical Officer, and from these it will be seen that the best results were obtained from the fine material, the section of circular filter containing the largest size invariably giving the worst effluent, the percentage of purification effected in this section being 91 per cent. as shown by oxygen absorbed, whereas the finer material gave from 94 per cent. to 97 per cent.

PARTS PER 100,000.

Sample.	Size of Material.	Solids.			Chlorine.	Free Ammonia.	Organic Ammonia.	Oxygen Absorbed in 4 hours.	Nitric Nitrogen.
		In solution.	In suspension.	Total.					
	Ins.								
Sewage . .	—	125·4	62·9	188·3	8·9	2·109	0 765	3·854	0·00
Septic tank .	—	105·5	4·4	109·7	8·7	1·820	0·270	1·725	0·00
Rectangular. Sec. 1	$\frac{3}{16}$ to $\frac{1}{8}$	112·0	0·4	112·4	8·5	0·081	0·029	0·273	1·75
Rectangular. ,, 2	$\frac{1}{2}$ to $\frac{1}{8}$	111·9	0·3	112·2	8·3	0·098	0·032	0·278	1·73
Circular. Sec. 1 .	$\frac{3}{16}$ to $\frac{1}{8}$	112·1	0·2	112·3	8·4	0·096	0·025	0·242	1·66
Circular. ,, 2 .	$\frac{1}{2}$ to $\frac{1}{8}$	112·9	1·4	114·3	8·3	0·036	0·029	0·259	1·53
Circular. ,, 3 .	$\frac{1}{2}$ to $\frac{1}{4}$	112·8	0·7	113·5	8·4	0·037	0 030	0·252	1·62
Circular. ,, 4 .	$1\frac{1}{2}$ to $\frac{1}{2}$	113·1	1·7	114·8	8·3	0·119	0·046	0·327	1·62

Although ordinary filtering media is by no means so regular in shape as a perfect sphere, a brief consideration of the properties of a sphere may serve to illustrate the principles determining the relative amount of space occupied by the media and the interstices, and at the same time to emphasise the great importance of securing a fairly uniform size in order to prevent consolidation by the small pieces working their way between the large ones, and thereby reducing the water capacity of the bed as well as the space for aeration. The following is an abstract from a Report by Colonel T. W. Harding and W. H. Harrison, M.Sc., on Sewage Disposal experiments at Leeds, 1905, page 136.

"If spheres or balls be stacked regularly within a given cubic space, there will be a constant relation between the space occupied by the material and the intervening spaces, and this will be so whatever the diameter of the balls. Thus: A cubical tank of 3 feet measure would have a capacity of 27 cubic feet. If one solid sphere 3 feet diameter were put into it, this would take up 14.13 cubic feet, and leave a water capacity of 12.87 cubic feet. If again, instead of the single sphere, 27 spheres each of 1 foot diameter are stacked in this 3 feet cubical tank, each sphere has solid contents of .543 cubic feet, and the whole 27 will take up 14.13 cubic feet, leaving a net water capacity of 12.87 cubic feet, which is the same as in the preceding case, and equal to 47½ per cent. of the capacity of the tank.

"If stacked in the closest possible positions (as seen in piles of round shot), the 3 feet cube would contain 31½ spheres of 12 inch diameter, provided it formed part of a larger tank. These would have a volume of 16.5 cubic feet, and have a water capacity of 38.8 per cent. In practice, however, the balls used for filter material would fall into less regular positions, leaving arched spaces here and there—as with other forms of material—and the water capacity would probably be about 50 per cent. of the tank capacity.

"But while the capacity will be the same, whether large or small spherical material of equal size be used, on the other hand the available surface area of the material will be greatly larger with small than with large spheres."

There can be no question that the efficiency of many bacteria beds would have been much increased if greater care had been exercised in preparing and grading the filtering media and observing the results obtained by experiments under ordinary working conditions before deciding on the best size to adopt, but if this matter is to be reduced to an exact science, it would seem necessary to go a step further still by making a mechanical analysis of the media to be tried, as has been done with the sand and gravel used in the experimental filters at Lawrence, U.S.A.

In these experiments the size of each particle is considered for convenience to be the diameter of a sphere of equal volume, and when the weight and specific gravity of a particle are known, the diameter can be readily calculated. Having selected and weighed a sample of the material to be analysed, the particles are spread out so that all are in sight, and for sizes that will be retained on, say, a $\frac{1}{2}$ in. mesh, there is no difficulty in picking out a definite number of the largest. These are then weighed and the diameter calculated from the average weight, while the percentage which they represent of the whole is shown by comparing their weight with that of the original sample. Another set of the largest remaining particles is then selected and weighed as before, and so on, until the sample is exhausted.

A sample may thus be graded into different sizes with great accuracy, and the number of particles of each size may be conveniently expressed in percentages of the whole and plotted in the form of a diagram, but it is found that in mixed materials containing particles of various sizes the capacity of the interstices is practically governed by the finest portion which fills the crevices between the larger particles, and in the Lawrence experiments the standard or effective size of each sample was assumed to be such that 10 per cent. by weight of the particles are smaller and 90 per cent. larger than itself.

In order to show whether the particles in a sample are all about the same size, or whether there is a great range in their diameters, a uniformity coefficient has also been suggested to designate the ratio of the size which has 60 per cent. of the sample finer than itself to the size which has

10 per cent. finer than itself, and when the weight of each size is plotted in the form of a diagram the proportion that would be wasted by rejecting all particles above or below a certain size can be readily ascertained by direct measurement from the curve.

When the particles are too small to be retained on a $\frac{1}{2}$-inch mesh, and the number in each sample is too great to be conveniently counted, the different sizes may be separated by the use of sieves with varying mesh; but owing to the irregular shape of the particles and the varying thickness of wire used for the sieves, the method of hand-picking is more accurate when not too laborious.

In order to determine the actual water capacity of the interstices or voids in a sample of media, the material should first be thoroughly wetted to provide for absorption, and then, after draining off the water, a watertight box, say one cube foot capacity, may be filled with it and well shaken until the surface of the media is just level with the top of the box, so that the volume of water necessary to fill the voids in one cube foot of the material may be accurately measured by weighing the box and its contents before and after filling up the interstices with water.

The weight of filtering media is another matter that deserves attention, especially when it has to be brought from a distance, as it necessarily has an important effect on the cost of carriage, and although a heavy material may be preferred to a light one on account of its hardness, the cost of crushing is correspondingly increased, and there is really nothing gained by using an excessively hard material so long as it will not disintegrate.

In obtaining tenders for filtering media it is important to clearly define the method of measurement to be adopted, as many disputes have arisen owing to the absence of some clear understanding on this point; and as bulk is required rather than weight, it is usually better to buy it by the cube yard than by the ton, though it may be well to specify the minimum weight per cube yard required for the different kinds of media, since this frequently varies from 50 to 100 per cent., and much must depend on whether the material is wet or dry.

As an example of the variation in weight, it will frequently be found that whereas one sample of furnace clinker may weigh 18 cwt. per cube yard, the weight of another may not exceed 12 cwt., but the following approximate figures may be taken as a fair average for four of the materials most commonly used in England :—

Clinker.		Slag.		Saggars.		Granite.
15	...	17	.... .	18	......	20

The cost of suitable material for filtering media has risen considerably during the last few years owing to the growing popularity of bacteria treatment, but under ordinary conditions the price of raw material is usually between 2s. and 5s. per cube yard, and from 5s. to 10s. when properly graded to the sizes required, the difference representing the cost of washing, screening and carriage, as well as the waste due to the removal of fine dust, so that it is desirable to save unnecessary expense by selecting sizes which can be produced without an excessive proportion of waste.

With regard to the crushing of filtering media, the method of doing this must depend very largely on the kind of material used, but it may be of interest to give some particulars as to the method of crushing and screening that has been found most successful in preparing saggars at Hanley. (For description of this material see page 29.)

It was in the first instance proposed to use ordinary jaw crushers, but it was found, on making experiments, that owing to the fact that the pots from which the saggars are made are usually under one inch thick, this method of crushing produced a large proportion of flat pieces which would not go through the screen and also caused excessive waste on account of the large amount of dust resulting from the grinding action of the crusher.

It has therefore been found advisable to substitute another crusher of an entirely different type, which works on the same principle as an ordinary mortar mill, shown in Fig. 27, the revolving pan or trough being provided with interchangeable bottom plates, in which holes are formed to the required sizes, and as the saggars become crushed small enough under the heavy rollers they drop through these holes and are mechanically sorted into the different sizes required by passing through a revolving screen placed at a sufficient height for the screened material to be collected in trucks underneath, so that it can be at once conveyed to the filters, the material dropping from the crusher being raised to this height by an ordinary bucket elevator, so that from the time the rough material is thrown into the crusher to the time when it is deposited in the filters, no manual labour is required for its manipulation.

The whole of the plant is driven by a portable steam engine (9 horse-power), and it is found that the average quantity of crushed saggars produced by the above plant, not including dust, is about 400 tons per week, working 10 hours per day, and the quantity of raw material required to produce this quantity of filtering media is about 500 tons, the difference of 20 per cent. representing the waste dust which is used for forming footpaths and also for mixing with sand for concrete.

The cost of raw saggars delivered on the works at Hanley varies from 1s. 2d. to 2s. 2d. per ton, and from careful accounts that have been kept during the past three

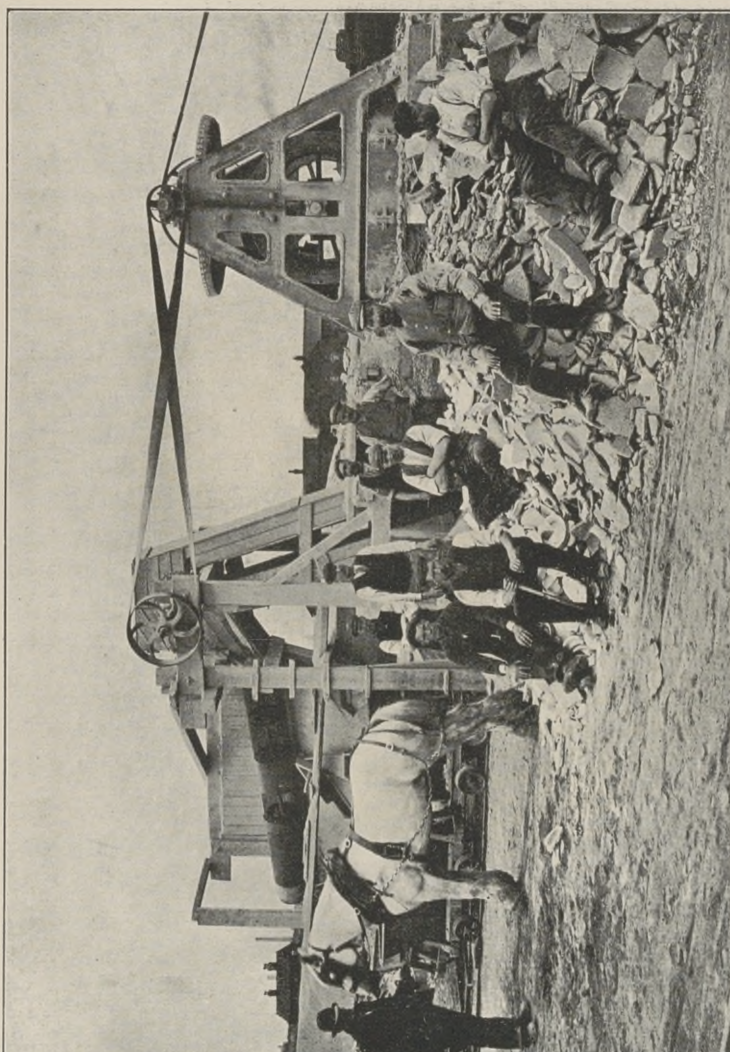

Fig. 27.—Plant for Crushing and Screening Filtering Medium at Hanley, Showing "Saggars" Before Crushing.
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years by our Resident Engineer, Mr. Makepeace, it has been found that the cost of crushing and screening by the above method is about 2s. per ton of finished material, which, together with the present price of 1¼ tons of raw material at 1s. 8d., makes a total cost of 4s. 1d. per ton of filtering media produced.

The cost of crushed saggars and placing in position in the filters is about 4s. 9d. per ton, and as about 18 cwts. of crushed saggars equal one cubic yard, the cost of this material in position and ready for use is about 4s. 6d. per cubic yard, which is very considerably less than the price which has frequently to be paid for a less suitable material in places which are not so fortunate in having such a good waste product available in large quantities in the immediate neighbourhood of the works.

Another improved type of crusher which is now being used for preparing filtering media is that illustrated in Fig. 28, its action being dependent on the gyratory motion of a central revolving shaft or cone, which is not quite concentric with the outer casing, so that as the material to be broken passes down from the top it is crushed smaller and smaller until it passes out through the space at the bottom, which is adjusted to give the size required by raising and lowering the central shaft.

This machine is capable of crushing to any size required from 2 ins. downwards, and generally appears to produce less dust and flat pieces than pan or jaw breakers.

The raised ribs on the central shaft can be made sharp or rounded according to the nature of material to be crushed, since it is found that the best results are obtained by using sharp edges with comparatively soft material like saggars, and blunt ones with hard stone.

The following table shows the percentage of different sizes produced with this machine when tested with saggars :—

$\frac{1}{8}$-in.	cube including	all dust	... ...	10 per cent.
$\frac{1}{4}$-in.	,, ,,	no ,,	... ...	20·50 ,,
$\frac{3}{8}$-in.	,, ,,	no ,,	... ...	13·07 ,,
$\frac{1}{2}$-in.	,, ,,	no ,,	... ...	13·63 ,,
$\frac{3}{4}$-in.	,, ,,	no ,,	... ...	19·20 ,,
1-in.	,, ,,	no ,,	... ...	11·50 ,,

The ordinary revolving cylindrical screen has hitherto been almost universally used for grading the material, and the usual method of fixing it is shown in Fig. 27, but in removing dust from damp clinker or saggars, better results are obtained by a flat screen worked with a jigging motion, though the only really efficient means of removing all the dust from damp material is by washing and screening it at the same time, as shown in Fig. 28.

Where plenty of water is available under a good pressure, the simplest method of washing is by using a jet on the media as it passes over the screens, but when this necessitates pumping the water it is cheaper to pass the material through a trough of running water, in which it can be pushed along by a worm conveyor from one end to the other and the washed material can be delivered by a bucket elevator into trucks ready for use.

A still more simple method of washing is to use a perforated iron plate to form a false bottom to the washing-box, through which the water may be admitted under pressure, while the dirty material is dumped from wheel-barrows into the box and stirred with a fork, or as an alternative air may be admitted by perforated pipes in the bottom, the dust and dirt being carried off by the water as it overflows, while the washed media sinks, and can be shovelled out when clean, the bubbles of air having the same effect as stirring.

This is the method adopted at Hampton-on-Thames for cleaning the clinker from contact beds which had become

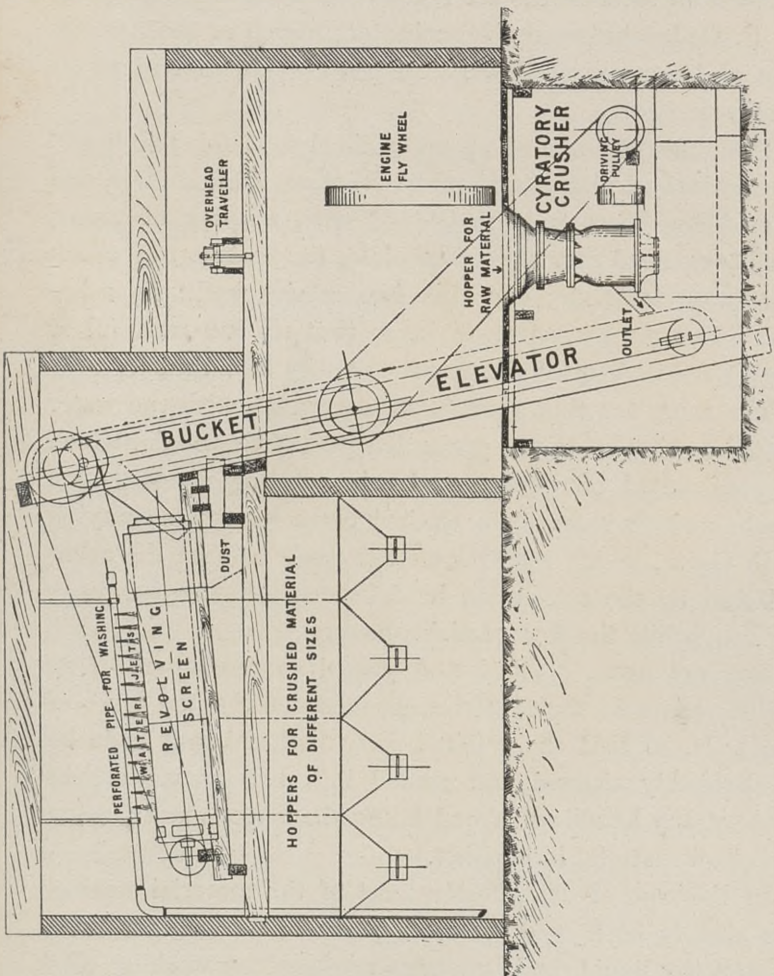

Fig. 28.—Typical Arrangement of Gyratory Crusher and Revolving Screen, Showing Method of Washing with Water Jets.

(Reproduced by permission of Messrs. T. C. Fawcett, Ltd., Leeds.)

clogged, the total cost of removing, washing and replacing the material being about 1s. 6d. per cubic yard.

At the Manchester Sewage Works the contact beds were originally filled with unscreened engine ashes, and the following notes on the system of washing and screening adopted on these works are taken from a Paper read by Mr. A. B. Ogden before the Manchester Branch of the Association of Managers of Sewage Disposal works in November, 1906.

The ashes are hauled up an inclined roadway and tipped on an elevated platform about 11 ft. above ground level, and after being thoroughly moistened with a spray of water, they are passed over a jigging riddle, the first part of which has no perforations, and therefore retains both the ashes and water discharged on to it, so that all fine material or dust is reduced to the consistency of very liquid mud.

The ashes are thus thoroughly shaken up with the water before passing on to the perforated part of the riddle, which is constructed of woven steel wire netting about $\frac{1}{4}$-inch mesh, and they are then washed clean by again spraying with water, which removes all the mud, so that the ashes retained by the screen can be delivered into wagons ready for use, while the fine particles passing through this $\frac{1}{4}$-inch screen are again washed and passed over a finer screen which separates the material required for the top layer of the beds, so that the original dirty material may thus be mechanically cleaned and graded into two or more sizes without any handling beyond filling the wagons and placing the clean material in position.

In the case of Manchester most of the material washed has already been used for some years in the contact beds, so that the liquid mud or sludge produced by washing contains a large proportion of organic matter in addition to the dust removed from the ashes, but as the latter can be easily disposed of by tipping on any waste ground that requires filling up, whereas the organic sludge has to be carried out to sea by steamers, it is desirable to separate one from the other as far as possible.

This is accomplished by allowing the wagons to overflow, so that the lighter organic matter carried away with the water is conveyed by pipes to lagoons, where the solids in suspension are deposited, while the supernatant water may be drawn off and used again.

The very fine ashes and dust, being heavier, naturally settle to the bottom of the wagons, and the cost of treating this is therefore saved, while the sewage used for washing is found to contain considerably less impurity after settlement than it did in the first instance, so that it is quite unnecessary to use clean water for this purpose when sewage or sewage effluent can be obtained.

The difference in bulk of media before and after washing shows a reduction of about 25 per cent. in the case of ashes removed from Manchester contact beds after about five years' work, so that in calculating the total cost of cleaning this material it is necessary to include the cost of supplying and preparing the new material required to make up for this loss, as well as the interest and depreciation on washing the plant, which cost about £350.

Apart from the above items, the actual cost of removing, washing, and replacing the media in a half acre bed, 3 ft. 6 ins. deep, is given in detail by Mr. Ogden as follows, the cubic contents of the bed being 2,823 yards.

	£	*s.*	*d.*
Emptying bed	41	8	11
Washing ashes	50	1	6
Filling bed	15	1	6
Locomotives	21	12	7
Platelayers, etc.	5	13	3
Repairing wagons, etc.	4	9	10
Total	138	7	7

The above figures include the tipping of refuse, removal of settled sludge, and general cleaning up; also the men's time occupied in storing the smaller washed material for future use, so that the cost per cube yard works out at about 1s. on fouled medium, and 1s. 3d. on washed medium.

The average output of the washers is about 150 tons of washed material per day of 10 hours, and the quantity of water or sewage required for washing is about 60,000 gallons per day, which is supplied by a No. 4 pulsometer pump, so that, including all incidental expenses, the total cost of washing may be taken in round figures at about 1s. 6d. per cube yard of clean material produced.

This figure practically agrees with the result of similar records kept at Birmingham, when the media for about two acres of percolating filters has been washed for 1s. 5d. per cube yard, including cost of renewals required to make up the reduction in bulk due to loss of dust, but in the latter case the loss was much less than at Manchester, where the character of material used is different.

The distinguishing characteristics of various materials that have been used with more or less success in England may be briefly summarised as follows, it being understood that an ideal material should not only be hard and durable, but the particles should be cubical in shape, with a rough surface rather than flat and smooth, as the latter form has too great a tendency to consolidate, and a smooth surface does not afford such a good hold for bacteria as a rough one.

1. Burnt clay was tried at Manchester and other places, but it was found that when exposed to constant wetting and drying the material very rapidly reverted to something approaching its original condition, the lumps gradually

breaking up into fine dust, which by accumulating in the interstices of the remainder and in the effluent drains, very soon blocked up all the air passages and caused the filter to become waterlogged, so that although cheap in first cost it is decidedly unsuitable for the purpose.

2. Coal was first suggested by Mr. Garfield, and has been used successfully at Lichfield among other places in the neighbourhood of collieries where coal can be obtained at a low price and is sufficiently hard to resist disintegration, but it is essential that it should be perfectly free from dust, and although this material is very superior to burnt clay, its hardness being usually much less than other materials that have since been used, it is not likely to be very generally adopted.

It has, however, been observed that coal filters have the peculiar property of producing a good effluent almost directly they are set to work, whereas the amount of purification accomplished with other materials only increases very gradually as the bed becomes matured, and coal may have some special advantage on this account.

3. Coke being a waste product from gas works can generally be obtained at a low price in the vicinity of large towns, but although its lightness effects some saving in carriage, this advantage is counterbalanced by its tendency to float when submerged in water, which results in a slight movement of the particles each time contact beds are filled, and in percolating filters this material also settles considerably on account of the fine particles working their way into the interstices left in the dry coke when placed in position; a large amount of waste also occurs on account of the formation of dust, both before and after the material is brought into use.

The porosity of coke or any other material appears to be of no lasting value, as the pores soon get filled with water, which is held up by capillary attraction.

4. Gravel, where obtainable on the site, if thoroughly washed and carefully graded, will no doubt give more satisfactory results than when formed into land filters in its natural state, but in order to allow for the free circulation of air it is necessary to remove all the fine material, including sand, by screening, and while this adds considerably to the cost, the smooth surface of the rounded pebbles is a disadvantage as compared with other material of a rougher description, since it is important that the gelatinous growth which forms in the interstices should not be too easily displaced, and it is no doubt for this reason that the use of smooth chalk flints has not been found very successful.

5. Slag is used successfully at various places in the Midlands, but since its quality varies very much in different localities it is important that very great care should be exercised in selecting it in order to avoid the risk of disintegration, which may result from the decomposition of certain chemicals which it frequently contains; and, as in the case of furnace clinker, the slag should be as free as possible from honeycomb or small holes. Any slag containing lime or sulphur should be avoided, as their presence may cause rapid disintegration. It may be useful to observe that the presence of sulphur can frequently be detected by the smell of sulphuretted hydrogen given off when the slag is wetted, and the effect of free lime when slaked by water can be easily understood and recognised without explanation.

The most suitable kind of slag is that produced by the old cold blast furnaces, this being apparently more thoroughly vitrified than that obtained from modern ironworks, and less liable to disintegration.

6. Sandstone has been used at Carlisle in the experimental contact beds constructed there some years ago, but its porous nature appears to encourage the growth of moss on the surface, and this must result in impeding aeration, besides which it takes a long time to drain, and it is almost impossible to obtain this kind of stone of sufficiently hard quality to stand breaking to small sizes without losing a very large proportion of it in dust which is useless.

7. Granite has been used extensively for filling contact beds at Nuneaton, also for percolating filters at Birmingham and Kenilworth; where it can be obtained locally of the sizes required, free from dust and dirt, it is undoubtedly a very suitable material, owing to its extreme hardness rendering it proof against disintegration, but where the stone is mixed with clay this should be carefully removed by washing, and the flat flaky pieces of stone produced in dressing the large blocks should be avoided as they lie too close together.

8. Furnace clinker of the very hardest description and when broken to suitable sizes is also an excellent material, but its quality varies very much, and some of it is so soft that it is quite useless, while considerable difficulty is experienced in getting it free from dust, especially when the material is at all damp, as the dust adheres to its rough surface.

The weight of clinker is generally a fair indication of its hardness, the best material weighing about 18 cwt. per cubic yard, whereas some of the inferior kinds only weigh about 12 cwt. per cubic yard, and although the clinker from refuse destructors is sometimes good, its composition is very uncertain.

9. Overburnt bricks obtained from brickyards in the neighbourhood of Birmingham, where the clay becomes vitrified in burning, are of an exceedingly hard and

impervious description very suitable for filtering media, but it is not economical to break up good sound bricks, and the supply of waste material from brick-yards being limited, they have not been very extensively adopted, though a considerable quantity has been used for the new filters of the Birmingham Tame and Rea Drainage Board.

10. Saggars, which are a waste product in the Staffordshire Potteries, consist of the rough earthenware pots shown in Fig. 27, in which the finer china is burnt, and since this material is repeatedly exposed to a very high temperature and is consequently very hard, it is in every way suitable for use in bacteria beds, and has therefore been adopted at Hanley, Newcastle, Fenton, and other places in the district, where it can be obtained for very little more than the cost of carting, and after five years' use it has been found that no appreciable amount of disintegration has taken place, while the somewhat rough surface presented by the fractured pieces appears to afford a very suitable home for the bacteria. Fig. 29 shows one of the Hanley filters being filled with this material.

Broken firebrick from the Stourbridge district may be used as a substitute for saggars, and when it has been thoroughly burnt it appears to possess all the advantages of the former material, the best firebrick being obtained from old gas retorts, which are necessarily very hard, but as in the case of vitrified bricks the supply is very limited.

11. Slates have been used by Mr. Dibdin at Devizes, where they are placed in layers as shown in Fig. 30, with small blocks of slate about two inches thick between each layer; but as these slate beds are chiefly intended for the removal of suspended matter from crude sewage, the slates are arranged so that any solid deposit which accumulates between them may be readily flushed out by the use of a

Fig. 29.—Placing Crushed "Saggars" in Filters at Hanley, Showing Houses in Close Proximity to Sewage Works.

(Reproduced by permission of Messrs. **Willcox & Raikes, Westminster and Birmingham.**)

water jet with a bent nozzle, small vertical shafts being left in the slates at intervals of about 10 feet for this purpose.

Mr. Dibdin also recommends the use of slates on the ground that they possess the maximum surface area for the growth of bacteria, while at the same time occupying a comparatively small proportion of the total cubic capacity of a bed that is filled with them, thus leaving more room for the sewage, but although waste slate debris can be obtained very cheaply near the quarries, the blocks for separating them have to be specially prepared, and the cost on rail of the slates ready for use, with the necessary number of blocks for separating them, is said to be about 10s. per ton, so that, even assuming that one ton will fill three cube yards when packed as shown in illustration, the price of this material at the quarry is 3s. 4d. per cube yard, and Mr. Dibdin gives the total cost, including carriage and laying, as 9s. 3d. per cube yard, which apparently represents the extra cost of these beds when used as a substitute for ordinary tanks of the same capacity in which no medium is employed, as explained in Chapter IV.

12. Sand can hardly be regarded as a suitable medium for sewage treatment by artificial bacteria beds, owing to the small capacity of interstices, which are rapidly choked with suspended matter, but for the final treatment of very dilute sewage from which most of the impurities have already been removed by some kind of preliminary treatment, sand filters may sometimes be adopted with advantage; in fact, sand filtration is the usual method of removing a moderate amount of pollution together with pathogenic bacteria from public water supplies.

This system of continuous filtration under pressure can only be successful, however, so long as the water itself contains enough air in solution to oxidise the organic impurities present, and sewage effluents which have reached this degree of purity can usually be discharged into a water

Fig. 30.—Slate Beds at Devizes, Showing Method of Placing Slates in Position.

(Reproduced by permission of Mr. W. J. Dibdin, Westminster, S.W.)

course without further treatment, as they are not liable to putrefaction.

Sand filtration (as distinguished from land treatment) is therefore seldom adopted in England except for the protection of water supplies or shell fish, and under ordinary circumstances responsibility for this is undertaken by those requiring such protection rather than the sewage disposal

Authorities, it being at present considered sufficient if the latter discharge an effluent which is non-putrescible and colourless.

The rate at which water will pass through different kinds of sand can be easily determined by placing the materials in tanks similar to those used by the Massachusetts Metro-

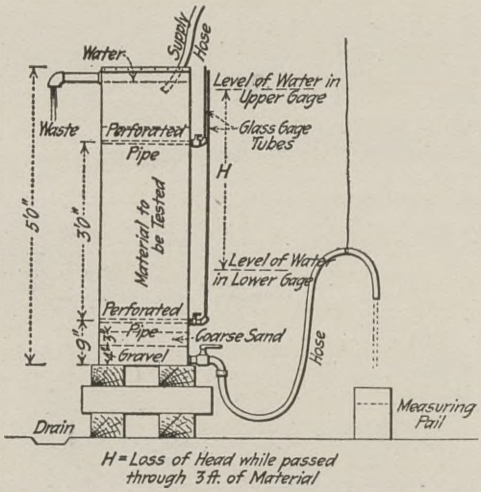

Fig. 31.—Apparatus for Testing Rate of Filtration Through Sand or Other Fine Material.
(Reproduced by permission of Mr. D. C. Henny, and Mr. E. G. Hopson, Portland, U.S.A.)

politan Water Board, as shown in Fig. 31, and the head required to overcome friction in passing through the interstices can be measured at the same time; the tanks being of galvanised iron 18 ins. diameter and 5 ft. deep, with horizontal perforated pipes 3 ft. apart, each connected with vertical glass gauge tubes, while the rate of discharge at the outlet is regulated by adjusting the level of rubber hose pipe attached to the outlet valve.

A somewhat similar apparatus has been used by Mr.

Scott Moncrieff for testing the relative amount of purification effected by different kinds and varying depths of media used for filtering sewage, the media being supported by a series of trays placed one above the other, the sewage being discharged on to the top layer by means of an automatic tipping trough, and samples of the filtered effluent can be drawn off for analysis by means of taps placed at vertical intervals of about one foot.

The same arrangement of taps has been in use for some years at Hanley for taking samples of effluent from percolating filters in actual operation at depths of 1 ft., 2 ft., 3 ft., and 4 ft. below the surface in order to ascertain the amount of work done by each layer, and the results of Dr. Reid's analysis of the samples so taken are given in Chapter VIII., but in this case the taps are fixed in the wall of effluent chamber, each being connected with a short channel pipe laid in the body of the filter at the required depth, and it seems obvious that where such experiments can be made with bacteria beds in actual operation under normal conditions, the observations form a more reliable basis of calculation than any rules derived from results obtained elsewhere under conditions which may not be identical.

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"Report on Sewage Disposal Experiments at Leeds." By Colonel T. W. Harding and W. H. Harrison.

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CHAPTER VII.

Contact Beds and Their Operation.

Capacity and size—Number of fillings per day—Aeration and drainage—Floors and walls—Capacity of beds—Quantitative efficiency of beds—Area of primary and secondary beds—Effect of varying cycle—Character and size of material—Loss of capacity—Condition and successful working—Cycle of operation—Cameron's apparatus—Birch Killon's apparatus—Mather & Platt's apparatus—Adams' apparatus.

Although the special circumstances which are favourable to the adoption of contact beds for the final purification of sewage by oxidation have been briefly referred to in preceding chapters, the various questions relating to their construction and alternative methods of operation still remain to be dealt with.

Since contact beds depend for their action on the sewage being held up in contact with the filtering media for a given time, it is obviously essential that they should be water-tight, and this necessitates the construction of walls and floors in much the same manner as that adopted in the case of precipitation or liquefying tanks, and although the fact of the contact bed being filled with filtering media may in certain circumstances be a source of strength, it is also liable to be a source of weakness, especially where the beds are constructed above ground, when the walls have to sustain the sewage in the beds as well as the filtering media, the specific gravity and consequent pressure due to the two combined being somewhat greater than that due to the sewage alone.

Having determined the length of time for which it is best to hold the sewage up in the contact beds, it naturally follows that any deviation from the time fixed upon must be more or less detrimental to the results, providing, of course, that the original estimate is correct, and in order to secure that the whole of the sewage shall be in the contact bed for approximately the same length of time, it is important that the process of filling and emptying should be accomplished as rapidly as possible, while it is usually found desirable to shorten the duration of contact and extend the period of aeration as far as possible, since it is in the latter stage that the oxidation of organic matter is chiefly effected.

Contact beds should, therefore, not be so large that the volume of sewage that can be discharged into them in dry weather would occupy an unduly long time in filling them, and it is found in practice that, in order to facilitate the arrangement of a satisfactory cycle of filling, standing full, emptying, and aeration, the total area of beds should be divided, so that the capacity of each is not more than, say, one-fourth of the minimum dry weather flow, and on large works it is usually found convenient to still further increase the number of units so as to secure an arrangement whereby the variation in the flow of sewage may, as far as possible, be dealt with at all times without alteration in the regular period of cycle adopted as that which will give the best results.

It is also advisable to avoid excessively large contact beds on account of the increased time required for their complete draining and aeration after each filling, added to which the fall required on very long under-drains renders it necessary to make the beds shallower at one side than the other, and, assuming the maximum depth is limited by the fall available, the minimum will be less than that which might be obtained with smaller units and shorter drains, so that although the adoption of large units may save cost of division walls, this advantage may be counterbalanced by the increased area required in order to make up for the reduced depth.

In the case of Manchester, which is, no doubt, by far the largest installation of contact beds at present existing, about half an acre has been fixed upon as the maximum size for a single bed, and it is now generally agreed that the maximum efficient depth for a contact bed is about 4 feet, though a depth of 3 feet is more usual.

In calculating the effective water capacity of a contact bed something must depend upon the kind of material that it is filled with and the size of the interstices, but it has been taken as an approximate rule that with all kinds of material broken to the sizes usually adopted, the effective water capacity should be about one-third of the total capacity, though this effective capacity is still further decreased when the beds have been in operation for some time, especially where a considerable quantity of solid suspended or colloidal matter is discharged on to them, and in order to provide for the possible contingency of the beds becoming sludged up, the Manchester Corporation have estimated for renewing the material at intervals of about every four or five years.

The relation between the capacity of the beds and the quantity of sewage they are dealing with depends upon the number of times during the 24 hours that they are to be filled and emptied, and it is usually found that where the beds are not worked automatically two fillings per day is as much as they are capable of treating satisfactorily, though it is quite practicable to work them at an accelerated speed during storms, and thus increase the number of fillings to three times per day occasionally, providing that the normal rate of working is maintained for a sufficient time afterwards to let the beds recover from the extra duty imposed upon them during wet weather.

Assuming that the beds are 4 feet deep, with a water capacity equal to one-third the total capacity, it will be seen that two fillings per day represents 150 gallons per superficial yard and three fillings per day equals 225 gallons per superficial yard, these figures being based on the assumption that the original capacity of the bed is maintained, though, as previously pointed out, this is by no means invariably the case, and if the water capacity is reduced to one quarter the total it will be seen that the quantity treated is reduced to 112 and 168 gallons per day for two and three fillings respectively.

It has been found from very extensive experiments conducted at a number of large towns that a satisfactory effluent cannot usually be obtained by one contact alone, and it is therefore almost invariably found necessary to use two beds, the first being placed at a sufficient height for the effluent to be discharged on to the second, in which the process of oxidation may be still further advanced. Indeed, the Local Government Board have refused to sanction loans for treating sewage by single contact alone.

The construction of the high and low level beds is not necessarily different, though, in view of the fact that the first contact is likely to remove all the matters in suspension, and is therefore the most liable to become clogged, whereas the second has only to deal with the impurities remaining in solution, it is generally found desirable to use a somewhat finer material in the latter than in the former, but this is in itself sometimes a source of difficulty owing to the fact that the water capacity of the second bed filled with material crushed to a different grade may not be the same as the first, so that when a high level bed is discharged the second contact bed may not be capable of holding the whole of the effluent from the first, although their dimensions may be precisely the same. This either results in a portion of the partially purified effluent from the first contact bed being discharged without further purification or else the depth of one bed or the other must be increased by the addition of an extra quantity of filtering media, since it is quite useless to fill the sewage up above the surface of the filtering material, as the liquid standing on the top is not brought into contact with the bacteria except in the process of emptying, when the whole of the oxygen in the bed has already been absorbed and its oxidising capacity has therefore practically ceased.

Since the contact bed must necessarily be watertight, the first essential is a thoroughly good floor, and as concrete is the most convenient material for this it is almost universally adopted, the variations in construction consisting more in the arrangement of underdrains on the floor rather than the formation of the floor itself; but by way of illustrating the different methods in use the diagrams in Fig. 45 have been prepared, from which it will be seen that, while some methods involve practically a false floor over the whole area of the bed, others merely consist in a series of draining tiles laid at intervals, but in either case the object is to draw off the liquid as rapidly as possible and facilitate aeration of the filter by preventing the accumulation of carbonic acid gas in the lower portion of the media.

It is, however, very important to bear in mind that the sewage which stands in the effluent drains does not undergo any material amount of oxidation during the period of contact, and since this liquid is the first to be discharged when the bed is emptied, it frequently suggests that the work of the bed is less effective than may really be the case, so that although the volume of this unpurified liquid is comparatively small in relation to the total capacity of the bed, the mere fact of its existence must be recognised as an objection to the contact bed system, and efforts have been made to meet the difficulty in various ways.

One method is to arrange the effluent drains with the actual level of outlet valve slightly above them, so that at the end of each discharge they remain filled with liquid that has already been in the bed during one contact; and although this may, and no doubt does, eliminate the possibility of some sewage being entirely unoxidised, its adoption involves another difficulty owing to the prevention of any air circulating through the underdrains, and the consequent liability of the lower portion of the bed becoming to some extent water-logged, or at any rate so charged with carbonic acid gas as to prevent any oxidising action taking place in it, so that in obtaining increased purification for the sewage in the effluent drains the degree of oxidation in the greater volume of liquid dealt with in each contact may be very seriously reduced, the remedy being thus really worse than the original defect, especially in the case of first contact, since the effluent gets mixed up in its passage on to the second bed, and any marked variation in its quality disappears by the time it reaches the outlet from the low level bed.

With regard to the walls of contact beds, it has already been stated that the design of these depends practically on the same governing principles as those affecting the design of tank walls, but the height being considerably less, their thickness is of course correspondingly reduced, and it is sometimes found convenient to form the sides of the bed by merely sloping the excavation to a batter of say 1 to 1 and covering the surface with concrete in the same way as the floor, but although this construction occupies greater space and can only be adopted with advantage in solid ground where there is no risk of settlement, it is undoubtedly economical under favourable conditions, and since the work of a contact bed depends upon its cubic capacity only, the variation of depth round the outside is not a matter of importance.

With regard to the period of contact and the results obtained from alternative methods of working, the observations made in connection with the very extensive works at Manchester will afford a better idea of what is practicable in this direction than any general description, and the following particulars are therefore taken chiefly from the reports of Dr. G. J. Fowler, now Consulting Chemist to the Manchester Rivers Committee, who was till recently the Superintendent and Chemist in charge of the Manchester Sewage Works at Davyhulme.

As the result of trials at Davyhulme, it was found that excellent purification was obtained by triple contact in all cases, both from raw and settled sewage. With double contact the results varied somewhat with both raw and settled sewage, according to the composition and strength of sewage brought on to the bed, and it soon became evident in the case of raw sewage that the amount of suspended matter brought on to the bed would tend to rapidly reduce its capacity, so that although satisfactory results had been obtained by Mr. Dibdin at Sutton, by treating crude domestic sewage in contact beds, it was concluded that in the case of Manchester sewage at any rate, some amount of preliminary treatment would be necessary before it was put on the beds. It is also evident that, in order to obtain uniform results, the composition of the liquid passing on to the beds should be as free from variation as possible, and as these two conditions are insured by the use of liquefying tanks, the bulk of the sewage is now receiving preliminary treatment in such tanks.

Experiments in the treatment of effluent from liquefying tanks were chiefly directed towards the following points. (1) To determine the length of life and rate of loss of capacity of contact beds. (2) To determine the quantity of tank effluent that could be dealt with safely on a given area. (3) To determine the relative area of preliminary and secondary beds. (4) To determine the effect on the beds and on their activity of variations in the cycle of operation; and (5) To determine the character and size of material best suited for filling the beds.

1. *Capacity of Beds.*—In the earlier stages of work there was a rapid loss of capacity, but this loss of capacity was accompanied by an increase of efficiency, and further experiments showed that with careful management and suitable grade of material the capacity tends to become constant at about 40 per cent. of the original water holding capacity of the material, or 25 per cent. to 30 per cent. of the actual volume of tank holding the material.

In order that the water capacity of contact beds may be accurately determined meters are sometimes provided by which the quantity dealt with at each filling can be measured, and by this means a fairly accurate idea can be obtained of the extent to which a bed is losing its capacity owing to the accumulation of solid matter, whereas if no such observations are made the sludging up may continue until all aeration ceases, and it is then practically impossible to renew the efficiency of the bed without taking out the material and cleaning it.

It has, however, been observed that as the efficiency of a bed increases with time it frequently happens that although its water capacity is reduced, the number of fillings that it is capable of purifying is increased, and consequently there may be no reduction in the total quantity of sewage dealt with on a given area in 24 hours, though, of course, this principle can only be followed within certain limits, and if the loss of capacity becomes very rapid while the purity of the effluent is also decreasing, this must be taken as an indication that the bed is being over-worked, and a period of rest should therefore be allowed.

2. *Quantitative Efficiency of Beds.*—Experience has shown that in Manchester an average quantity of about 500,000 gallons of septic tank effluent may safely be passed through an acre of contact bed 3 ft. 4 ins. deep in 24 hours, but although this is only about half the quantity that is successfully treated on a similar area of bacteria beds at many other places, the Manchester sewage is somewhat exceptional and contains a large quantity of manufacturers' waste.

3. *Relative Area of Primary and Secondary Beds.*—As it is found impossible to reduce the total impurities in solution below the limit allowed by the Mersey and Irwell Joint Committee unless a certain area of secondary beds is provided, careful experiments have been conducted to ascertain the proper proportion which the area of these should bear to that of the first beds, with the result that it is found practicable to obtain thoroughly satisfactory purification when the area of secondary bed is only about half that of the primary bed, and under favourable conditions the proportion may be still further reduced to one-third, it being found that as the primary beds mature, their efficiency rapidly increases.

4. *Effect of Varying Cycle.*—Owing to the natural varia-

tion in rate of flow of sewage, it is a matter of some importance to determine whether an extra number of fillings can be applied to a bed in rapid succession without detrimentally affecting the results, provided a proportionately longer period of rest is given afterwards, and it has been found at Manchester that this can be done so long as the total quantity put on to a given area does not exceed a certain fixed maximum.

5. *Character and Size of Material.*—The experiments conducted at Manchester with a considerable number of alternative kinds of material have shown conclusively that, on the ground of economy combined with reasonable efficiency, clinker was the best available material for the purpose, though it has been observed that the smallest particle should not be less than $\frac{1}{8}$ in., while anything over 2 ins. should also be avoided.

It would appear that clinkers derive their advantage over many other materials from the fact that they are both hard and vesicular, for although certain qualities of coke are hard, they are usually porous rather than vesicular, and the small pores tend to become choked up with solid matter, thus reducing the area of surface brought in contact with fresh sewage.

As already pointed out, the chief difficulty encountered in connection with contact beds is their loss of capacity which arises from the following causes.

(*a*) Settling together of the material; (*b*) Growth of organisms; (*c*) Impaired drainage; (*d*) Insoluble matter entering the bed; (*e*) Disintegration of material.

(*a*) Settling together of material is a natural result of constantly filling and emptying the beds, and is the chief reason for the rapid decrease in capacity which takes place when they are first put into operation, so that in order to allow for this it is advisable to make the depth of material somewhat greater in the first instance than is eventually required.

(*b*) Growth of organisms. Since this represents an increased efficiency, the loss of capacity involved is of minor importance, and Dr. Fowler's observations at Manchester have shown that on examining the material of contact beds in active condition, every piece is seen to be coated with a slimy growth which, when removed, soon dries to a stiff jelly so that it can be cut with a knife. This gelatinous matter is usually found by microscopic examination to contain large masses of bacteria, and if placed in a tube containing air, they will rapidly absorb all the oxygen and produce carbon dioxide.

It has also been found that this action will sometimes produce a vacuum equal to several inches of mercury, and this would appear to show that there is no necessity to force air into the bed so long as means are provided for removing the gases produced by its operation, and when a bed is in good condition a large amount of oxygen should always be present in the bottom portion of it.

The behaviour of this bacterial jelly appears to afford a clue to the successful working of bacteria beds, for by filling them frequently without long periods of rest the effluent may remain good, but bacterial growth so rapidly increases that the bed becomes too spongy, and consequently holds up the water by capillary attraction, and this also explains the fact that within limits the decrease of capacity is accompanied by increased efficiency.

With regard to the period of rest to be allowed when a bed has been overworked, it has been found that this should not exceed about a fortnight, as the bed tends to dry up and the activity of the organisms diminishes, though the length of time allowed depends to some extent on the season of the year, as the loss of heat resulting from suspension of work during cold weather may be quite as detrimental to the activity of bacteria as the excessive drying which is liable to take place during the warmer weather of the summer. It is therefore much better to avoid working the bed at such an excessive rate as to necessitate any special period of rest, as its recovery may not be complete, and it is far better to keep the plant in regular operation rather than overwork a portion of it while the remainder is not worked up to its full capacity, providing, of course, that the plant is properly designed to meet the duty imposed upon it.

(*c*) Defective drainage very rapidly decreases the actual water capacity of the beds by preventing thorough aeration, while at the same time, and for the same reason, it also has a very prejudicial effect on the results by reducing the amount of oxidation that can take place, so that it is of vital importance to provide ample means of drainage and ventilation.

(*d*) Insoluble matter entering the bed is undoubtedly the most certain way of destroying its efficiency, since accumulations of such matter in the interstices cannot be reduced by rest, but in cases where the sewage undergoes a proper preliminary treatment in sedimentation and liquefying tanks this difficulty should not be a serious one. In course of time, however, the residual products of oxidation of the colloidal matters referred to in Chapter IV. may accumulate to such an extent as to need removal by washing the material. Under ordinary circumstances this should only be necessary after long periods, and the consequent expense is not excessive. The washed out material is of an inoffensive earthy character.

(*e*) Disintegration of material is practically fatal to any bacteria bed, and, as already pointed out, no material should be used for filling them which is liable to this defect, as the cost of renewing it at frequent intervals will in most cases more than counterbalance any saving of capital outlay in the first instance, and the necessity for this is now so generally recognised that no material that is not of a hard and durable character is considered suitable for this purpose.

Conditions of Successful Working of Contact Beds.

The following is a short summary of the procedure recommended by Dr. Fowler for adoption in connection with the Manchester Works as the result of his very careful observations of results obtainable both from experimental and permanent beds.

1. The bed should be worked very slowly at first, in order to allow it to settle down and the bacterial growths to form. In this way there will be less danger of suspended matter finding its way into the body of the bed while the material is still loose and open.

2. The burden should not be increased until analysis reveals the presence of surplus oxygen, either dissolved or in the form of nitrates in the effluent.

3. Analyses of the air in the bed may usefully be made from time to time during resting periods.

4. The variations in capacity should be carefully recorded. If the capacity is found to be rapidly decreasing a period of rest should be allowed.

5. Long periods of rest should be avoided during winter, as when deprived of the heat of the sewage the activity of the organisms decreases. If necessary the burden on the bed should then be decreased by reducing the number of fillings per day, rather than by giving a long rest at one time.

6. The insoluble suspended matter should be retained on the surface by covering, at any rate, a portion of the latter with a layer of finer material not more than 3 ins. in depth. The suspended matter thus arrested should not be raked into the bed, but when its amount becomes excessive it should be scraped off. This should be done, if possible, in dry warm weather, after the bed has rested some days, and by placing the inlet and outlet penstocks as close together as possible the suspended matter will tend to concentrate in their vicinity and its removal will be facilitated.

The method of distribution adopted for the contact beds at Manchester is shown in Fig. 32, from which it will be seen that shallow radial grips or channels are formed on the surface of contact beds with very fine screenings, so that when the sewage is discharged into these grips the liquid soaks through the sides, leaving the bulk of the suspended matter on the surface, so that it can be scraped off and removed, say, once a fortnight.

Prolonged experience has shown that the above principles of working contact beds are quite sound, except when it is necessary to accelerate the rate of working for a prolonged period in wet weather. The grips are then apt to retain water and impede the proper aeration of the bed.

Operation of Contact Beds.

The proper cycle to be followed in the operation of contact beds has long been a fruitful subject of discussion, and there are still wide differences of opinion as to the relative duration of the time that should be occupied in filling, standing full, emptying, and standing empty, but it is pretty generally agreed that, although no hard and fast rule can be laid down for all circumstances, the thorough

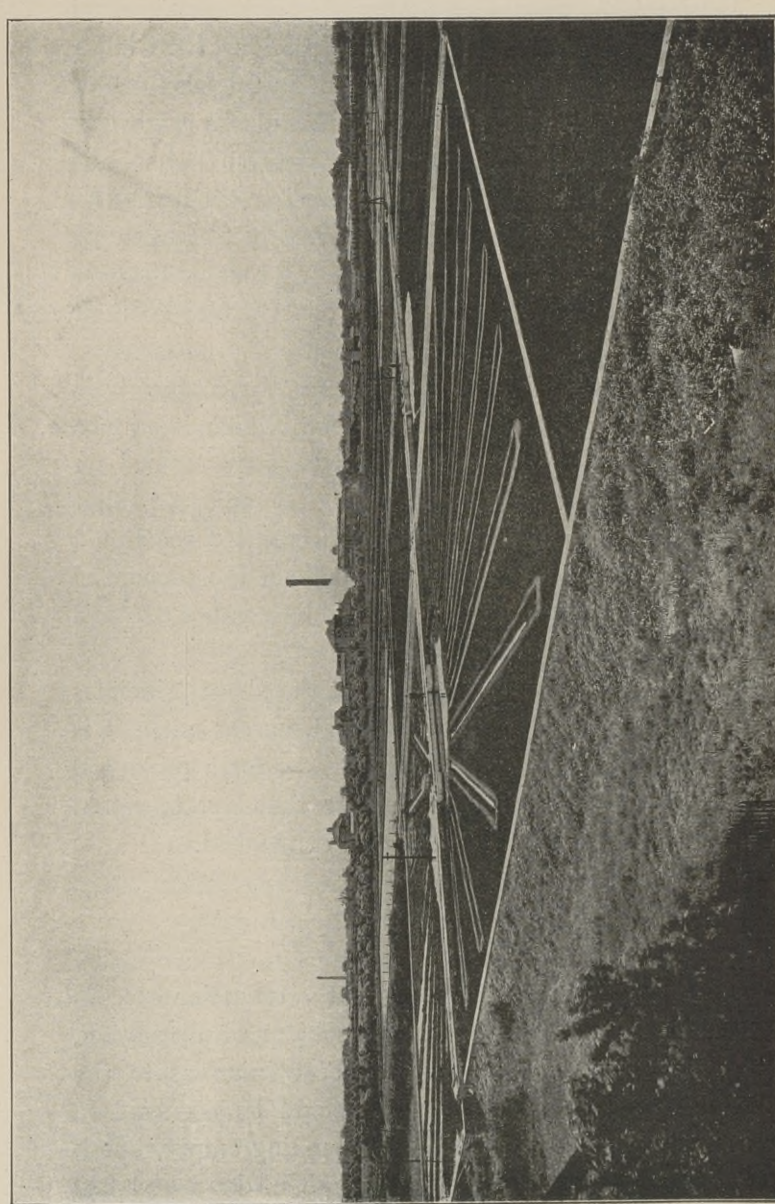

Fig. 32.—Contact Beds at Manchester Sewage Works, Showing Method of Distribution by Surface Channels Formed with Fine Clinker.

(Reproduced by permission of Mr. J. P. Wilkinson, Manchester.)

aeration of the beds after each filling is essential to their success, and the time allowed for draining and standing empty should therefore be as long as possible.

The minimum duration of contact or standing full must largely depend on the quality of the sewage and the nature of the media used for filling the bed, since a sewage containing a large proportion of trade waste may take longer to oxidise than ordinary domestic sewage, while it is also evident that the use of fine material may result in effecting considerable purification by the percolation of sewage through the media in the actual process of filling, especially when it is evenly distributed over the surface; whereas the sewage contained in the large interstices of coarse material may remain unaffected by the bacteria in the bed for a considerable time.

In the case of Manchester, where the filtering media consists of furnace clinker, the duration of contact is usually about one or two hours, this being found to give the best results, and although it by no means follows that this is the best for all circumstances, it may be taken as a rough guide in the absence of experimental data, which should be obtained under the peculiar conditions of each particular case whenever this is possible.

In order to allow as much time as possible for contact and aeration it is desirable that the beds should be filled and emptied quickly, and as the time occupied in filling a bed depends on its capacity in relation to the total volume of sewage treated, it has been found convenient to limit the size of each bed, so that its water capacity does not exceed, say, two hours' average dry weather flow of sewage, though, as previously mentioned, in the case of large works such as those at Manchester, the largest beds now being constructed do not exceed half an acre, and the dry weather flow is usually sufficient to fill several of these beds in one hour.

In order to reduce the time required for filling the sewage is sometimes stored in tanks or measuring chambers until a sufficient quantity has accumulated to fill one bed, but this arrangement necessarily requires additional fall equal to the depth of the tank.

The time required for emptying contact beds is naturally governed by the size of effluent outlet and the readiness with which the filtering media can be drained when the outlet valve is opened, so that in order to avoid curtailing the time available for aeration the underdrains and outlet from contact beds should be far larger than those required for continuous percolating filters of the same capacity, and the time required for draining should be reduced as far as possible by the use of fairly large sized filtering media, in which the liquid will not be held up by capillary attraction.

Apart from the process of draining which may continue during the period of aeration, it is evident that if contact beds are to be worked three times a day with an 8-hour cycle they must have a total water capacity equal to one-third the maximum volume of sewage to be treated, and if the outlet valves and underdrains are to be capable of emptying each bed in, say, one hour, then the total discharging capacity must be equal to eight times the rate of flow representing the maximum volume to be treated.

It has already been pointed out that it is only by adequate aeration that the efficiency of bacteria beds can be maintained, and whatever cycle of operation is adopted, the aim should always be to make the period of aeration as long as possible, thus giving the bacteria time to thoroughly decompose all the organic impurities left in the bed after each filling, and providing them with an ample supply of air, without which their oxidising action is impeded.

It is for this reason that, although the number of fillings may vary from one to three per 24 hours, according to the rate of sewage flow, the time allowed for filling, standing full, and emptying should, if possible, be fairly uniform, the variation being made in the time allowed for aeration; and assuming that two hours' contact is found to be sufficient, while the filling and emptying each take one hour, the time available for aeration will be 20 hours out of the 24 with one filling, 16 hours with two fillings, and 12 hours with three fillings per day.

Since the efficiency of contact beds is so very largely dependent upon the precision with which they are filled and the relative duration of the periods of time occupied by filling, standing full, emptying, and aerating, it is of the greatest importance that no irregularity should occur in the opening and closing of the valves provided to control the inlet and outlet, and as the expense of keeping a man constantly on the spot for this purpose is considerable, especially in the case of small places, the advantage of some automatic arrangement as a substitute for manual labour is obvious; though the design of such apparatus presents some difficulty, not only on account of the mechanical details but also because it is required to work in accordance with varying conditions which cannot be prescribed beforehand, since they depend upon the weather and flow of sewage.

So far as the Author is aware the first automatic apparatus which was designed to meet this difficulty was that installed by Mr. Cameron in connection with the experimental contact beds at Exeter, and since adopted at a number of other places where the automatic control of contact beds was required.

The gear referred to is designed for the automatic regulation of the supply of tank effluent to and the discharge of the filtered effluent from a group of four contact beds, so that each in rotation passes through a regular cycle

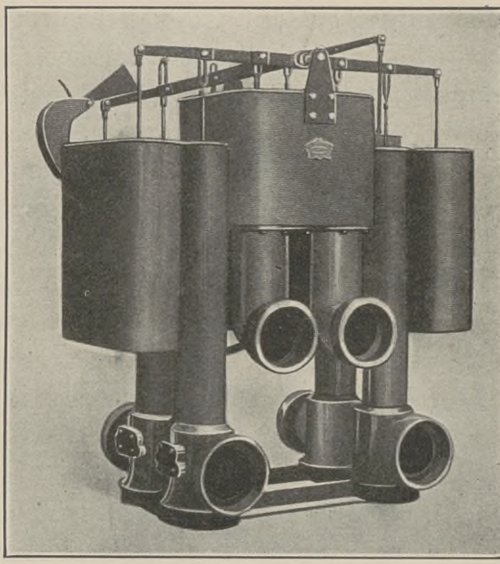

Fig 33.—Cameron's Alternating Gear for Filling and Emptying Contact Beds.

(Reproduced by permission of The Septic Tank Co., Ltd., Westminster.)

of filling, contact, emptying, and aeration without attention.

The arrangement of this gear is shown in Fig. 33, in which it will be observed that each inlet and outlet valve is attached to a lever, the ends of which are alternately raised and lowered by floats in chambers connected with the next bed, so that the inlet and outlet valves of each contact bed are thereby opened and closed in succession.

The method of operation will, however, be more readily understood by reference to the diagram, Fig. 34, in which the various connections are merely indicated by straight lines, and it should be noted that the inlet and outlet valves of each filter are attached to the levers on opposite sides of the fulcrum A B. The lever controlling the valves of beds 1 and 2 is actuated by the floats connected with beds 3 and 4, while the lever controlling beds 3 and 4 is actuated by the floats connected with beds 1 and 2, so that while each bed is standing full in rotation, the float connected with it holds open the inlet valve of the next bed and the outlet of the last, all the other valves remaining closed, thus :—

When Contact Bed No. 1 is full.

Inlet 3 and outlet 4 opened by float 1 rising.
,, 1 ,, ,, 2 closed ,, ,, 4 sinking.

When Contact Bed No. 3 is full.

Inlet 2 and outlet 1 opened by float 3 rising.
,, 3 ,, ,, 4 closed ,, ,, 1 sinking.

When Contact Bed No. 2 is full.

Inlet 4 and outlet 3 opened by float 2 rising.
,, 2 ,, ,, 1 closed ,, ,, 3 sinking.

When Contact Bed No. 4 is full.

Inlet 1 and outlet 2 opened by float 4 rising.
,, 4 ,, ,, 3 closed ,, ,, 2 sinking.

Typical 8 hours' Cycle assuming a Uniform Rate of Sewage Flow.

Method of Timing Contact.

Hours.	Full.	Filling.	Empty.	Emptying.
From 2 till 4	No. 1	No. 3	No. 2	No. 4
,, 4 ,, 6	No. 3	No. 2	No. 4	No. 1
,, 6 ,, 8	No. 2	No. 4	No. 1	No. 3
,, 8 ,, 10	No. 4	No. 1	No. 3	No. 2

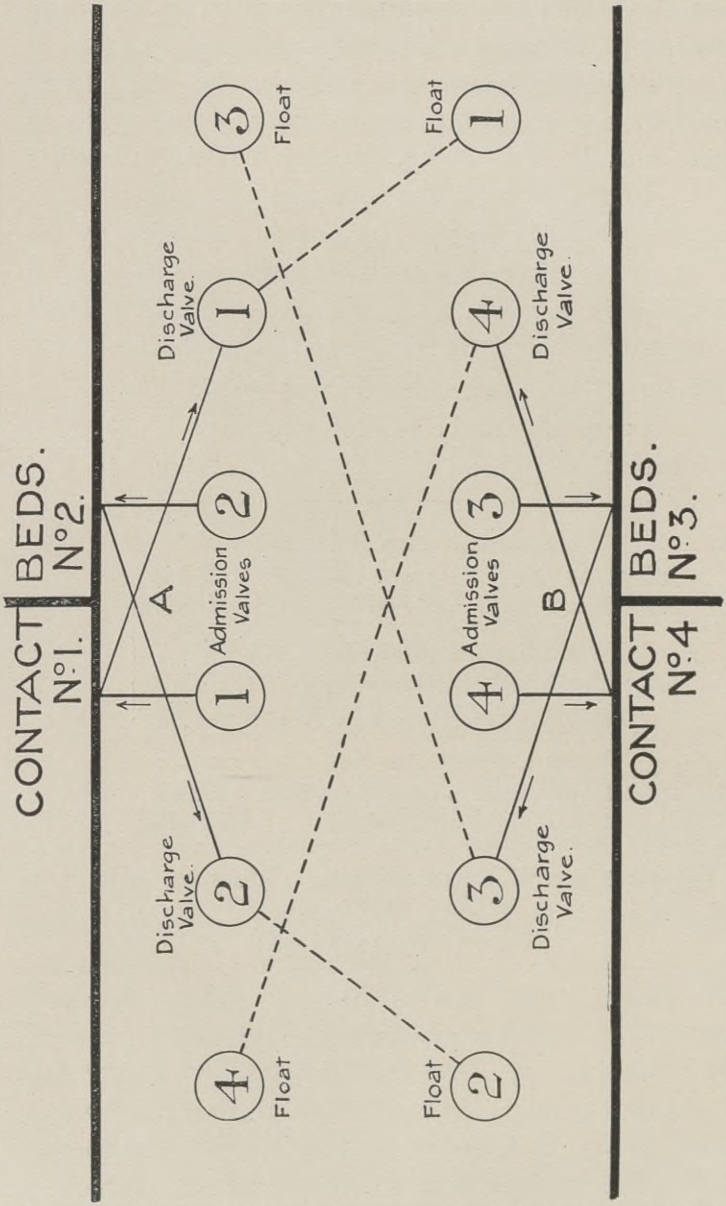

Fig. 34.—Diagram Illustrating Action of Cameron's Alternating Gear for Contact Beds.

(Reproduced by permission of Messrs. Willcox & Raikes, Westminster and Birmingham.)

In order to facilitate erection it is usually found convenient on small works to construct the whole of the gear in such a way that it can all be fitted together before delivery, as shown in Fig. 33, and from this it will be seen that the

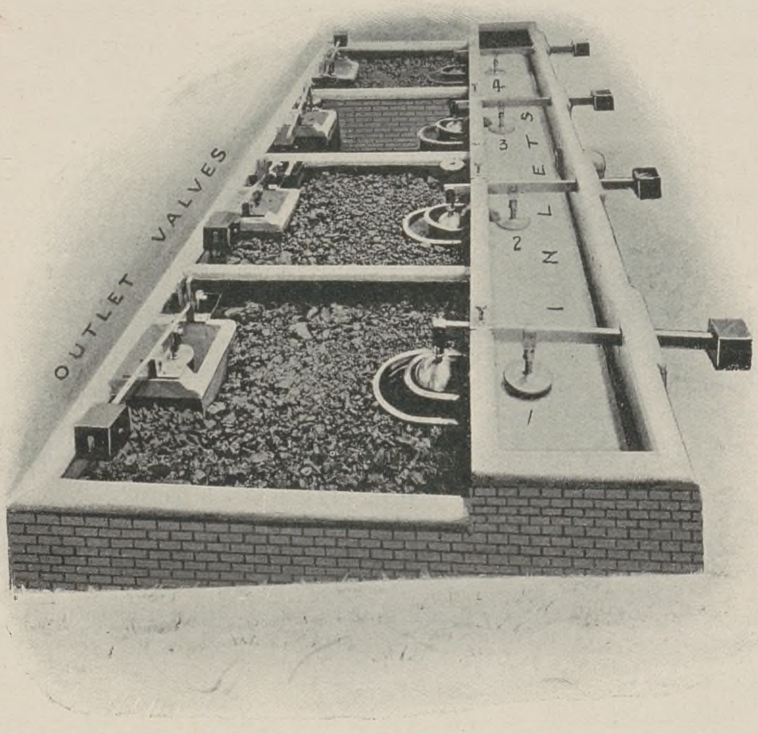

Fig. 35.—Birch Killon's Automatic Valves for Filling and Emptying Contact Beds.

(Reproduced by permission of Messrs. Birch-Killon & Co., Manchester.)

tank effluent is delivered into a shallow basin, in the bottom of which the four inlet valves are placed, while the outlet valves are fixed at the bottom of four cylindrical wells at a level below the floor of contact beds, so that these may be completely emptied when the outlet valves are opened as above described.

These four cylindrical wells also act as supports for the iron basin containing the inlet valves, and the float chambers being bolted to the sides of the discharge well of each bed, these can be easily connected with the corresponding float chamber by a short length of wrought iron tubing, so that the lever is automatically raised and lowered by the float each time the bed is filled and emptied, thereby operating the valves in the other beds in the manner already described.

Another type of apparatus used for the automatic operation of contact beds is that illustrated in Fig. 35, and the essential principles involved are somewhat similar to those described above, though it should be explained that the floats consist in hollow bells, and the float controlling the inlet valve to each bed is held up by the sewage or by the pressure of air confined under a dome in the adjoining bed until it is released by the discharge of sewage from that bed, or in the case of large installations by a small escape cock on air pipe, which is automatically opened when the bed is full, thus allowing the float to sink and so closing the inlet valve, the inlet to the next bed being simultaneously opened in the same way as the first.

The outlet valve of each bed is also opened and closed by a lever and floats in a chamber connected with one of the adjoining beds, though in case it is desired to have a fixed period of contact the float chamber may be filled through a small syphon pipe from the bed in which it is placed, the rate of discharge through the connecting pipe being adjusted by a small cock so as to give any period of contact desired. When the float chamber is full the main float is raised, and thus opens the outlet valve which empties the contact bed, and the contents of float chamber are also discharged by running back through the syphon feed pipe to the main outlet valve, which is held open by a second float near bottom of float chamber until the latter is empty.

Fig. 36 shows another apparatus in which the inlet of each bed is controlled by air pressure, but in this case

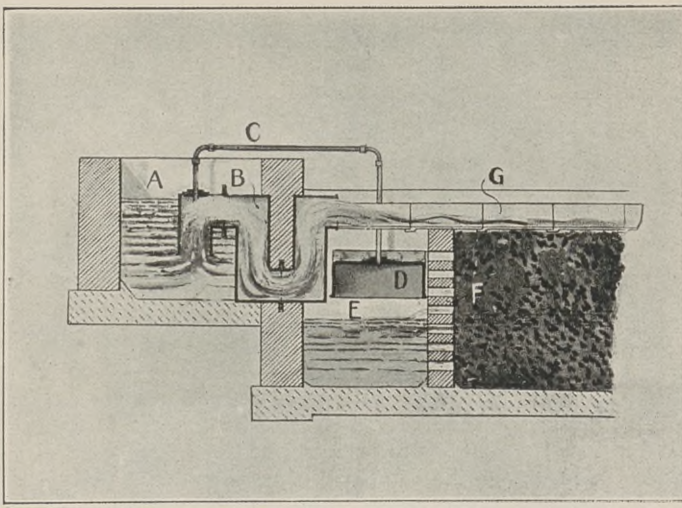

Fig. 36.—Section of Air Lock Syphon Discharging Sewage on to Contact Beds when Air Lock is Released.

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syphons are substituted for valves and levers, the passage of sewage through the inlet syphons being stopped by the air forced into them through the dome in the bed with which they are connected becoming submerged. Each inlet is also connected by a small air pipe to a similar dome in another bed, so that when this second bed is filled, the air confined under this dome forces the seal or air lock and again brings the first inlet into action.

The outlet syphons shown in Fig. 37 are enclosed in small chambers, and as they do not come into action until the chamber is full a fixed period of contact can be secured by regulating the small cock on pipe through which the chamber is filled from the contact bed. The syphons should, how-

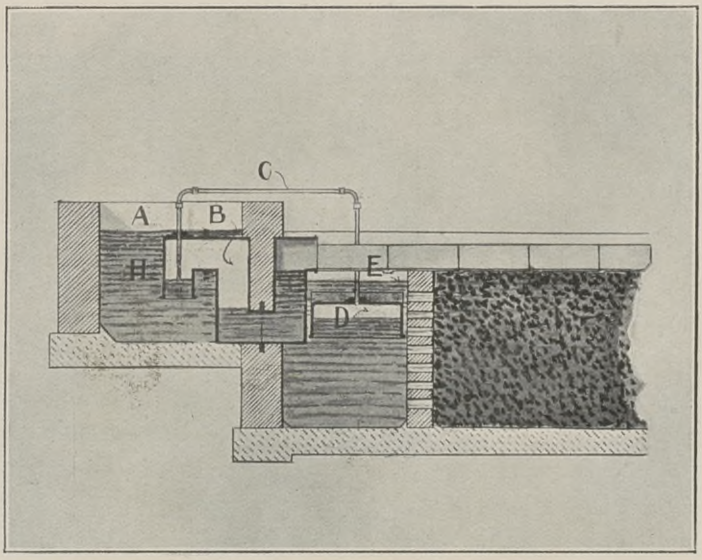

Fig. 36A.—Section of Air Lock Syphon, Showing Discharge Stopped by Pressure of Air Confined under Dome.

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ever, remain in action until the bed begins to fill again, thus permitting the complete drainage of the bed.

There is still another method of operating contact beds automatically which should be mentioned, since it is in practical operation at a number of places, though in a slightly different form to that shown in Fig. 38.

In this apparatus the inlet and outlet valves are opened by levers and counterbalance weights consisting of hollow iron cylinders or drums, the weight of which is increased by their becoming filled with sewage until they are heavy enough to open the valves to which they are attached, and the valves are again closed automatically directly the contents of the control cylinders are discharged.

Assuming that bed No. 1 is just full, the sewage overflows

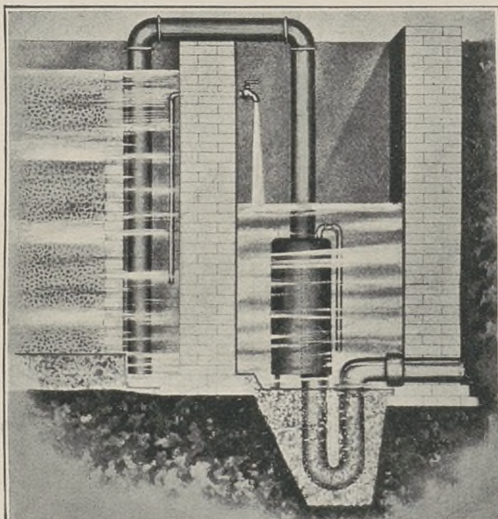

Fig. 37.—Automatic Syphon for Emptying Contact Beds.
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through a small pipe connected to the counterbalance cylinder controlling inlet to bed No. 2, which is thus opened automatically, while the sewage in bed No. 1 will remain in contact until a certain depth (say about 9 inches) has been reached in bed No. 2.

At this depth the sewage again overflows from bed No. 2 through a small pipe connected to the counterbalance cylinder controlling the outlet of No. 1, which is thus opened

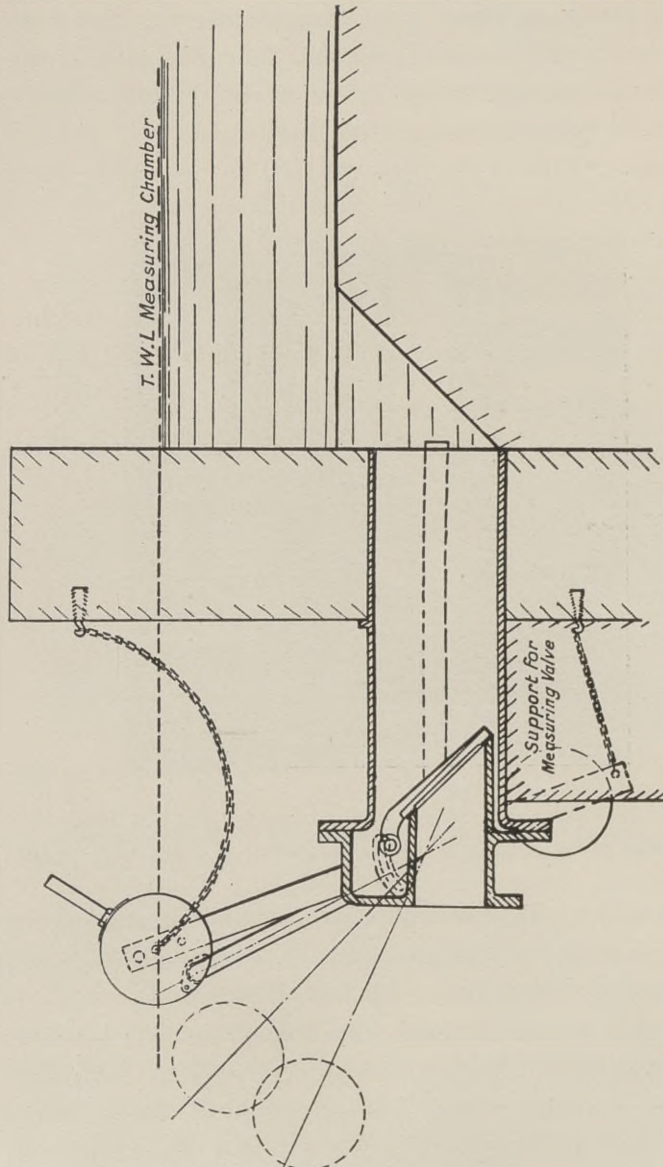

Fig. 38.—Section of Automatic Balanced Valve for Filling or Emptying Contact Beds.

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and the contents of the bed discharged, this main outlet valve remaining open until bed No. 2 is filled to within about 6 inches of the top, when the contents of control cylinder is allowed to escape to the drain through a small valve which is opened by an ordinary float and lever such as those previously described, and the main outlet valve of bed No. 1 then closes, as the weight of the empty cylinder is not sufficient to hold it open.

When bed No. 2 is full the contents of the cylinder controlling the inlet valve are also allowed to escape, so that the valve is closed in the same way while the inlet to No. 1 or some other bed in the same series is opened by the sewage overflowing into the control cylinder from bed No. 2.

From the above description of automatic apparatus it will be observed that the automatic control of contact beds is in most cases effected by making the duration of cycle for each bed directly dependent upon the rate of the sewage flow, but this being necessarily variable, this method of control cannot be considered so satisfactory as a system in which a fixed time is allowed, and with any apparatus having many joints and working parts exposed to corrosive action it seems inevitable that the cost of the repairs and adjustments necessary to keep the gear in working order and the valves watertight will place it at a disadvantage when compared with an apparatus in which all moving parts are eliminated as far as possible.

With regard to the variation in period of contact resulting from changes in rate of flow of sewage, it may be observed that this might possibly be an advantage if the shortest contact occurred when the sewage was most diluted, but under ordinary conditions it is usually found that at the beginning of a storm, when the volume is very much increased, the sewage contains so much foul washings from streets and other surfaces that its strength is not very materially altered, and Dr. Fowler stated in his evidence before the Royal Commission that in dry weather the maximum flow coincides with the strongest sewage.

The only practicable means of meeting this difficulty appears to be by some such arrangement as that adopted at Barrhead, near Glasgow, where the flow from the tanks

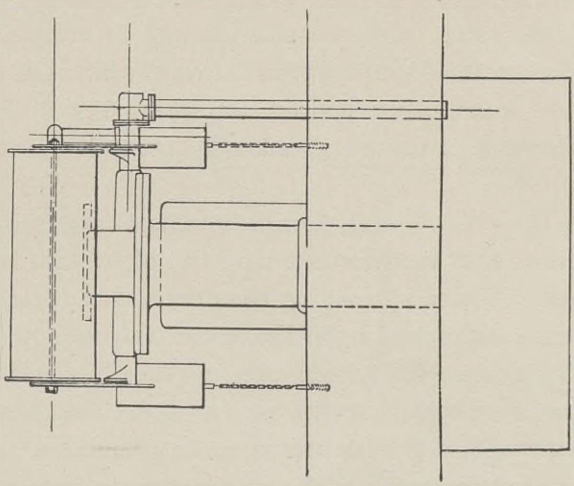

Fig. 38A.—Plan of Automatic Balanced Valve for Filling or Emptying Contact Beds.

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to the filters can be automatically regulated by means of modules, so that whenever the volume of sewage discharged at the works exceeds the ordinary capacity of the contact beds it may be stored in the septic tanks, and by passing the tank effluent through the contact beds at a rate slightly in excess of the average rate of sewage flow, any accumulation that may occur in the tanks when the flow of sewage exceeds the average is reduced when the flow falls below the rate at which the tank effluent can be discharged on to the contact beds.

As a result of recent experiments, it appears, however, that the rigid adherence to a fixed period of contact is not so essential as was at first supposed, and in another portion of his evidence before the Royal Commission, Dr. Fowler stated "that experiment has shown that the purification effected depends rather upon the amount of filtered effluent dealt with per unit of area than upon the length of cycle employed, two short cycles and one long one in the 24 hours sometimes giving better results than three cycles of equal duration." Variations in the rate of flow can thus be dealt with, and in cases of large increase in rate of flow the rate of working the beds may be temporarily increased without ill-effects.

The effect of each contact may be roughly said to result, as a rule, in removing about 50 per cent. of the dissolved impurity contained in the liquid turned on to it, so that the actual amount of purification accomplished in the second bed is half that in the first; and it has been found that whereas the results obtained from single contact do not in most cases come up to the standard usually required for final purification, the further purification resulting from the second contact may be actually more than is really necessary, and in such cases it has been found economical to only treat a portion of the sewage by double contact, and to mix the effluent so treated with that from the single contact, the resulting mixture being found to be materially better than if the whole of the sewage was treated by single contact alone; and when the correct proportions have been determined by actual experiments this method of working may result in a very material saving of cost owing to the reduced area of contact beds required, and in some instances it may be the means of utilising a site for the works, the extent of which might otherwise have been inadequate.

As an alternative to treating a portion of the sewage by double contact and mixing the effluent as above described the same object could doubtless be attained by working the second contact beds at a somewhat accelerated speed, as the amount of purification which they are required to accomplish is very much less than that which takes place in the first contact.

Apart from the question of capacity, it is also desirable to consider the most efficient depth for contact beds, and although, on the ground of economy alone, a given capacity can be most economically obtained by constructing the beds as deep as the fall available will permit, it has been found that the difficulty of securing thorough aeration is much greater in deep beds than in shallow ones, and as a result of Mr. Cameron's experiments at Exeter, as well as numerous observations made elsewhere, it is now generally agreed that the maximum depth should not exceed 4 feet, unless there is some exceptional reason to the contrary, and where this depth cannot be obtained it is fair to assume that equally good or even better results may be secured by the use of still shallower contact beds, provided their water capacity is the same, though it must obviously cost more to construct shallow beds than deep ones of the same cubic capacity.

The time required for a contact bed to mature appears to be very variable, as it has been estimated by different observers at anything from six weeks to six months, and in some cases it has been contended that bacteria beds once started, if properly worked, should go on improving indefinitely; but such wide discrepancies between the observations made at different places are, no doubt, chiefly due to the variation in the quality of the sewage as well as the material used for the filtering media, and where such observations are made in the summer the period found to be necessary would be less than that required during cold weather in winter, but satisfactory results can very rarely be obtained, and should not be expected for a little time after the contact beds have been put into operation or until the bacteria have had an opportunity of developing.

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CHAPTER VIII.

Percolating Filters, alternative Methods of Construction and Working.

Shape and size—Levels of site—Above or below ground—Fall required—Walls—Floors—Underdrains —Aeration—Feeding Constant *v.* intermittent—Rate of filtration—Distribution—Clogging—Effect of varying depth—Suspended matter in effluent.

Before proceeding with the design of percolating filters, the local conditions relating to the site require even more careful consideration than in the case of contact beds, especially in regard to the fall available, as the determination of the most convenient shape and size is largely governed by the method of distribution to be adopted, and the efficiency of percolating filters depends to a great extent on their depth in relation to surface area instead of their cubic capacity only.

The various alternative methods of distribution will be dealt with fully in the next chapter, at the end of which a brief summary is given of the conditions most suitable for the different systems now in vogue for discharging the tank effluent on to the surface of the filtering media.

In cases favourable to fixed distributors these may be used on filters of practically any shape, though the fact that the distributing pipes or troughs are most conveniently arranged in parallel lines usually results in the adoption of a rectangular plan wherever practicable in preference to any other shape. On the other hand, where any form of rotary

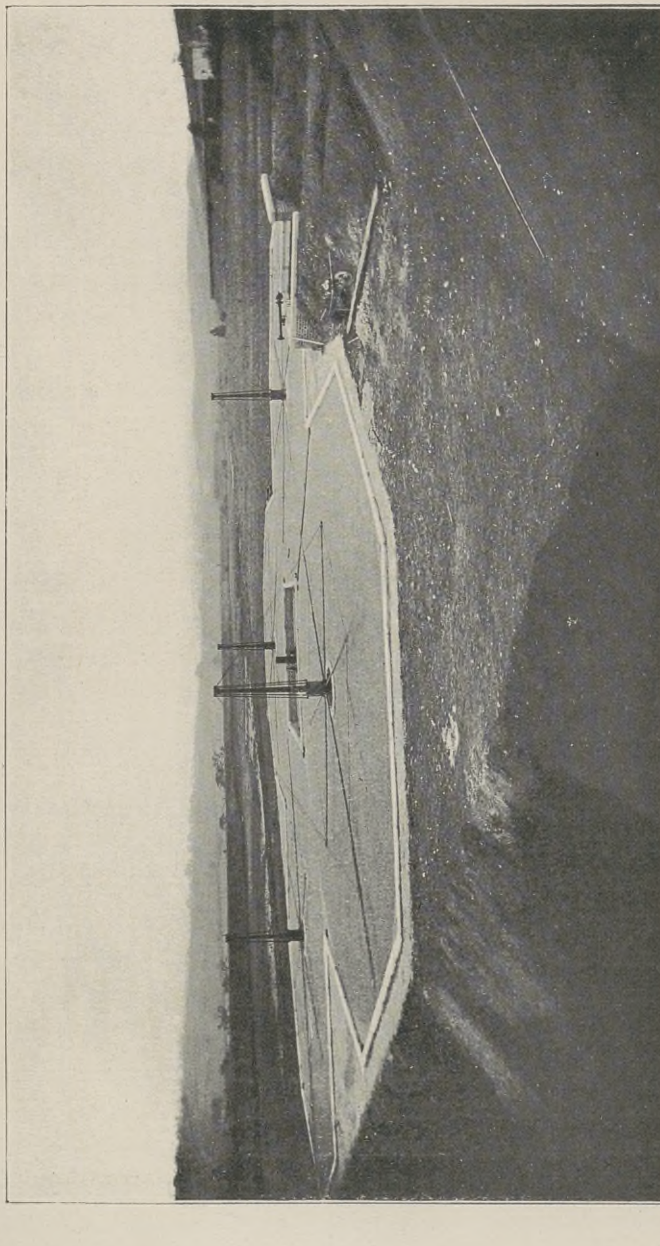

Fig. 39.—Four Octagonal Filters at Leek, Staffordshire, Fitted with Rotary Distributors.

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distributor is adopted, the shape of the filter should be approximately circular in plan in order to avoid wasting any portion of the area through its being beyond the reach of the distributor.

A square filter is unsuitable for such distributors, since about 20 per cent. of a square is outside the circle contained in it, but it will be seen from Fig. 39 that this objection does not apply with the same force to an octagonal plan, as the proportion of waste space in the latter, outside the enclosed circle, is comparatively small, and when a group of filters are built together this shape involves some economy in construction of walls, since a portion of them can be omitted between contiguous filters, whereas with circular beds each must be completely enclosed with an independent wall.

In some cases when the space available for the construction of works is limited, it is not only important to utilise every portion of the filters themselves, but also to avoid wasting ground by constructing them in too many independent units with considerable spaces intervening, as in the case of circular filters.

This waste can be most readily obviated by the adoption of rectangular filters in large blocks without any division walls, as shown in Fig. 40, and this method of construction is now generally recommended for large works, especially when power-driven distributors are to be used with a view to securing the highest possible efficiency from the area of filter put down.

Having determined the shape of the filters the next point to be considered is the question of levels, and it is on these that the suitability or otherwise of a site for sewage disposal works usually depends, as the cost of construction may be enormously increased when it becomes necessary to raise the floors of filters above ground, as in the case of the Chester works, or to construct them at any considerable

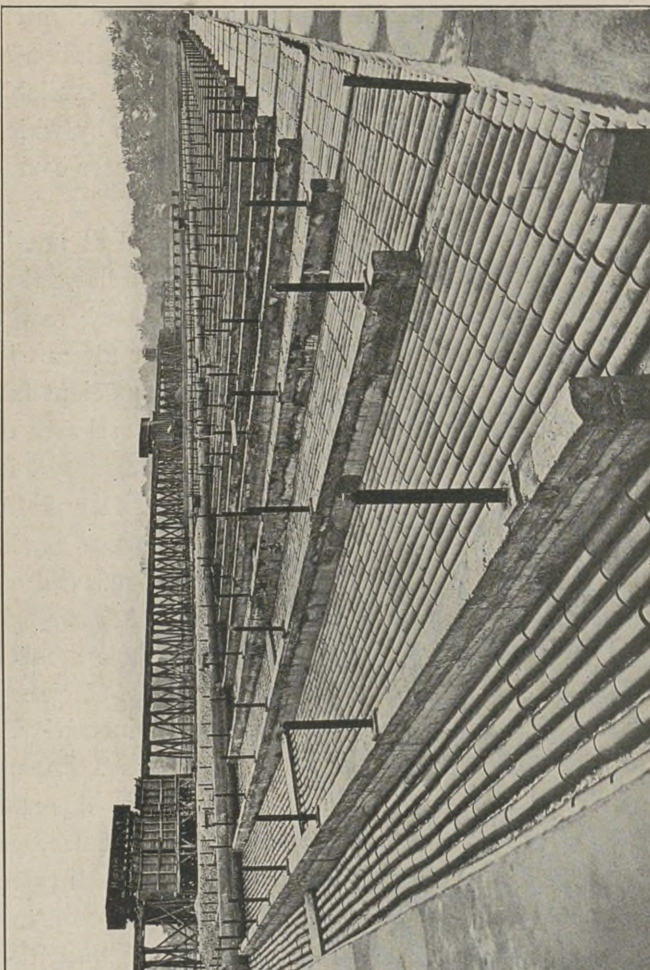

Fig. 40.—Percolating Filters in Course of Construction at New Sewage Works for Columbus, Ohio, Showing Under-Drains and Supports for Fixed Distributors.
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depth below the surface, while the extra expense involved by securing a sound foundation on treacherous ground for any kind of constructional work may frequently render it advisable to pay a higher price for the land if a more suitable site can be obtained elsewhere.

Assuming, however, that a site has been definitely selected, then the level of the proposed works in relation to the ground will be governed chiefly by the fall available between the supply carrier to filters and the pipes by which the effluent is discharged, either into a natural water course or on to land for further treatment.

If the effluent has to be discharged on to land at nearly the same level as the site of filters, it obviously follows that these must be built above ground, while in cases where the site is comparatively high, the space required for filters will have to be excavated below ground, but where sufficient fall is available it is a great advantage to divide the total area of filters into two or more sections which can be arranged in terraces one below the other, as shown in Figs. 41 and 42, so that in dry weather, when the volume of sewage is small, the effluent from the high level beds may be discharged on to the others, thus securing the highest degree of final purification, while at the same time keeping the whole area of filters in regular work, and thus avoiding the loss of efficiency which results from excessive periods of complete inactivity.

The available fall is undoubtedly by far the most important factor to be considered in designing sewage disposal works generally, and percolating filters in particular, as although the construction of shallow filters must involve increased expense as compared with deep ones of the same cubic capacity, the Author is fully convinced that the shallower beds will have a far higher degree of efficiency per cube yard than deep ones, owing to the greater facility they afford for complete aeration, so that within certain limits the depth of percolating filters may usually be reduced to suit

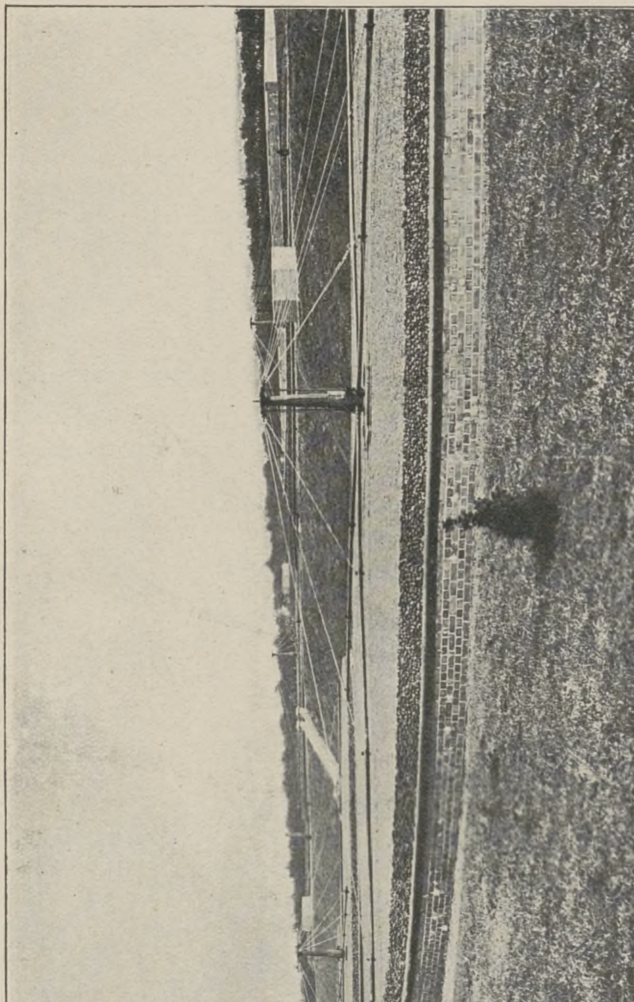

Fig. 41.—Circular Filters at Stratford-on-Avon, Showing Construction of Walls and High Level Beds in Background with Octagonal Distributing Chambers.

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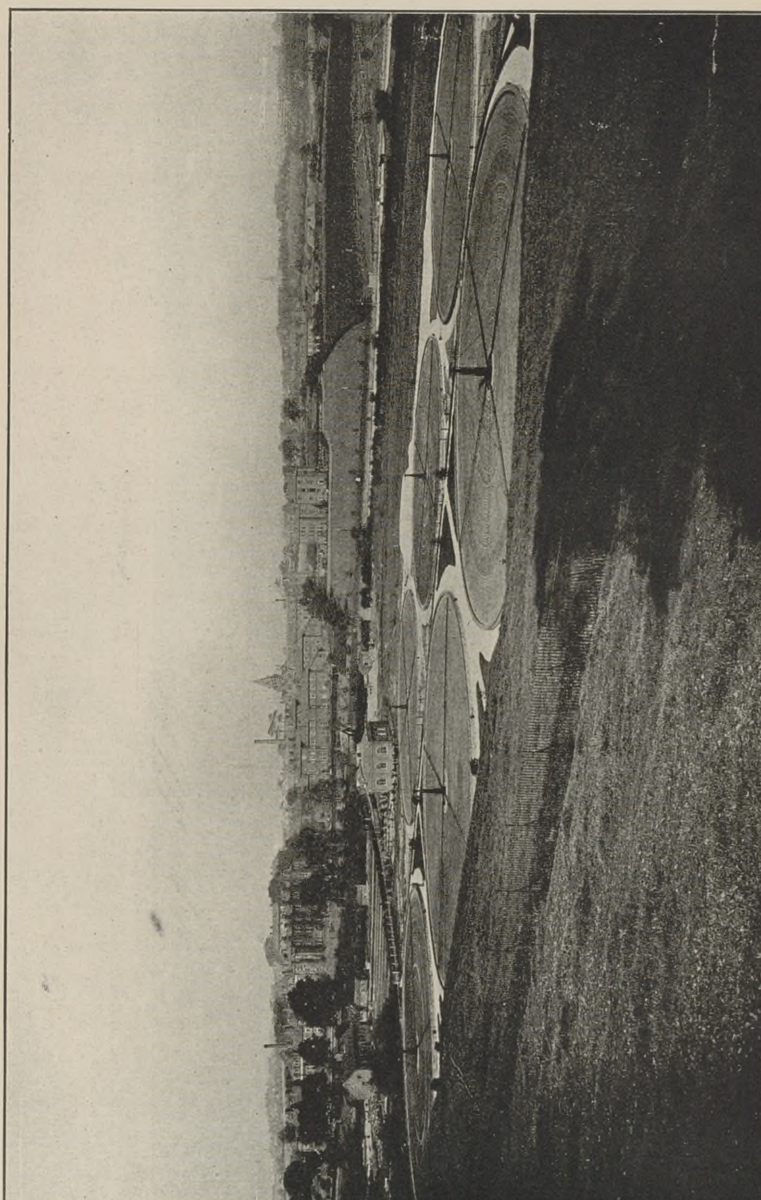

Fig. 42.—Six Circular Filters at Newcastle-under-Lyme Arranged in Two Terraces, Showing Low Level Liquefying Tanks and Pumping Station in Background.

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the local conditions when fall is limited, providing the area is correspondingly increased so as to maintain approximately the same rate of filtration per unit of capacity.

It is, however, very important to bear in mind that no matter what is the depth of filter, the minimum fall required for drainage and any particular method of distribution is practically fixed, so that although a total of, say, 8 ft. may be sufficient to permit the adoption of single filters 5 ft. deep, allowing 1 ft. for the underdrains and 2 ft. for distribution, the total depth of filtering media would have to be reduced to 2 ft. if double filtration were adopted under the same conditions, the remaining 6 ft. being required for distribution and drainage.

The relative cost of shallow and deep filters is far from being proportional to their depth, since the cost of distribution and drainage, as well as the construction of floor, are all practically proportional to the superficial area covered, so that lump sum prices per cube yard are not of much value for the purpose of comparing the cost of percolating filters unless due allowance is made for variations in depth in each case.

Since the Local Government Board's usual requirements in regard to percolating filters are based on a minimum cubic capacity, as in the case of contact beds, without regard to area, and since Local Authorities are usually anxious to meet these requirements at the least possible expense, it is only natural that deep filters should in many cases be put down in preference to shallow ones of the same capacity, especially as this course has been by no means discountenanced by the Local Government Board, who have themselves usually fixed the minimum depth of filtering media at about 5 feet, whereas in the Author's opinion better results would frequently be obtained by fixing the cubic capacity and limiting the maximum depth, especially when by so doing the filters can be arranged at two levels, so that the sewage may be treated by double filtration in dry weather, when the organic impurities are concentrated into a comparatively small volume.

Although the construction of percolating filters is different in many respects from that of contact beds, some of the questions considered in the last chapter apply equally to percolating filters, so that it is only necessary to deal here with the points which have not hitherto been discussed.

It is now generally agreed that no matter whether the filters are built above or below ground it is very desirable to provide some kind of wall with which to enclose the filtering material, as well as an impervious floor underneath it, but the necessary thickness of walls and their method of construction are open to very considerable variation according to circumstances.

Where the works are constructed entirely below the ground level it has sometimes been thought economical to dispense with the walls by merely forming the sides of the excavation to their natural angle of repose and filling in the filtering material, but this course involves a considerable increase in superficial area, and that portion of the filter which stands above the sloping sides being necessarily shallower than elsewhere, all the sewage cannot be evenly distributed over the whole surface without running the risk of some of it passing down the outside slopes without adequate purification.

If in order to prevent this no sewage is distributed on the outer portion of the filter it results in a considerable quantity of the filtering media in this part of the bed being rendered useless, so that it has frequently happened that although some saving has apparently been effected by the omission of walls, this is far more than counterbalanced by the cost of the extra filtering material required to obtain the same effective capacity. For instance, it has been found at Birmingham that if a one acre filter is enclosed with rubble walls to retain 6 feet of medium, the cost is less than half the cost of the additional work and material that would be required if the walls were omitted, though this disadvantage is of less importance in stiff clay land, where the sides of excavation can be formed with comparatively little batter.

Where walls are provided to enclose underground filters, it is evident that when the beds are filled with filtering media the pressure of this on the inside to a great extent equalises the pressure of the earth on the outside of the walls, but owing to the fact that the beds may sometimes have to be emptied and the walls have to be constructed before they are filled, it is necessary that the latter should be strong enough to sustain the weight of the earth behind them without the assistance of any internal pressure.

The ordinary rules for the design of retaining walls on the assumption that their stability depends on their weight alone are, however, hardly applicable to the short lengths of wall usually required for underground filters not more than about 6 feet deep, but it may be taken as a fairly safe rule that the thickness of the wall at the base should not be less than about one quarter of the height if constructed with good bricks or stone in cement mortar on a solid foundation, and though the thickness may be reduced in most cases to 14 ins. at the top, this is barely sufficient when the wall has to retain earth pressure up to its full height, especially if there is any possibility of the earth becoming saturated with water.

Where percolating beds are constructed above ground the walls, instead of being required to support outside pressure of the earth, are needed only to retain the filtering medium itself in position, but their adoption is usually economical, since they prevent the waste that necessarily results when they are omitted owing to the natural slope of the material, which makes the area covered by the filter considerably greater than the area of surface available for the reception of sewage.

Although this is exactly the reverse of the condition affecting underground filters, the result is the same, and since the filtering material is by far the most expensive part of their construction, it is generally found that filters without walls are more expensive than filters that are enclosed with walls having the same effective area of surface.

The thickness necessary for the walls of the filters constructed above the ground may depend to some extent upon the size, weight, or character of the filtering material which they are intended to retain, but although this is usually less heavy than consolidated earth, owing to the large proportion of air spaces, it is seldom considered safe to make brick walls of less thickness than 14 ins. at the top, with an increase of about $4\frac{1}{2}$ ins. for every yard in depth, even where good brickwork in cement is used, as there is always the possibility of the normal pressure being greatly increased by the filter becoming waterlogged, and when the top of walls has to be used as a path at a considerable height from the ground, the width of coping should not be less than 18 ins.

Although walls built at a slight angle with the vertical may be a little stronger to resist the pressure on one side only, this method of construction certainly has practical disadvantages, and is therefore seldom economical for walls up to, say, 6 feet high, but assuming there is a face batter of, say, 1 in 12, any additional increase of thickness required from the top downwards must be provided for by regular offsets on the opposite side to the batter. There is, however, no practical advantage to be gained by battered walls of the moderate height required for sewage works, and better work can usually be obtained when the walls are built without any batter.

The different types of filter walls illustrated in Fig. 43 have been selected as fairly representative of the various methods of construction adopted in actual practice at different places to suit the local conditions and materials available when the filters have to be built above ground, and as each illustration is practically self-explanatory, it is only necessary to refer to them very briefly.

(A) shows a very convenient type of wall which has been adopted at a number of places for circular filters up to about 100 feet diameter, and it possesses the advantage of enclosing the largest possible area of filter with the smallest quantity of brickwork, but neither this nor the rubble wall are designed to give any support or shelter to the distributors.

(B) is the section of a wall designed to not only retain the filtering medium, but also to carry the rail required for a travelling distributor on a rectangular filter, besides having a sufficient top width to be used as a footpath, while it was also carried down to a considerable depth below the floor of the filter to obtain a solid foundation.

(C) is a section designed for dry rubble masonry, which can be used with advantage in a district where suitable stone can be obtained at a reasonable cost, but in the neighbourhood of blast furnaces slag is usually the cheapest material available, though the pieces being of a very irregular rounded shape, it is somewhat difficult to construct a substantial wall with it unless a considerable batter is allowed on both sides, which necessarily increases the thickness at the base, and consequently requires more material than where stone or brick is used, so that this material is seldom really

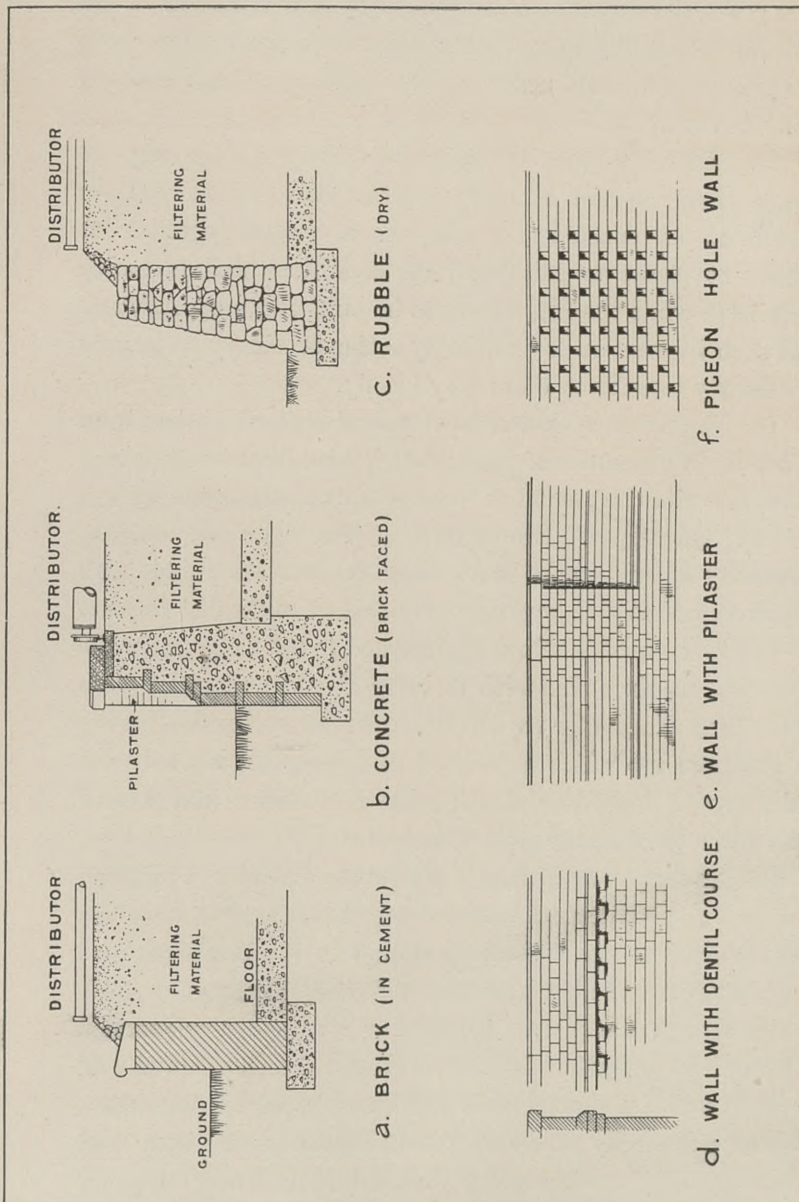

Fig. 43.—Alternative Types of Walls for Percolating Filters.

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economical, and as certain kinds of slag are very liable to crack and disintegrate when exposed to the weather, it is also somewhat unreliable as a building material.

(D) only shows a simple method of relieving the plain appearance of the perfectly flat filter walls so frequently seen, by building a projecting stringcourse about 18 inches or 2 feet below the coping, and the overhung coping also forms a wider path when there is no other convenient means of access to the filter.

(E) is an elevation of the wall shown in section above, and shows the pilasters provided for the purpose of affording additional strength when the wall is subject to the vibration caused by the distributor continually travelling backwards and forwards along the top, besides giving a little more room to pass the end of the distributor when walking along the wall.

(F) is a type of walling adopted at York, Accrington, Derby and many other places, with the double object of facilitating the aeration of the filter, while at the same time saving bricks, but this is not of much practical advantage, as the circulation of air is usually from the surface downwards, the effect of lateral ventilation being almost inappreciable even with a strong wind, and any saving in bricks is fully counter-balanced by the extra labour which this kind of work involves.

Fig. 44 shows the type of wall adopted at Derby, and a special form of brick has recently been tried for such walls, having small projections on one side with corresponding holes on the other side, so that the projections on one course of bricks fit into the holes of the next course, thus binding the whole together, and it is claimed for this system that the bricks can be laid dry without mortar, each course in a circular wall consisting in a continuous tension ring, so that it cannot fail until the bricks actually break, and the thickness can on this assumption be safely reduced to $4\frac{1}{2}$ inches for small filters, thus securing a great economy in labour and materials.

It seems evident, however, that the cost of these bricks

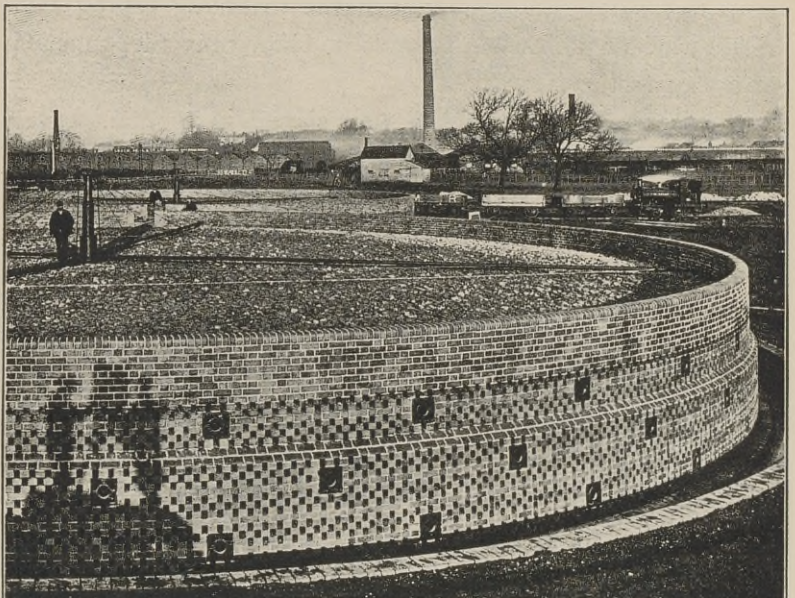

Fig. 44.—Circular Filter at Derby, Showing Pigeon-hole Wall with Ventilation Pipes and Effluent Channel.

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must necessarily be much greater than ordinary bricks, and since the tension increases with the diameter of filter, their advantage for large beds seems somewhat doubtful, while it is also clear that ordinary bricks used in the same way, jointed with cement mortar, are capable of resisting considerable tension, and when first-class workmanship can be secured the thickness of circular walls can for this reason be made less than that required for straight walls of the same height.

In cases where possible subsidence due to mining operations has to be provided for, and sometimes even when the walls are not liable to subsidence, the practice of using reinforced concrete is becoming more and more popular with a view to reducing thickness and consequent expense, and Fig. 18 shows one of several methods of construction involving the use of metal rods embedded in the concrete, which, compared with the ordinary construction, shows a very marked difference in the quantity of concrete that is required to obtain the same result in regard to stability.

It should, however, be recognised that the steel reinforcement is expensive, and where the thickness of a wall is reduced in proportion to the theoretical strength obtained by such reinforcement the stability of the structure depends almost entirely on the quality of the workmanship and materials; whereas with the ordinary form of construction, where the stability of a wall is mainly due to its own weight, the adhesion of one part to another is of less importance in resisting any tendency to failure by overturning, though it is by no means suggested that the question of adhesion at the joints of brickwork or masonry should be ignored, as this frequently forms a very valuable margin of safety.

The necessity for a thoroughly substantial and impervious floor in all bacteria beds cannot be too strongly insisted upon, as it is absolutely essential that the effluent should be drained off as rapidly as possible, and any tendency to form stagnant pools at the bottom of the filter should be carefully prevented, so that although it has for econonmical reasons been sometimes proposed to dispense with the floors, this course is almost certain to result in materially reducing the efficiency of the filter; while the admission of subsoil water at the bottom of a bacteria bed at once renders any analysis of the effluent totally unreliable as indicating the degree of purification effected as compared with other works, where no dilution takes place.

The most convenient material for the construction of floors is undoubtedly cement concrete, since it can be readily formed with a smooth surface to the required gradients, and it also lends itself to the economical construction of channels or drains for the conveyance of purified effluent after passing through the filter.

The thickness of the floor necessarily depends on the nature of the subsoil on which it is placed, but if this is fairly solid, 6 ins. of cement concrete is usually found sufficient, though where filters are constructed on made ground, this thickness may have to be increased to 9 ins. or even 12 ins., and in order to prevent cracking due to uneven settlement or mining subsidence, it may be necessary in exceptional circumstances to use expanded metal or some form of iron rods built into the concrete, for the purpose of reinforcing it and binding it together in a manner somewhat similar to that already illustrated in connection with walls in Fig. 18.

The construction of effluent drains is subject to endless variation, as may be seen from the examples illustrated in Fig. 45, showing a few of the alternative forms of artificial tile most commonly used for this purpose, and it will be observed that while some of these constitute a false bottom over the whole floor, others are only laid at intervals so as to take up the effluent which percolates into them after running along the floor for a short distance.

The object of underdrainage in bacteria beds is not only to afford an outlet for the effluent water, but also to provide a means of drawing off the heavy carbonic acid gas which

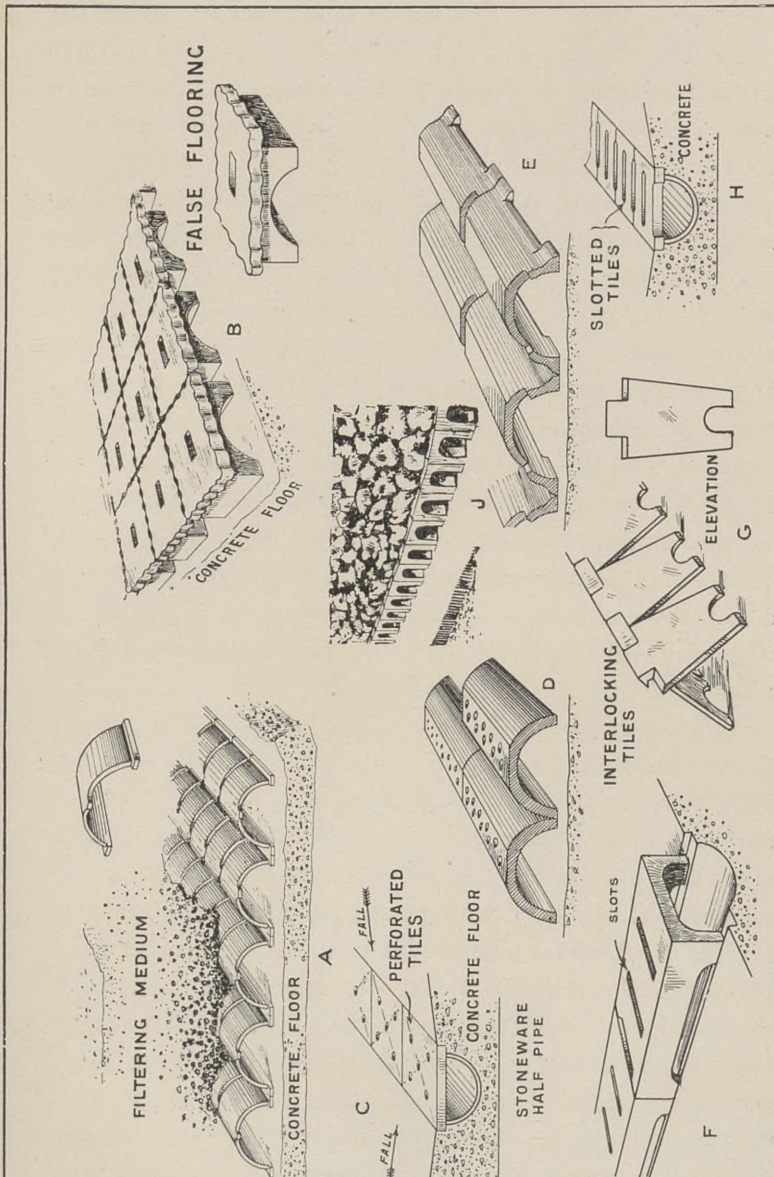

Fig. 45.—Alternative Types of Effluent Drains for Bacteria Beds.

(Reproduced by permission of Messrs. Willcox & Raikes, Westminster and Birmingham.)

is formed in the filter, and which if allowed to accumulate in the interstices of the filtering medium will prevent thorough aeration, and thus greatly impede the activity of the aerobic bacteria, good ventilation being the first essential for their efficient working.

In order to serve this double purpose, the effluent drains should certainly be far larger than the size actually required to carry off the effluent water, since a drain that is already nearly full of water is obviously useless as an outlet for carbonic acid gas, but it does not follow that the best results will be obtained by providing the greatest possible number of underdrains, so that the whole floor of the filter is covered with them, since this means that the effluent will only be flowing over the floor in a thin film, whereas with a smaller number of drains the greater depth and velocity of the water flowing in each should facilitate aeration by causing a slight current of air along the upper part of the drains, and will also tend to prevent the deposit of suspended matter at the bottom of the channel.

(B) shows a form of drainage tile which practically forms a false floor over the whole filter, but it would evidently be difficult to use this type of floor in anything but a rectangular bed, and the space under the tiles is too small to permit the convenient use of scrapers for removing any sediment that might be washed out of the filter, and which the velocity of effluent might be insufficient to remove.

(D) and (E) show two forms of semicircular tiles, which both have more space underneath than (B), but (D) is open to the objection that any dust washed out of the media is likely to accumulate between the tiles, and although this is obviated in (E) by the open space under the sides, a scraper is more likely to catch on the numerous corners so formed, especially when any of the tiles become slightly out of line.

(G) is an ingenious arrangement of interlocking tiles which dovetail into each other at the top, so that when placed in rows they form a succession of triangular ridges, but although the large openings at the side afford a free inlet for the effluent, they are so wide at the bottom that they may also allow the filtering medium to pass through, unless they are covered with a very large size material, and the same remark applies to (D) and (E), for any small particles of medium placed on these tiles would be likely to fall through the wide slots in the top of (E), while the round holes in (D) are very liable to become blocked, unless they are tapered to a larger size underneath.

(A) is another type of semicircular drain tile or false flooring, which has been used at Birmingham for several large areas of parallel-sided bacteria beds, at a cost of about 2s. 6d. per square yard laid complete, but although this is comparatively cheap for this type of flooring, it is considerably more than the cost of underdrainage by channels such as (C), (F), and (H), which are only provided at intervals of from 4 to 6 feet, instead of covering the whole floor, and since the effective depth of filtering medium must in any case be measured from the top of the tiles, the adoption of (A) does not effect any saving of fall or material.

(H) shows the type of effluent drain which has been used (6 feet apart) for about 9 acres of percolating filters at Hanley with satisfactory results, and since the slotted tiles were first made for these works, about six years ago, they should perhaps have been mentioned before the other types of drain, which have been more recently introduced, but, as in the case of (C), they leave the surface of the floor quite free to receive the filtering medium, which can thus be more easily placed in position or removed without the risk of displacing or breaking the tiles.

The space between these drains might, however, be reduced to 3 or 4 feet, instead of 6 feet, when the filtering medium is at all liable to form dust by disintegration.

(F) is designed with the object of reducing the depth of channel which has to be formed in the concrete floor for (C) and (H), but the latter possess the advantage of being equally applicable for rectangular or circular beds, and since the circular form is now so generally adopted for percolating filters, it is in many cases almost essential that the underdrains should radiate from the centre with a fall either towards the centre or the outside, though they are in some cases arranged in parallel lines to discharge into one main pick-up drain laid transversely across the centre of the filter.

It is, however, a great advantage if all effluent drains can be made accessible at both ends for scraping or flushing, especially when the filtering medium contains any considerable quantity of dust, which will find its way into the drains, and it is partly for this reason that when circular percolating filters are built above ground, it is especially desirable that the drains should radiate from the centre, and should extend through the walls.

It will also be observed that in order to economise every inch of available fall it is better to make the drains fall to an effluent chamber at the centre of the filter rather than an effluent channel round the outside; for example, assuming that the main effluent drain leaves the filter on the South side, this must in any case be low enough to give the fall required for the radiating drains under the filter, but if these discharge into an outside channel a fall must also be allowed for this from a point on the North side of the filter, opposite to the main outlet, whereas with a central chamber the length of drain from this to the main outlet is only about one-third the length of outside channel, half-way round the filter, so that the fall required is proportionately less, and this may be a matter of some importance in many cases where large filters are used and the available fall is very limited.

The gradient required for the effluent channels must necessarily depend to a great extent on their size and the depth of water which they contain, but where the filtering medium used has any tendency to disintegrate, a greater fall is advisable than under other circumstances, in order to prevent the accumulation of fine sediment causing the stoppage of the effluent drains.

In the Author's experience, it has been found that under ordinary circumstances the fall on effluent drains in percolating filters should not be less than 1 in 100, and the channels should be of such size that they would not run more than half full when the filter is working at its maximum capacity. It is also desirable that the drains should be well ventilated at the upper end, either by being carried through the outside wall or connected to an air pipe laid transversely across the upper end of the drains, and turned up with an open end above the top of the filter.

Having dealt with the details of walls, floors, and underdrains, as well as the size and shape of the beds, the next point to be considered is the best arrangement of percolating filters by which to secure the highest efficiency obtainable in each particular case; for although it has already been explained that the design of the works must in some respects be governed by the level and configuration of the ground, it almost invariably happens that several alternative plans present themselves, and it is only by fully understanding the peculiar advantages of each that an engineer can confidently select that which is best suited to the local conditions.

The first point to bear in mind is that the works should be so arranged that the operation of each unit is quite independent of the rest, so that, no matter which or how many filters are working or resting at any particular time, the total quantity of sewage to be treated during the year may be divided as equally as possible between them.

When the beds are arranged at two or more levels, so that the effluent from the higher level can be again treated on the low level beds, the latter should be fed in such a way that each can be worked in conjunction with several of the former and *vice versâ*, so that any of them may be temporarily rested without necessarily throwing a corresponding number at each level out of action at the same time.

Apart from the importance of equalising the work, it is also highly desirable that provision should be made for automatically increasing or decreasing the number of filters in operation, according to the variation in volume of sewage to be dealt with, either by working the whole of them intermittently when their full capacity is not needed, or else by arranging a series of overflows by which the sewage shall pass on to different filters in succession until their maximum capacity is reached, the surplus overflowing from one to another until they are all brought into operation during storms, while the supply shall be at once cut off from any particular bed when the flow becomes insufficient to give a fairly uniform distribution.

The first of these conditions can only be secured by feeding each filter by an independent branch direct from the main supply carrier, and, providing an accurate record is kept of the time for which each filter is in operation, there is no difficulty in equalising the work between them by regulating the valves on each branch, but in order to provide for the wide variations in the volume of sewage to be dealt with in wet weather, and at different hours of the day in dry weather, the Author prefers, and has frequently adopted, a system of adjustable bell-mouth overflows on the inlet of supply pipes to the different filters.

By this means it is a simple matter to set each inlet with the horizontal bell-mouth at a slightly different level, so that the lowest feed pipe is supplied to its full capacity before the next is automatically brought into operation, and by merely raising or lowering the bell-mouth inlet the frequency with which any particular filter comes into action can be readily adjusted, thus diverting the bulk of the work from one filter to another in rotation, while at the same time keeping them all ready for use whenever the volume of sewage reaches the maximum capacity of the whole plant, without the necessity of manipulating valves by hand whenever a storm occurs.

In order to secure satisfactory results, it is not only essential that the supply to each bed should be automatically cut off directly this falls below the minimum quantity necessary to ensure uniform distribution over the whole surface, but the bed should then be thrown out of operation until a sufficient quantity of sewage has accumulated in the supply carrier or measuring chamber to maintain efficient distribution at any rate for, say, five minutes.

This condition is usually met by one or other of the automatic syphons and other devices described in Chapters VII. and IX., and which are fixed on the supply pipe to each filter so that no sewage is admitted to the distributor until a sufficient quantity has been collected in the supply carrier or measuring chamber to keep the whole filter working uniformly for a reasonable period when the valve or syphon is automatically released.

This method naturally necessitates a fluctuating water level in the main supply carrier or measuring chamber and a corresponding loss of head, but when sufficient fall is available the syphons can be made quite efficient and automatic, while by the adoption of syphons which can be adjusted to work in rotation, the bulk of the work can also be diverted from one filter to another without difficulty, and with distribution by fixed or automatic distributors nothing further is required, as their action ceases directly the sewage is cut off.

There is, however, another point to be observed when travelling distributors are operated mechanically independent of the sewage flow, as in this case it is not only necessary to cut off the sewage but also to stop the distributor when the supply is insufficient to give uniform distribution, and for this purpose provision must be made for cutting off the motive power and the supply of sewage simultaneously by some such automatic arrangement as that adopted with the rectangular distributors at Hanley, which are described at the end of the next chapter.

A further difficulty sometimes arises in connection with filters at two different levels when it is desired to treat the sewage by double filtration up to a certain volume, but when this is exceeded to automatically supply unfiltered sewage to the low level beds, while at the same time diverting the high level effluent on to land or direct to the stream.

An ingenious method of accomplishing this is illustrated in Fig. 46, from which it will be seen that when the volume of sewage to be dealt with exceeds the capacity of the high level filters it overflows to the low level carrier or measuring chamber, where it fills a bucket acting as a counterpoise, by which the outlet valves on high level effluent drains are automatically closed, while the carrier to low level filters is supplied with the unfiltered sewage overflowing from the

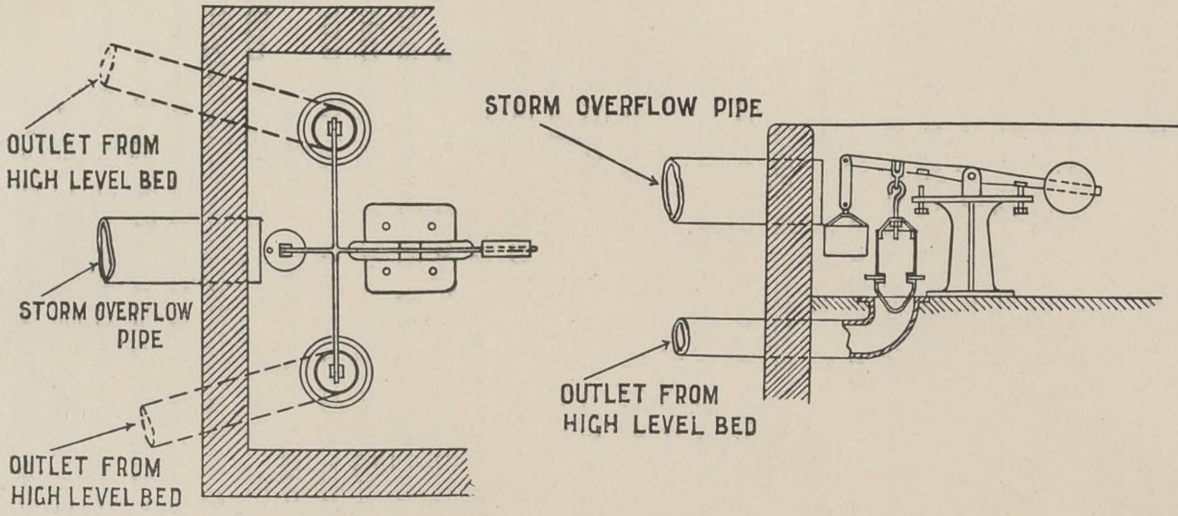

Fig 46.—Automatic Separator for Diverting High Level Effluent from Low Level Filters when the Latter are Required for Storm Water.

(Reproduced by permission of The Patent Automatic Sewage Distributors, Ltd., London.)

high level, the high level effluent gradually backing up in the effluent drains until it rises to the bye-pass pipe leading direct to the stream.

Before leaving this subject of feeding bacteria beds it should also be observed that pipes working under pressure as inverted syphons are almost always preferable to open channels or carriers, especially when they are used for the conveyance of septic tank effluent, not only on account of the possibility of smell from the latter, but also owing to the loss of fall represented by the depth of sewage in the carrier, which can be avoided by the use of inverted syphons, while with a system of pipes the pressure is equalised throughout, and is therefore available to overcome the resistance due to inequality of friction at any particular point without waste of fall where it is not required.

It may also be noticed that the operation of bacteria beds is very much facilitated when their number is any multiple of two for single filtration or four for double filtration, so that they may be worked in pairs or alternately, and in such cases where one measuring chamber is arranged to serve several filters with feed pipes to each at about 45 degrees with the main supply pipe, it is usually convenient to build the chamber octagonal on plan, so that the pipes need not be taken through the walls at an acute angle, and the masonry can therefore be more easily made watertight.

The Author is, however, of opinion that no method of distribution can be considered entirely satisfactory for percolating filters in which the rate of discharge cannot be automatically varied within a ratio of at least 3 to 1 without working the filter intermittently and without materially affecting the uniformity of the distribution, since it is only by this means that the filter can be operated at a rate which never exceeds that which is actually necessary to deal with the sewage flow for the time being, and it is far better to work the whole plant at a slow rate in dry weather than to have some filters working up to their maximum capacity while others remain idle.

The simplest method of securing this variable rate of discharge is by allowing the water level in supply carrier to rise and fall in proportion to the sewage flow, thus working the distributors under a variable head, which automatically increases or decreases their rate of discharge as required to suit the sewage flow.

As a result of the numerous tests which the Author has carried out with nearly all the different kinds of distributors now in use he has found that those which depend for their action on the Barker's mill principle can be so constructed that they will rotate when discharging at the minimum rate of about 150 gallons per super yard per 24 hours, with the water level in central feed pipe or tank about 4 ins. above the perforations in distributing arms.

Under these conditions the power developed is only just sufficient to make the distributor revolve in still weather, so that a slight wind causes it to stop, and in practice it is usually found that these distributors must discharge not less than about 200 gallons per super yard if they are to work satisfactorily under all conditions, and the minimum head required to give this discharge should be about 6 ins. from water level in central pipe or tank to the centre of jets.

It appears, however, that although rotary distributors can be designed to give a uniform distribution over every part of a circular filter when working at a certain specified rate, considerable difficulty arises in maintaining this uniformity of distribution when the rate of discharge is varied, partly owing to the alteration in speed of rotation, and the consequent effect of centrifugal force, but more particularly on account of the head which is absorbed by friction in the distributing arms, rendering the pressure on the more distant jets very appreciably less than on those near the centre.

For this reason it has been found that although a rotary distributor may give a perfectly uniform distribution when working at a minimum rate of, say, 200 gallons per yard, it does not by any means follow that the same distributor will give equally uniform distribution when the rate is increased by, say, 100 per cent.; in fact, it has been proved that in the case of several distributors which worked satisfactorily at 200 gallons per yard, the rate of distribution round the outside part of the filter was only 300 gallons when the head was sufficient to discharge 400 gallons per yard near the centre, so that although the average rate of filtration could be automatically increased to about 350 gallons per yard over the whole area, this by no means represented the actual rate of filtration at different parts of it, which under these conditions was far greater near the centre than at the outside of the bed.

The above difficulty may, however, be overcome to some extent by the use of distributing arms, in which some of the jets are placed at the side as usual, while others are placed at the top of the pipes, the propelling power developed by the former being sufficient to make the distributor revolve when discharging at a minimum rate of, say, 150 gallons per yard of filter with the pipes just full, so that when the discharge exceeds this rate the other jets come into action, and these can be so spaced as to correct the inequality of distribution that results from increased loss of head due to friction in pipes when the top jets are not provided, but in order to make this method efficient it is important that the perforated pipes should be fixed with a slight fall from the centre of the filter towards the outside; in fact, the inclination of the pipes should correspond with the hydraulic gradient of the sewage when discharging at the maximum rate.

Another method of overcoming this difficulty is by the use of extra compensating arms, as shown in Fig. 52, into which the sewage overflows when a certain rate of discharge is exceeded, as explained in the next chapter, but with all the perforations placed at the side of the pipes the rate of revolution, and consequently the centrifugal force, is increased approximately in proportion to the rate of discharge, so that it becomes very difficult to secure perfect uniformity of distribution combined with a variable discharge.

In considering the proper rate of filtration in any particular case, it is important to bear in mind that insufficient air and excessive feeding are alike injurious to bacteria and human beings, the fatal process of suffocation or choking being materially accelerated by the loss of appetite which immediately results from an inadequate supply of air, so that when a bacteria bed is already receiving the maximum quantity of sewage that it is permanently capable of purifying without becoming choked, any increase in the rate of filtration must inevitably restrict the air supply by filling the interstices of the media with sewage, thus reducing the appetite of the bacteria, while at the same time choking them with an increased quantity of food which cannot be consumed, and therefore accumulates until all the unfortunate aerobic bacteria are partially paralysed or completely destroyed.

In order to avoid these fatal consequences of overwork it is essential that bacteria beds should be very carefully watched when the rate of filtration approaches their maximum capacity, so that the slightest tendency to become waterlogged may at once be detected, and their efficiency restored before any permanent clogging takes place by a period of rest, which is usually an effective remedy in such cases if applied soon enough, and continued long enough, for all the media to become thoroughly aerated.

There now seems to be a fairly general consensus of opinion that with properly constructed percolating filters, dealing with ordinary domestic sewage, 200 gallons per super yard, or one million gallons per acre per 24 hours, may be taken as a fair average rate of filtration for permanent work, and though this rate may be doubled for short periods during storms without permanent injury to the filters, this variation is usually accompanied by a corresponding temporary deterioration in the purity of the effluent.

The proper depth for percolating filters is a question on which there has recently been much discussion, and not a little difference of opinion, owing to the comparison of results obtained under different conditions, but it seems clear that the depth should be governed chiefly by the peculiar characteristics of the sewage to be dealt with, while it should also depend to some extent on the size of particles used for the filtering medium, as affecting the time occupied by the sewage in passing through any given depth of filter.

In this connection it has been observed that with media from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. the sewage only travels downwards at the rate of about one inch per minute, whereas with $\frac{1}{2}$ in. to $\frac{3}{4}$ in. media this rate is doubled, and while it takes about half an hour for the sewage to pass through the standard design of fine grain Hanley filters, 4 ft. 6 ins. deep, there are many coarse grain filters in operation at other places where most of the liquid pases through the same depth in about four minutes.*

Some experiments which have recently been made by Mr. W. Clifford, at Manchester, seem to confirm the Author's observations that the time actually required for sewage to pass through a percolating filter must depend to a great extent on the quantity of liquid held up in the interstices by capillary attraction and which must be displaced before a fresh supply can pass through, though this displacement is no doubt accompanied by a considerable amount of mixing, and the time required for liquid to pass through dry filtering media is frequently double that occupied in passing through the same depth of wet media under normal working conditions.

With a view to ascertaining the degree of purification obtainable at Hanley with varying depths of filtering media, a very interesting series of observations have been made by Dr. George Reid, the County Medical Officer of Health for Staffordshire, and the results of his analysis are shown in the table on page 254.

It is evident from these results that in this case at any rate a perfectly satisfactory effluent can be obtained by filtration through one foot of $\frac{1}{8}$ in. to $\frac{1}{4}$ in. filtering medium (saggars), but it is also important to observe that these results are obtained with a power-driven distributor, described in the next chapter, which gives an absolutely uniform rate of distribution, both as regards quantity and interval of time between each dose.

The filter on which these experiments were made is 4 ft. 6 ins. deep, and has now been in constant use for about five years, at the rate of one million gallons per acre, or 200 gallons per square yard, its total area being about one-third of an acre.

* N.B.—This does not mean that all the liquid travels at the same rate.

HANLEY SEWAGE DISPOSAL WORKS.

ANALYSIS OF SEWAGE AND FILTERED EFFLUENTS.

Parts per 100,000.

Sample.	Number of Records.	Total Solids.	Solids in Suspension.	Solids in Suspension (Organic).	Solids in Suspension (Mineral).	Chlorine.	Fr Ammonia.	Albuminoid Ammonia.	Oxygen Absorbed in 4 hrs. at 80 degs. F.	Oxygen Absorbed in 3 mins. before Incubation.	Oxygen Absorbed in 3 mins. after Incubation (3 days).	Nitric Nitrogen on day of collection.	Nitric Nitrogen day after collection.	Nitrous Nitrogen on day of collection.	Nitrous Nitrogen day after collection.	Column necessary to obscure test lines (inches).
Sewage . . .	18	170·9	63·5	28·5	34·9	11·0	2·154	0·972	5·019	1·862	2·176	0·02	0·10	0·029	0·029	0·5
Detritus Tank .	13	118·1	17·0	6·8	10·1	10·0	1·643	0·486	2·726	0·975	1·095	0 02	0 09	0 014	0·022	1·6
Septic Tank. .	16	107 8	7·6	3·8	3·8	9·9	1 716	0 340	2·184	0·836	1·571	Nil.	0·09	Nil.	Nil.	1·5
Filter, 1 ft. . .	16	101·5	0·25	0·16	0·08	9·4	0·036	0·052	0·328	0·093	0 067	0·64	2·07	0·003	0·003	Over 24
,, 2 ft. . .	16	101·1	0·09	0 05	0·03	9·5	0·020	0·037	0·286	0·077	0·060	1·82	1·99	0·011	0·007	,,
,, 3 ft. . .	16	101·8	0·14	0·06	0·08	9·4	0·009	0·031	0·244	0·060	0·052	1·75	1·85	0·005	0·008	,,
,, 4·5 ft. .	16	103·5	—	—	—	9·5	0·043	0·027	0·259	0·070	0·039	1·70	1·99	0·005	0·002	,,

For the purpose of taking the samples for analysis, four shallow troughs or trays were fixed in the filter with perforated covers at depths of 1 ft., 2 ft., 3 ft., and 4·5 ft., the effluent being drawn off from each tray by a small pipe taken through the wall of the filter, and in order that the results from the lower depths might not be affected by the presence of the trays above, the trays were placed obliquely from above downwards, so that no tray had another in a vertical line above it.

It might appear from the result of this experiment that the depth of filters at Hanley is unnecessarily great, but since they have to comply with the requirements of the Local Government Board, which are based on cubic capacity alone, any reduction in depth would have to be made up by a corresponding increase of area, which would increase rather than reduce the cost, while it should also be mentioned that since these experiments were made the strength of the Hanley sewage has been greatly increased by the elimination of subsoil water from the sewers, so that it would not be safe to assume that all the purification will in future be effected quite so near the surface of the bacteria beds as hitherto.

The chief advantage claimed for coarse grain filtering media is that when the tank effluent contains a considerable quantity of suspended matter which can only be very slowly decomposed, it is better to let it pass right through the filter with the effluent, rather than allow it to accumulate in the interstices of fine media, where it will tend to reduce the space available for aeration; but with efficient preliminary treatment in tanks the suspended matter should be reduced to from 5 to 10 parts per 100,000, and if this matter is capable of decomposition by the action of aerobic bacteria, the surface layers of a well-aerated filtering medium would seem to be the best place for this to be effected.

If it is found that this surface layer becomes clogged with material that cannot be decomposed, it is a far less expensive matter to remove two or three inches at the top, as in the case of a sand filter for water, than to renew or wash the whole contents of the filter, which is very likely to become necessary if the medium is not fine enough to intercept the suspended matter near the surface.

It would therefore seem reasonable to conclude that the material used for percolating filters should either be very fine or very coarse, but it is generally agreed that the sewage should in all cases be rendered as free from suspended matter as possible by preliminary tank treatment before it is applied to bacteria beds, since these should be designed for dealing chiefly with the dissolved impurities, while the use of properly designed tanks is usually a far more effective and economical method of removing the suspended impurities.

There are cases, however, where the bulk of the suspended matter in the tank effluent is of such a stable character that it is not readily capable of oxidation, and in such cases it is claimed for coarse grain bacteria beds that they retain and decompose all the more easily putrescible matters in suspension, only allowing the comparatively inoffensive residue to pass through, and this can be easily intercepted by discharging the filtered effluent into a small settling tank, through which it passes with a sufficiently slow velocity for this suspended matter to be deposited by gravitation.

Whether the final effluent is in this way so thoroughly purified as it would be by its slower passage through a fine grain filter is open to considerable doubt, and even if the latter is more liable to become clogged, it is still possible that this disadvantage may be more than counterbalanced by the saving effected through the reduced depth of material required to produce the same degree of purification in the effluent; but a further series of experiments is now being conducted with a stronger sewage at Hanley, with a view to proving whether this is so or not, and it is to be hoped that similar experiments may be conducted at other places under varying local conditions, as no one is justified in drawing general conclusions from individual experiments in connection with sewage disposal.

CHAPTER IX.

Distribution over Percolating Filters.

Flooding surface of filter—Open troughs—Perforated iron plates —Perforated iron pipes—Jets and sprays—Barker's Mill principle—Centre joints and bearings—Regulating discharge—Turbines and waterwheels—Power-driven distributors—Adjustment of speed and discharge—Propelling power and maintenance.

Since it is becoming more and more fully recognised that the best results cannot be obtained from percolating filters unless the sewage is uniformly distributed over each unit of superficial area and the rate of its application is carefully regulated, the need for automatic apparatus for securing these conditions has been more and more appreciated, with the result that a very large number of more or less ingenious mechanical devices have been applied to this purpose. The selection of a really efficient method of distribution is therefore such an essential factor in the successful design of percolating filters that a separate chapter is devoted to explaining the mechanical principles involved and the practical difficulties encountered in the different kinds of apparatus which are in use for this purpose at the present time.

In the early experiments with percolating filters the sewage was applied to them in flushes and distributed over the surface by flooding, the top layer of media being so fine that the liquid could only pass through it at a moderate rate; in fact they were worked on much the same principle as that usually applied to downward intermittent land filters, but with the difference that the medium was specially prepared and graded.

It was soon found, however, that although very fine material on the surface had the effect of distributing the sewage, it at the same time impeded aeration, consequently impairing the efficiency of the filter, and in spite of the efforts that were made to overcome this difficulty by forcing air into the filter and providing longer intervals of rest between each dose of sewage, it was soon recognised that the distribution could be more satisfactorily accomplished by some form of fixed troughs.

The adoption of troughs certainly did away with the necessity for such a fine surface layer of material and the disadvantages which it involved, but in order to utilise the whole area of the filter the troughs had to be arranged in parallel lines at intervals of about 2 or 3 feet, and as the sewage was discharged by means of notches in the edge it was essential that the troughs should be kept perfectly level in order to get anything like uniform distribution.

Since wooden troughs gave a good deal of trouble on account of their tendency to warp, and considerable difficulty was therefore experienced in keeping them level, it was found necessary to use iron, and even then the notches required very frequent cleaning in order to keep them clear, so that the results were not entirely satisfactory, and the comparatively small area served by each trough rendered the cost of distribution by this means almost prohibitive except in the case of very small works, for which they are still used, and with the improvements recently introduced they answer the purpose well.

An improved apparatus* of this type consists in a number

* This apparatus has been patented by Mr. W. E. Farrer, of Cambridge Street, Birmingham.

of parallel iron troughs fixed about 18 inches centre to centre, which are perforated with $\frac{1}{4}$-inch holes about one foot apart along each side close to the bottom, these troughs being periodically filled by an automatic tipper, which fills up to a certain level, when the weight of the sewage causes it to fall over and discharge the contents into the troughs, from which it escapes on to the filter at a fairly uniform rate through each of the small holes in the side until the trough is empty, when the filter is allowed to rest until the tipper has again received sufficient sewage to cause its discharge.

The tipper is divided into two sections, each of which holds enough sewage to fill the troughs on one side, and as the tippers work on a horizontal pivot underneath each end, they fill and empty alternately, thus discharging into the series of troughs on either side in turn.

Although this apparatus is only an ingenious combination of troughs and tippers which had both been used independently before, it embodies a number of improvements in matters of detail by which many of the difficulties previously encountered have been overcome. For instance, springs are provided to resist the concussion due to the falling of the heavy tipper, and by means of a specially constructed pipe the whole of the sewage is discharged into the tipper that is filling without splashing over into the other, as it did formerly, when an ordinary pipe was used, and the idea of using perforated troughs instead of notches along the edge is also a decided improvement.

With a view to ensuring more constant and uniform distribution than can be obtained by troughs, especially where the available fall is not sufficient for flushing or tippers, a special form of corrugated iron sheets has been designed by Mr. F. Stoddart, so that the sewage runs from the main carrier into the small channels formed by the corrugations, and holes being cut at intervals in the top of each little ridge between these channels the sewage escapes through the holes and drops on to the surface of the filter below from a number of small points which project downwards from the under side of the channels or corrugations, thus ensuring uniform distribution over the area covered so long as the same quantity of sewage escapes through each perforation.

It is, however, very evident that to obtain this result it is essential that the corrugated sheets should be absolutely level and the holes should be kept perfectly free from obstruction by frequent brushing, so that although this system possesses the important advantage of requiring very little fall it needs a considerable amount of care and attention to maintain its efficiency, and by covering up the surface of a filter in this way an obstruction is formed to the free access of air and light which it is desirable to facilitate as far as possible.

It may also be observed that in order to discharge, say, 200 gallons per superficial yard of filter per 24 hours through about 400 perforations in these corrugated sheets, the quantity which shall escape through each hole would be only half a gallon per day, which represents such a slow rate of discharge that even when the holes are perfectly clear there is a tendency for some to take no sewage, while others give a constant trickle.

In consequence of the difficulties encountered in the use of open troughs and tippers on his early experiments at Wolverhampton, Mr. Garfield designed a system of perforated pipes which worked under pressure and discharged the sewage in fine sprays by means of small metal plates placed over each hole, so that the escaping jets impinging upon them are spread over a very much larger area than could be covered by the jet alone.

This arrangement was first installed at Lichfield about 1898, where it has been in successful operation ever since, the jets working under a head of about 7 ft., and the perforated pipes, which consisted in $\frac{3}{4}$-in. galvanised wrought iron water-tubing, were placed about 3 ft. apart with $\frac{1}{8}$-in. holes every 3 ft. of their length; each distributing pipe is connected to the main supply pipe with a small stuffing-box, so that it can be occasionally turned over by a series of levers coupled together, the spray being thus thrown out on either side alternately instead of vertically upwards, and the sewage being thereby distributed over a much wider area.

It will, however, be observed that the head of 7 ft. which is available for distribution at Lichfield is much greater than that which can usually be obtained, so that this system requires some modification to suit altered conditions, especially when a fluctuating volume of sewage has to be dealt with, or when the pressure is variable owing to the sewage being pumped direct into the distributing pipes, as in the case of Chesterfield, where the radius reached by the spray varies in proportion to the pressure at different periods of each discharge from the ejector by which the distributing pipes are supplied.

At Brownhills and Pelsall in Staffordshire fixed perforated pipes are also used with satisfactory results, but as the available head is less than a foot no attempt is made to spray the jets, and in order to obtain the greatest possible depth of filtering media this is formed into low ridges between the rows of distributing pipes, so that the jets just reach the top of the ridges, which are about 6 ins. above the pipes themselves, the loss of head being really reduced by this amount, while the surface area is increased and the aeration of the filter is consequently facilitated.

When there is a considerable variation in the volume of sewage to be dealt with at different times of the day it is either necessary to make a corresponding variation in the area of filter in use by shutting off some of the distributing pipes, or else to make their action intermittent by collecting the sewage in a flushing tank or carrier until it is full, when the contents can be automatically discharged through the distributing pipes until the tank is empty, when the discharge will cease until it is full again, thus equalising the work of the whole filter by stopping the distribution directly the volume of sewage is not sufficient to keep the whole of the distributing pipes fully charged.

Another example of fixed distributors is to be found on the works of the Birmingham Tame and Rea Drainage Board at Curdworth, where their engineer, Mr. J. D. Watson, has adopted this method for a large area of rectangular filters, the general arrangement being illustrated in Fig. 47, and this also shows details of the alternative types of sprinklers or nozzles which have been used for the purpose of spraying the sewage, instead of the metal discs referred to above in connection with the Lichfield and Chesterfield works.*

In this case the distributing pipes are 3 ins. in diameter spaced 9 ft. apart and supported on the filtering medium by means of cast iron chairs 12 ins. in diameter. The distributing pipes are formed of light iron hot-water pipe having a thickness of $\frac{3}{16}$ in. and cast with bosses spaced 4 ft. 6 ins. centre to centre, in which are fitted the brass sprinkler jets shown in illustration.

The available pressure on the jets after allowing for loss

* These nozzles have now been superseded at Birmingham by an improved pattern supplied by Messrs. Jones & Attwood, of Stourbridge.

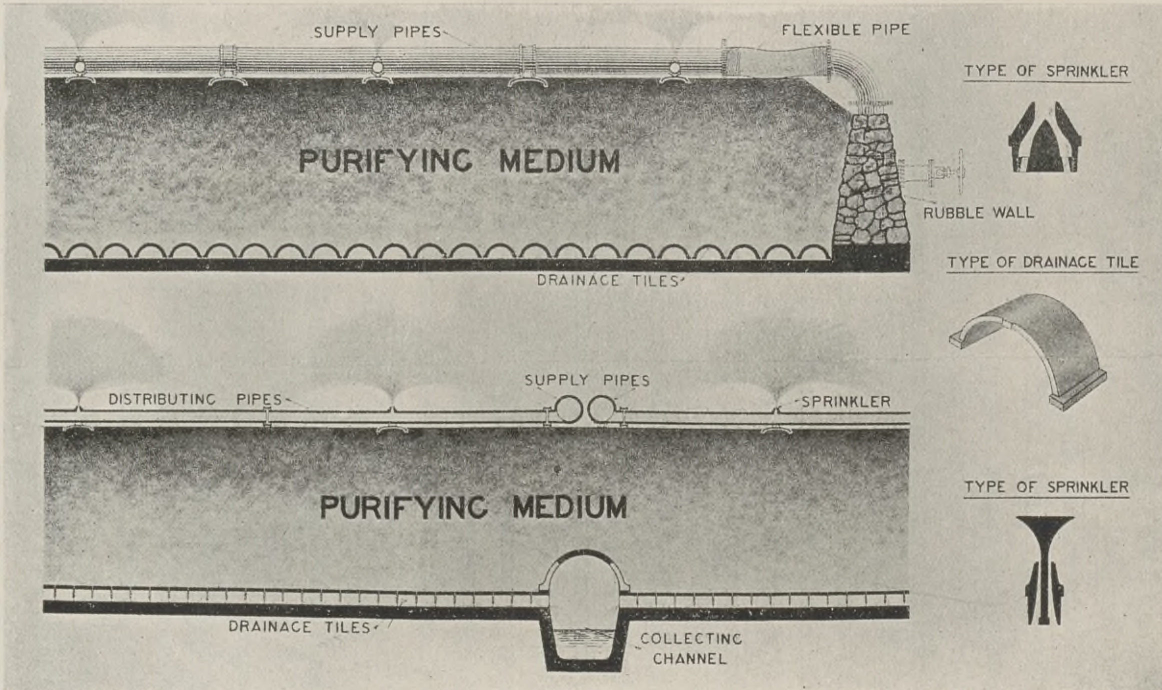

Fig. 47.—Sections of Percolating Filters at Birmingham, Showing General Arrangement of Fixed Distributors and Under-drains, also Alternative Types of Sprinkler Nozzles.

(Reproduced by permission of Mr. J. D. Watson, Birmingham.)

of head by friction is about $7\frac{1}{2}$ ft., which would give a discharge of about 400 gallons per square yard per day, but the actual rate of working is reduced to about 200 gallons or less

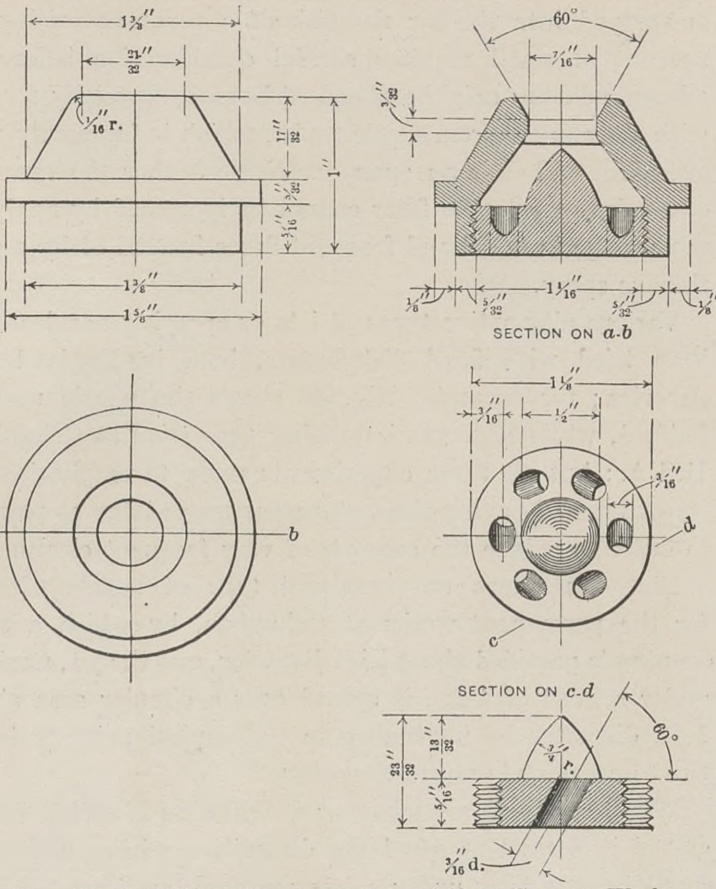

Fig. 48.—Sprinkling Nozzle used at Salford Sewage Works.

(Reproduced by permission of Mr. J. H. Gregory, Columbus, U.S.A., and the American Society of Civil Engineers.)

by partially closing the regulating valve on main supply pipe, or plugging some of the jets.

Although the above system has certain advantages over those previously described, it should be borne in mind that it cannot be successfully adopted unless a considerable pressure is available, and owing to the fact that the sewage is sprayed into the air the risk of a nuisance arising on account of smell requires careful consideration before its adoption in the neighbourhood of houses, especially for use with the effluent from septic tanks, which is frequently very offensive, and it is an open question whether the quantity of air drawn into the filter cannot be increased by applying the sewage in small and frequent doses instead of by a continuous spray.

Various alternative types of jets or spraying nozzles have been tried with fixed distributors, both in England and America; for example, Fig. 48 shows the nozzle used at Salford, while Fig. 48A is another type tried at Columbus, U.S.A.; but all these experiments seem to emphasise the importance of having the water passages as large as possible in order to reduce the expense of very frequent cleaning.

Fig. 48B shows the improved type of nozzle adopted for the permanent works at Columbus, by which a clear opening is provided about ½ in. diameter, and the jet, working under a head of 4 ft., is spread over a circular area about 7 ft. diameter by impinging on the conical point or baffle fixed immediately above the orifice.*

When the head available for distribution is under 4 feet, and it is desired to avoid the difficulties arising with very small jets working under a low pressure, good results have been obtained by the use of open troughs fixed as high as possible above the surface of filter, with holes in the bottom

* Discussion by Mr. John H. Gregory on "The Advance in Sewage Disposal." Trans. Am. Soc. of C.E., Vol. LVII., 1906, page 128.

at intervals, so that the sewage escaping from each hole may be distributed over the greatest possible surface by falling on a small concave disc (fixed under the trough), which

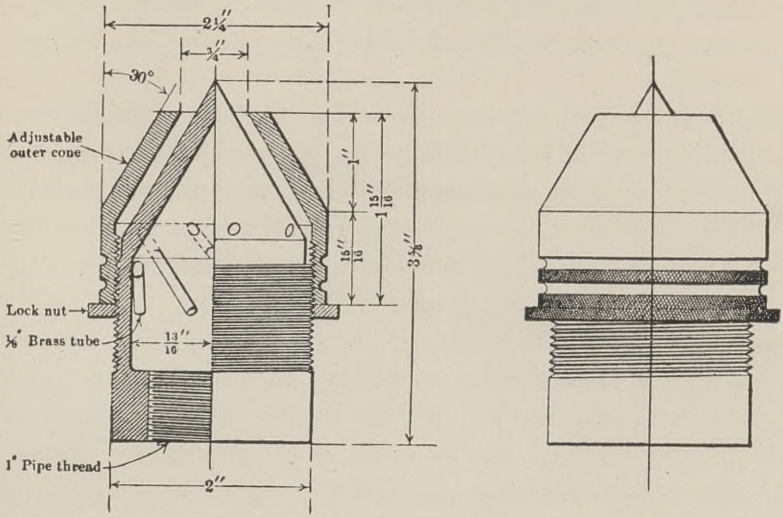

Fig. 48A.—Sprinkling Nozzle First Used at Columbus, Ohio.

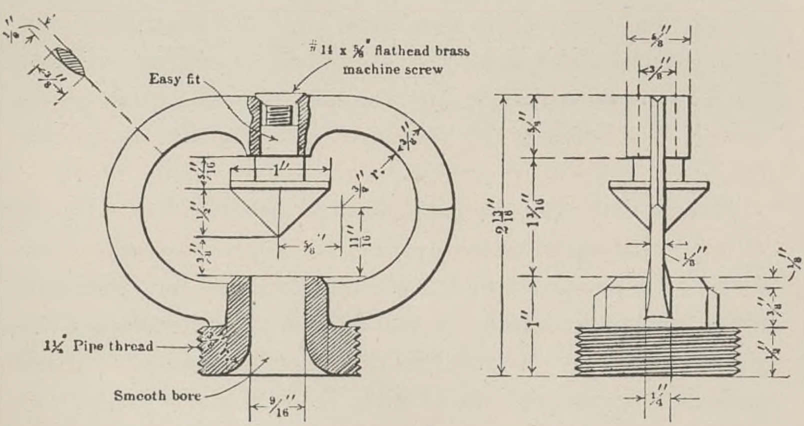

Fig. 48B.—Sprinkling Nozzles Adopted for Sewage Works at Columbus, Ohio.

(Reproduced by permission of Mr. J. H. Gregory, Columbus, U.S.A. and the American Society of Civil Engineers.)

spreads it over a circular area; the diameter of circle covered should correspond with the space between the holes in the trough, while the size of the holes may, by this means, be made much greater than when the jets are thrown upwards under pressure instead of falling by gravity from an open trough.

It is evident, however, from Fig. 49 that with the most perfect form of spray discharging over a circular area it is only possible to distribute over about 80 per cent. of the total filter area, owing to the space wasted between the circles, and when the sprays are affected by the wind the proportion is frequently much less. A new form of jet has recently been designed to throw a spray over a square area, but it seems uncertain whether this actually gives more uniform distribution than the circular ones.

Owing to the great difficulty of securing really uniform distribution over the whole area of large filters as well as the risk of creating a nuisance with fixed sprays, it soon became evident that the problem would be simplified by the adoption of a moveable distributor which would travel over the surface of the filter and discharge the sewage on to it at a rate proportionate to the area covered, without the necessity of flooding the surface or spraying the sewage into the air.

It will, however, be realised that although the adoption of moveable distributors appears to eliminate some of the difficulties involved by fixed pipes or troughs, they introduce fresh obstacles owing to the difficulty of developing the power necessary to produce the required motion without materially increasing the cost.

The attempts made to overcome this fresh difficulty were naturally directed to using the sewage itself as the most economical means of developing the power required when sufficient fall was available, and it is therefore not surprising that the simple device known as a "Barker's Mill" should soon be selected for application to this purpose in various forms of revolving distributors, which consist essentially in a number of perforated iron pipes attached to and radiating

Fig. 49.—Fixed Sprinklers in Operation at Tunbridge Wells.

(Reproduced by permission of The Ames Crosta Sanitary Engineering Co., Ltd., Westminster, S.W.)

from a central pillar, through which they are supplied with sewage, and the holes being all on one side of the pipes the reaction of the escaping jets causes the whole of the pipes to revolve round the centre, while at the same time discharging the sewage over a circular area of filter.

Since the outer ends of the distributing arms necessarily traverse a far greater area than the ends near the centre, it is important that the number and size of the perforations should be proportionate to the distance from the centre in order to equalise the quantity of sewage discharged on to all parts of the filter during each revolution.

The attainment of uniform distribution on comparatively small filters does not involve any serious difficulty, but with the larger filters, say 100 feet diameter and over, the rate of discharge from the two ends of each radiating pipe is so widely different that, whereas the perforations near the centre are very widely spaced, those at the outer end are excessively close together, and in order to meet this difficulty it is sometimes found convenient to have some of the arms perforated for the outer portion of their length only, and with this object four arms are sometimes made to discharge over the outer portion of the filter, while two of them are sufficient to supply the inner or central portion.

Since all the distributors constructed on the above principle consist in a series of pipes travelling round a fixed pivot at the centre of the filter, the most convenient means of admitting the sewage is through the pivot itself, which can readily be formed with a hollow casting and kept supplied with sewage by a pipe laid through the body of the filter or below the floor as a protection from frost.

Considerable difficulty has, however, been experienced in forming a satisfactory joint between the fixed pivot or supply pipe and the revolving arms, and it may therefore be well to briefly describe some of the alternative means which have been devised for overcoming this difficulty.

Perhaps the simplest means of admitting the sewage to the distributing arms is by connecting the radiating pipes to an annular trough which is deep enough to give the head required to work the distributor at its maximum rate of discharge, and is carried on a ring of ball bearings round the central supply pipe, through which the sewage rises and overflows into the trough by outlet pipes projecting over the edge.

This arrangement has the advantage of avoiding the necessity for making any watertight joints, but in case the holes in distributing pipes become partially blocked and the rate of discharge is consequently diminished, there is no means of automatically checking the supply, and the surplus sewage is liable to overflow from the annular trough and find its way direct to the effluent drains with little or no purification.

Another method is that shown in Fig. 50, where the annular trough is arranged in much the same way, but the sewage is discharged into it from the central supply pipe by means of syphons, and since it is possible with this arrangement to provide an emergency overflow on the supply pipe outside the filter, the water level cannot rise beyond a certain height even if the discharge from the distributors entirely ceases, as this merely checks the flow through the syphons, which depends upon the relative water level in the central supply pipe and the annular trough.*

With the above exceptions, the centre joints in revolving distributors are formed below the level of sewage in supply pipe, so it is essential that they should be perfectly watertight; and although it would seem to be a simple matter to ensure this by the use of an ordinary stuffing-box and gland, such an arrangement necessarily introduces considerable friction, and consequently increased resistance to the free movement of the distributors, which is a matter of great importance with automatic apparatus, when the power has to be derived from the sewage itself with a very limited amount of fall.

* Certain improvements have recently been made in the details of syphons which are not shown in Fig. 50.

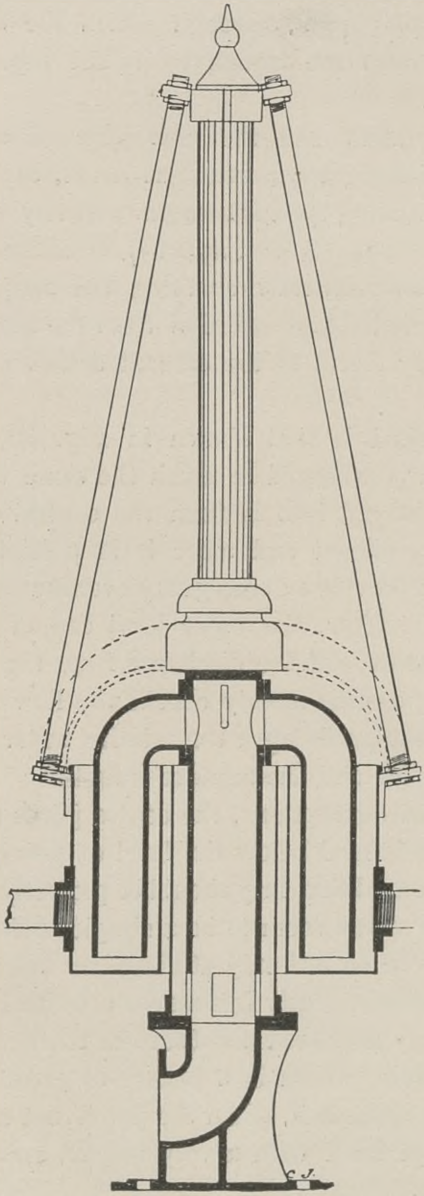

Fig. 50.—Section through Centre Pillar of Circular Distributor with Syphonic Feed.

(Reproduced by permission of Messrs. George Jennings, Ltd., London, S.E.)

The joint shown in Fig. 51 consists in two brass rings with accurately-ground faces so that they fit very closely, one being fixed to the supply pipe, while the other is attached to the moveable part of the distributor by a flexible sheet of india-rubber, so that while the two metal rings are pressed together by the pressure of water above them, they in no way act as a support for the weight of the distributor itself, which is entirely carried by independent ball bearings at the top of the central pillar.

Another ingenious arrangement is that shown in Fig. 52, in which a kind of trap or seal is formed by the use of mercury, and since the specific gravity of mercury is about 12 times that of water, a depth of 3 inches in the trap is sufficient to prevent leakage so long as the pressure of sewage is not more than 3 feet head, but some margin has to be allowed for any sudden increase of pressure that may be caused by the careless opening of a valve on the supply pipe, which would result in forcing the mercury out of the joint, so that it falls into the filter or effluent drains and is lost, though it will be seen from the section that a check ring is now provided to prevent this.

So long as the mercury seal is deep enough this joint is perfectly watertight, but as the 9 lb. of mercury required for a 100 ft. distributor costs about 22s. 6d. any accident which necessitates its renewal involves a very appreciable expense.

The only other form of joint with which the Author has had any experience is that shown in Fig. 53, where the principle is somewhat similar to the last, but instead of using a mercury seal the leakage of sewage is prevented by an air lock or double trap formed by two concentric iron cylinders attached at the top to the moveable part of the distributor, and dipping into the water in two annular

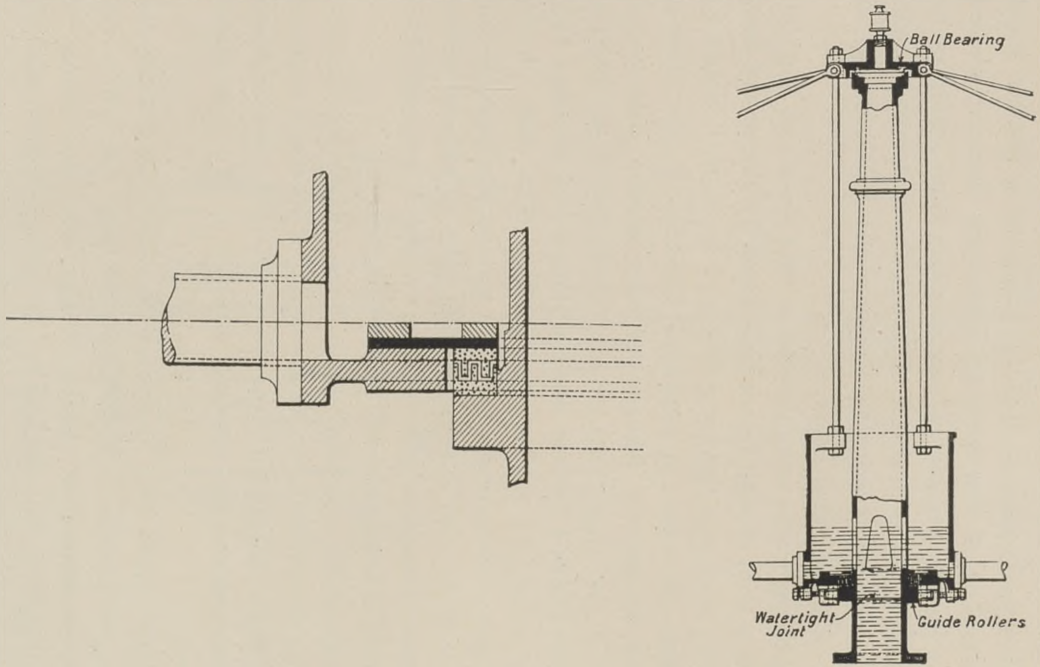

Fig. 51.—Section through Centre Pillar of Circular Distributor, Showing Construction of Joint with Supply Pipe. Enlarged Section of Centre Joint.

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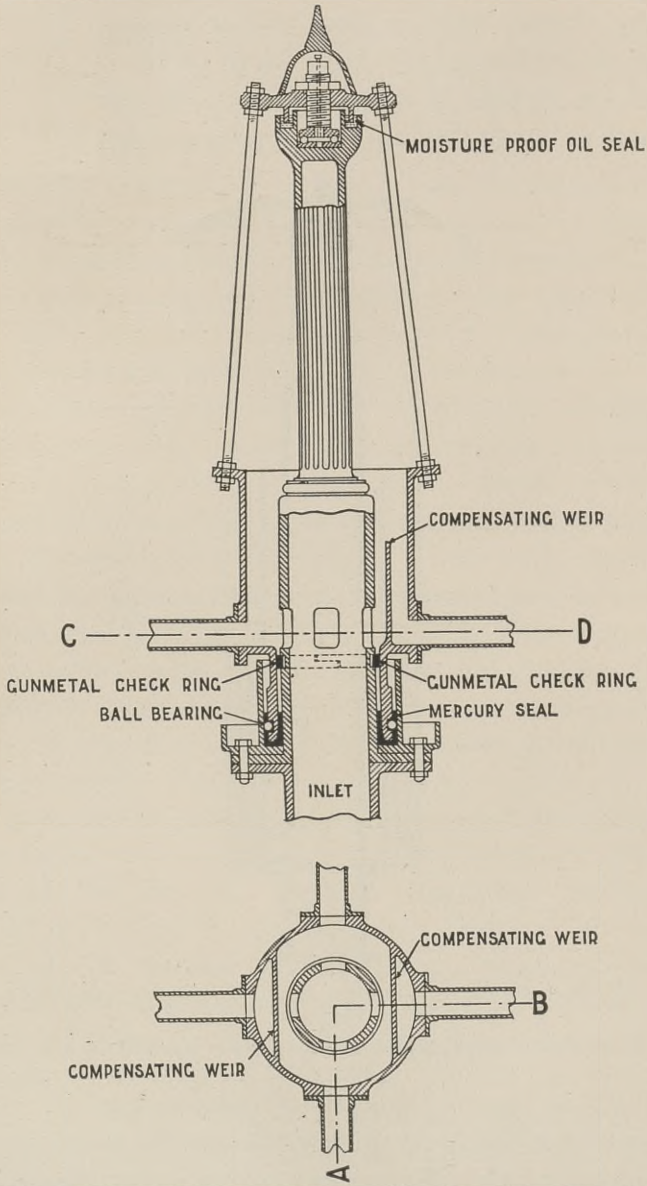

Fig. 52.—Section and Plan of Centre Pillar for Circular Distributor with Mercury Seal and Compensating Arms.

(Reproduced by permission of The Patent Automatic Sewage Distributors, Ltd., London.)

spaces formed between three similar concentric cylinders fixed at the bottom to a large flange on the central supply pipe, the leakage of sewage through the joint being prevented by the air confined between the two traps so formed.

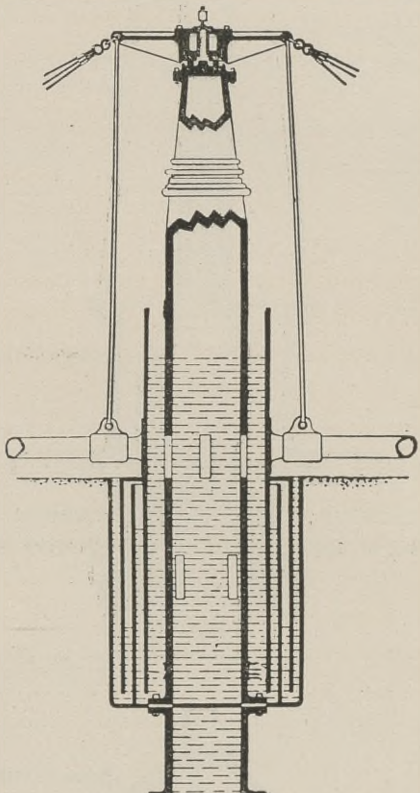

Fig. 53.—Section through Centre Pillar of Circular Distributor with Air Lock.

(Reproduced by permission of Messrs. Adams' Hydraulics, Ltd., York.)

It will be observed from the illustration that the relative water level in the two traps depends upon the level of sewage to be retained, the difference in level representing the column of water necessary to counterbalance a corresponding head of sewage; but although the difference is only 2 ft. 6 ins. in the illustration, it will be seen that this might be increased to 3 ft. 6 ins. before the air lock would be broken, and it is important to allow this margin over the ordinary working head in order to provide for a sudden rush of sewage due to the careless manipulation of valves above referred to, though in case the seal is broken it can be readily renewed in a few minutes by stopping the distributor and admitting a fresh supply of air by a small cock provided for the purpose, so that the effect of such an accident is not serious.

It is claimed for this last form of joint that all loss of power due to friction in centre joint is practically eliminated, since the moving parts are not in contact, and the resistance due to the cylinders revolving in water is quite inappreciable, but in all cases so far mentioned the weight of the distributor must be mainly carried by independent bearings, and hardened steel balls are usually adopted for this purpose in order to reduce friction as far as possible, and it is important that means should be provided for raising the weight off the bearing, so that it may be readily cleaned, lubricated, and repaired when necessary.

A simple method of securing this consists in the provision of a vertical screw at the top of the central standard, as shown in Fig. 52, so that when the distributor is pushed round in the reverse direction to that in which it travels when working, the top block carrying the weight rises up the screw clear of the bearings, so that these can be readily taken out and renewed when necessary, the weight being again lowered on to them directly the distributor is set to work and begins to revolve in the proper direction. Fig. 54 shows method of attaching guy ropes to centre pillar.

When the whole weight of the distributor is carried on these central bearings the wear is somewhat heavy in the case of large filters, and a portion of the weight is in some cases carried on a rail fixed round the circumference of the filter; this, however, involves considerable extra expense, and it is therefore sometimes found desirable to use a large

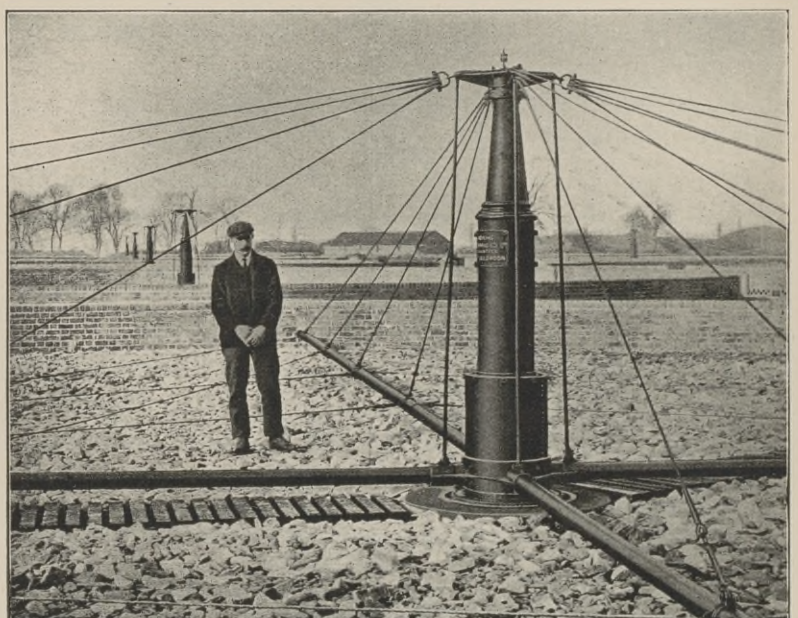

Fig. 54.—Centre Pillar of Circular Distributor, Showing Method of Supporting the Radiating Arms with Guy Ropes.

(Reproduced by permission of Messrs. Adams' Hydraulics, Ltd., York.)

iron float immersed in a tank full of water at the centre of the filter, on which the bulk of the weight may be carried.

With this arrangement the float revolves in water and the friction is consequently very small, but the float necessarily occupies a considerable space and renders it somewhat difficult to gain access to the central joint or the effluent drains when these are arranged to discharge into a chamber at the centre of the filter, unless the chamber is made so large as to materially reduce the effective area of the filter, the float itself for a 100 ft. distributor being usually about 5 ft. diameter and 4 ft. deep, which, allowing for central tube 2 ft. diameter, gives a displacement of about 55 cubic ft., which will support a weight of $1\frac{1}{2}$ tons.

As the distributor is heavier when the arms are full of sewage than when they are empty, there is a variation in the actual weight to be supported by the float which causes it to sink about $\frac{1}{4}$ in. deeper in the water when the distributor is in operation than when it is empty, but the bearings are so designed as to allow for this vertical movement, there being three rows of balls which permit a rise or fall of $\frac{3}{8}$ in., but prevent any movement either upwards or downwards beyond this limit, and also check any tendency to horizontal movement of the central pillar.

The next question which needs consideration in connection with automatic rotary distributors is the method of controlling the flow of sewage so that the distributor may be thrown out of action directly the supply or head becomes insufficient to make it work satisfactorily, while the maximum rate of discharge shall never exceed the quantity which the filter is capable of dealing with.

There are many different methods of accomplishing this result, and some of them have already been referred to in the last two chapters, but as the efficiency of percolating filters is directly dependent upon the proper control of sewage flow, it may be of interest to further consider the different principles applied to this purpose, and to give a brief description of the leading features embodied in the design of the apparatus usually employed.

It has already been explained that the best means of limiting the maximum rate of discharge is by providing an overflow on the supply pipe at a height above the outlets of distributor corresponding with the greatest head under which it is intended to work, or the same result may be secured by a regulating valve on the supply pipe which can be set to discharge any quantity desired, but the chief difficulty arises in automatically stopping the discharge when the flow of sewage is insufficient to make the distributor work efficiently, and restarting it when a sufficient quantity has accumulated to again keep the distributor going for a short time.

It is also a matter of some importance to bear in mind that when the capacity of filters is calculated to treat two or three times the dry weather flow of sewage as now required by the Local Government Board, a large proportion of the filters are frequently inoperative for a considerable period during dry weather, as the whole area is only required when a large volume of storm-water has to be treated in addition to the sewage proper.

In order to equalise the work between the different units some means must therefore be adopted for discharging the dry weather sewage on to different areas alternately or in rotation, so that the bacterial life in each may be maintained in a high state of activity, as it is otherwise futile to expect satisfactory results when the whole area is brought into operation by a sudden storm.

In large works this can, of course, be provided for by suitable valves controlled by hand, but this labour is a constant source of expense which it is very desirable to reduce as far as possible, especially in small works, the maintenance of which does not justify the employment of a man for the whole of his time.

Many efforts have therefore been made to devise a means of automatically ensuring that the filters shall not only work intermittently when the sewage flow is too small to keep them going constantly, but that they shall be brought into action alternately or in rotation.

In order to provide for intermittent action the first essential is a storage tank or measuring chamber in which the sewage can be collected until a sufficient quantity has accumulated to work one or more distributors for at least five or ten minutes at a time, and when such a measuring chamber becomes full its contents can be very readily discharged by automatic valves or syphons.

To obtain an alternating action between several distributors supplied by syphons, it is necessary that the syphons should be constructed with a deep seal or trap, and they can be so arranged that when one discharges, a portion of the water is forced out of the trap of the next, and this is consequently more easily broken through by the air pressure when the chamber fills up again after the first discharge, and by coupling a number of syphons together they may thus be made to discharge in rotation when there is not enough sewage to keep them all working continuously.

It is sometimes found, however, that a difficulty arises with the syphons through their having a tendency to merely act as overflows instead of quickly discharging the whole contents of the measuring chamber directly it is full, and to obviate this it is necessary that the air confined in the top of the syphon should be suddenly released when the sewage rises to a certain point, thereby starting the syphonic discharge, but as the water level sinks the syphon will only continue to discharge so long as no air is admitted to break the partial vacuum which is formed at the top, and it is therefore necessary that the air-releasing valve should be automatically closed directly the syphon begins to discharge.

Fig. 55 shows a clever but somewhat complicated arrange-

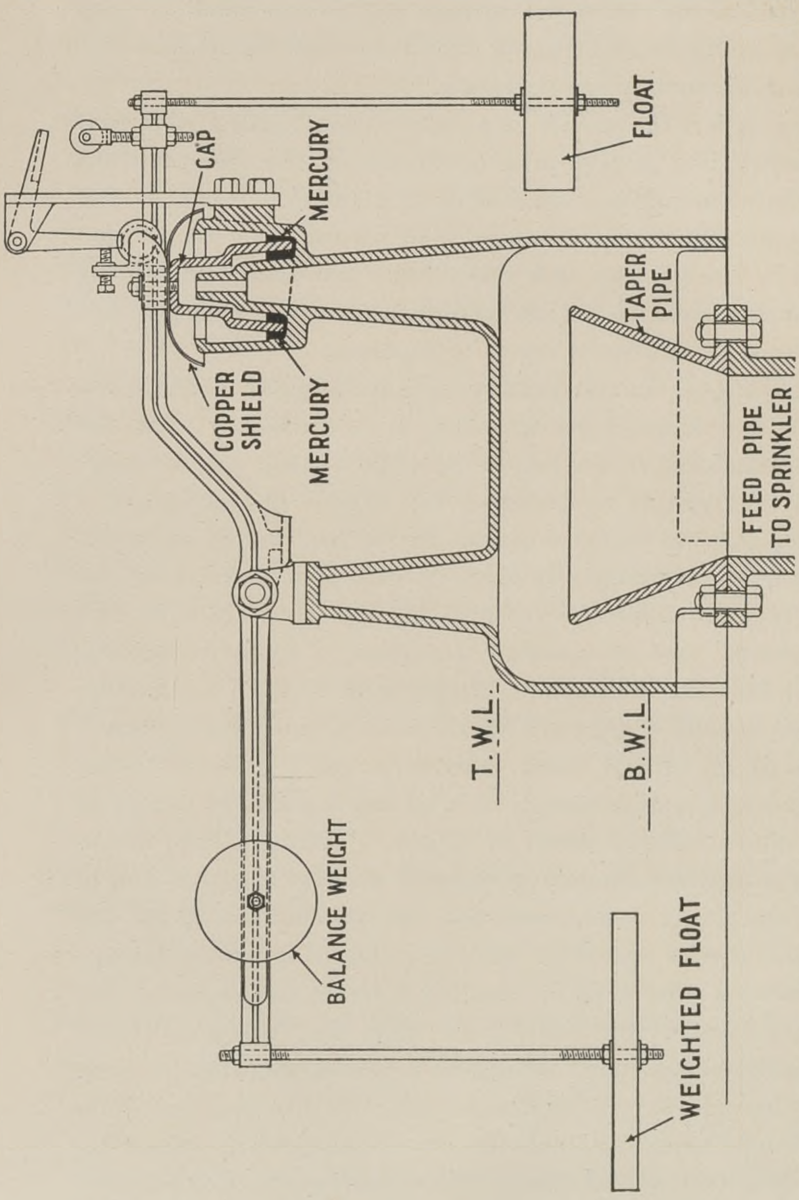

Fig. 55.—Automatic Syphon for Discharging Contents of Measuring Chamber or Carrier when Sewage Rises to a Certain Height, Showing Method of Opening and Closing Air Release Valve.

(Reproduced by permission of The Patent Automatic Sewage Distributors, Ltd., London.)

ment of combined floats and levers by which the above object is secured, the release valve consisting in a small air pipe on the top of the syphon, terminating in the centre of a cup containing mercury and covered by another inverted cup or dome, which dips into the mercury all round the open end of the air pipe, thereby forming a trap to retain the air until the dome is lifted by a counterbalanced lever held in position by a catch till the chamber is full, and then released by a float which rises on the surface of the sewage.

This float is also weighted with lead, so that when the water level sinks the float acts as a counterweight and closes the release valve when the air has escaped, while the partial vacuum formed in the syphon when the measuring chamber is nearly empty is again broken by a second weighted float attached to the opposite end of the same lever as the first, but which, having the same specific gravity as water, only acts as a counterpoise when the water level sinks below it, and thus counterbalances the lead on the other float and allows the release valve to open sufficiently to admit air and break the vacuum, thus stopping the discharge instantly.

An effective form of valve designed to ensure the instantaneous opening and closing of outlet valve when the feed chamber is full and empty respectively is that shown in Fig. 56; but in this case the lever has a mercury cup at each end, with a connecting pipe, through which the mercury may run from one cup to the other when the equilibrium is destroyed by the rise or fall of a float which causes the balance weight to fall over to one side or the other, so that the end of the lever to which the valve is attached is raised or lowered with a jerk, and then held in position by the weight of mercury until this is again transferred to the other end.

It will, however, be observed that all these valves are only designed to provide for an intermittent discharge on to one or more filters, but when it is desirable to work the filters in rotation this may also be provided for by the

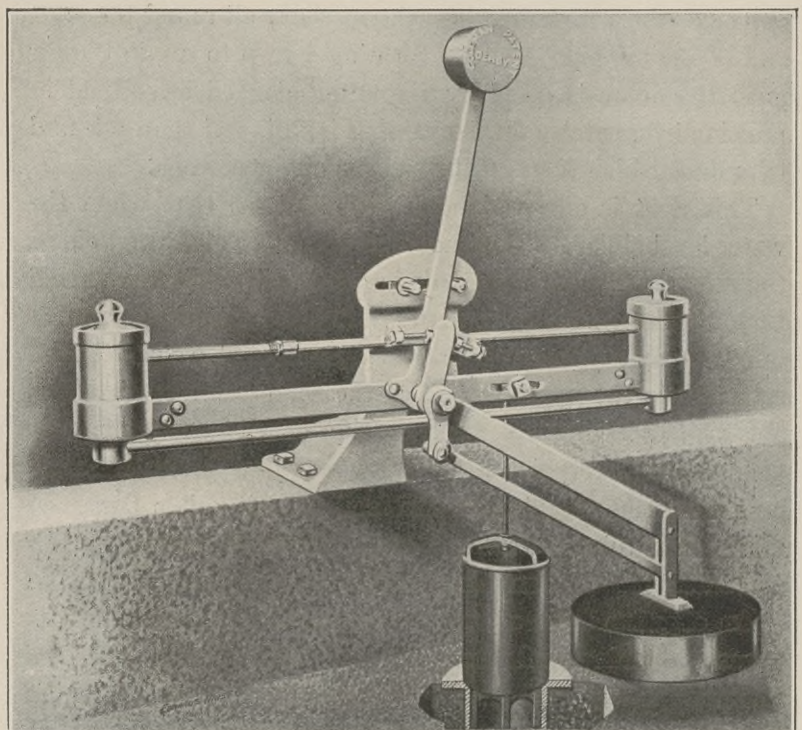

Fig. 56.—Automatic Apparatus for Alternately Opening and Closing Valve on Supply Pipe to Distributors when Feed Chamber is Full and Empty Respectively.

(Reproduced by permission of The Ames Crosta Sanitary Engineering Co., Ltd., Westminster, S.W.)

arrangement illustrated in Fig. 57, when the air release valve at the top of the discharge syphon is controlled by a special form of pawl and cam, which is actuated by the rise or fall of a float, and so arranged that only one tooth of the cam engages with the pawl in each revolution, and, the number of teeth in the cam corresponding with the number of filters, the air is released from each supply syphon in turn, so that they discharge on to the filters in rotation, the air

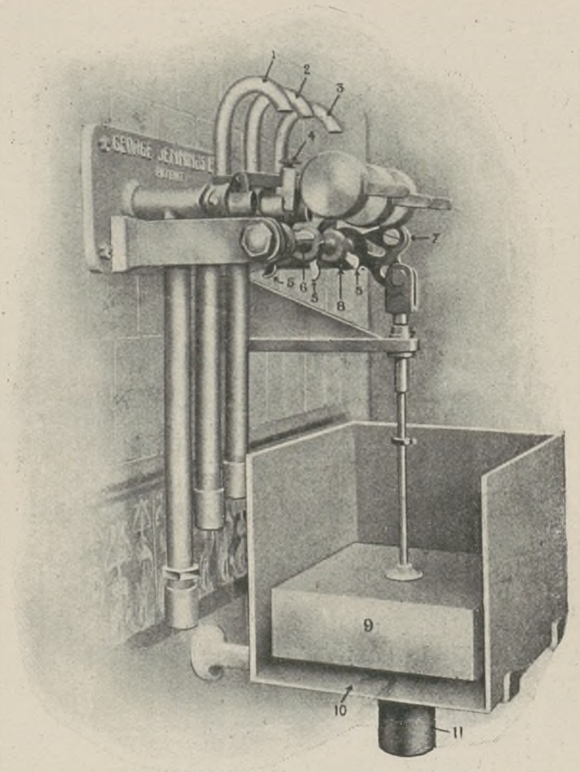

Fig. 57.—Automatic Valve for Discharging Sewage on to a Number of Filters in Rotation.

(Reproduced by permission of Messrs. George Jennings, Ltd., London, S.E.)

confined in all the floats being released after each discharge by a special air pipe, the outlet from which is submerged until the supply pipes and chambers are nearly empty.

Although most of the apparatus described in Chapter VII, can only be used in connection with contact beds, the intermitting gear described can also be applied to percolating filters.

When the sewage is pumped and the filters can therefore be worked at a fairly uniform rate, the use of automatic regulating valves is not necessary, and when sufficient fall is available for the rate of discharge from distributors to be regulated by the natural variation of head it is generally found far better to dispense with all mechanical apparatus.

Although the "Barker's Mill" principle already described is common to almost all the automatic rotary distributors with which the Author is acquainted, attempts have also been made to develop power by passing the sewage through a kind of turbine when it leaves the central supply pipes before entering the distributing arms, and in some cases a system of jets and vanes are used with the same object, but it seems clear that the propelling power of the sewage can be far more effectually utilised by the "Barker's Mill" principle, since the leverage exerted by the reaction of a jet escaping from near the end of a long arm must be far greater than that of a corresponding jet at a short distance from the centre or pivot of revolution.

Another method of developing the power necessary to rotate a revolving distributor over a circular filter is by constructing the radiating arms in the form of small water wheels, with buckets round their circumference extending from end to end, so that they can be charged with sewage by means of a pipe fed from the centre of the filter and attached to the water wheel in a position parallel to its axis, and provided with outlets at intervals along its length which are controlled by weirs so that the rate of discharge may be regulated in proportion to the area of filter covered by the section of the wheel which each outlet supplies.

The general arrangement of this type of distributor is shown in Figs. 58 and 58A, from which it will be seen that the weight of the distributor and the sewage which it carries is necessarily greater than the perforated pipes previously referred to, while the power required to drive it must also be

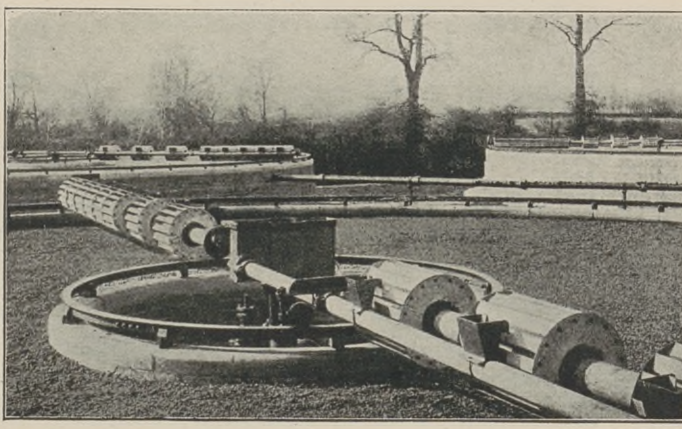

Fig. 58.—Water-wheel Distributor for Circular Filters, Showing Arrangement of Feed Pipes and Rails for Wheels Carrying Distributor.

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materially greater owing to the large surface exposed and the resistance that may consequently have to be overcome in a strong wind, though this additional resistance due to wind or snow apparently only has the effect of making the distributor travel more slowly.

Some advantage is claimed for this distributor on account of the fact that it will continue to travel slowly over the filter, no matter how small a quantity of sewage it may be distributing, and no intermitting gear is therefore required, but this may sometimes mean that excessively large doses of sewage are suddenly applied to a small part of the filter each time a bucket discharges, the capacity of the buckets being necessarily considerable in order that the

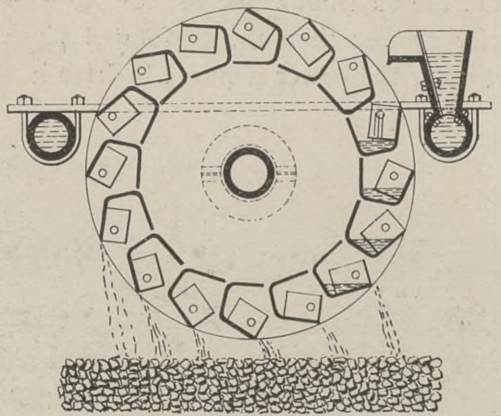

Fig. 58A.—Section of Water-wheel Distributor, Showing Arrangement of Buckets and Feed Pipe.

(Reproduced by permission of Messrs. Birch-Killon & Co., Manchester.)

weight of sewage they contain may be sufficient to make the wheel revolve.

Another form of distributor in which the propelling power is developed on the principle of a water wheel is that shown in Fig. 59, from which it will be seen that, instead of revolving over a circular path, the apparatus is designed to travel backwards and forwards over a rectangular area of filter.

It will, however, be noticed that duplicate feed pipes are in this case required, and in order to reverse the motion the sewage is turned from one side to the other by an automatic valve, thus causing the wheel to revolve in the reverse direction, the buckets being so arranged that half of them receive sewage when travelling in one direction, and the other half being designed to work in the opposite direction, each half working and remaining empty alternately.

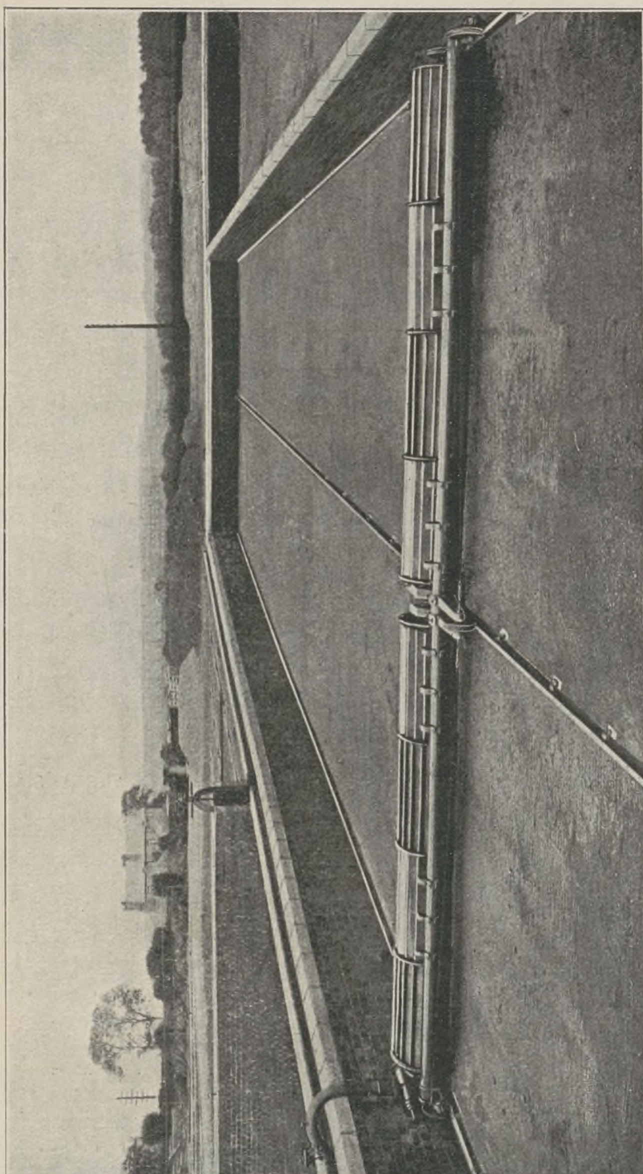

Fig. 59.—Water-wheel Distributor for Rectangular Filters, Showing Arrangement of Feed Pipes and Rails for Wheels carrying Distributor.

(Reproduced by permission of Messrs. Ham, Baker & Co., Ltd., London, S.W.)

The difficulties encountered with this distributor were chiefly due to the large surface exposed to the wind, and there may be a tendency for the discharge from different sections of the wheel to overlap slightly, but the fact that it is applicable to rectangular filters is certainly in its favour owing to the economy of space which can be thereby effected, as well as the consequent saving in cost of filter, which has already been dealt with in the last chapter.

In the whole of the automatic distributors hitherto described the propelling power is derived from the sewage itself, but in cases where the fall available is insufficient for this, or when it is desired to have the rate of filtration more completely under control and capable of adjustment without affecting the speed at which the distributor travels, it is necessary to provide an independent means of developing the power required, and in order to comply with these conditions a distributor has been specially designed for use on a circular filter bed by Mr. Scott Moncrieff.

This distributor consists in a large open trough 36 ins. wide by 18 ins. in depth and 65 ft. long, supported at one end on the vertical supply pipe forming a pivot at the centre of the filter round which the trough revolves, while the other end is carried by a wheel running on a circular rail round the outside of the filter, the trough being stiffened throughout its length by lattice girder bracing and provided with a small subsidiary regulating trough along one side of it.

This small trough is 8 ins. by 4½ ins., and is divided into lengths of 7 ft., into each of which the sewage is admitted from the main trough by means of adjustable openings in the side of the latter, so that it overflows on to the filter along the whole length of the trough at a rate proportionate to the area of circular path covered by each separate section, any deviation from the desired quantity being easily regulated by slightly opening or closing the adjustable inlets, while uniformity of distribution is also secured by a series of small raised ribs cast on the side of the trough, so that the sewage falls straight on to the filter at the point where it overflows from the trough, whereas it would otherwise have a tendency to run along the bottom, especially when there is much wind.

The propelling power is provided by a $5\frac{1}{2}$ b.h.p. oil engine carried on the outer end of the trough immediately over the wheel, to which it is connected by suitable gearing, so that it travels slowly round the circumference of the filter at a perfectly uniform speed which is quite independent of the rate of filtration, but capable of adjustment by altering the gear, so that the time occupied by each journey round the filter may be lengthened or shortened so as to increase or decrease the interval between each dose of sewage discharged on to any particular section of the bed.

The circular filter bed for which this distributor was constructed at Hanley is 132 ft. 6 ins. in diameter with an area of about a quarter of an acre, and at the ordinary speed the engine travels about half a mile per hour, making one revolution every eight minutes. By placing shallow measuring boxes one yard square at different parts of the filter the uniformity of distribution has been accurately tested with different rates of flow, thereby demonstrating the absence of any irregularity such as is sometimes found with the "Barker's Mill" type of distributor, owing to the centrifugal force developed by their greater speed of rotation, which tends to increase the discharge near the outer ends of the revolving arms.

The great disadvantage of this distributor is its weight, of

U 2

which about 12 tons is carried by the single wheel travelling on the outer rail, on which the wear is consequently very heavy, a 45 lb. bridge rail being worn out at Hanley in about $2\frac{1}{2}$ years.

The cost of renewals and repairs on this quarter acre distributor amounted to about £50 per annum, while the cost of oil, fuel, and waste together with about half a man's time came to about £150 per annum in addition, making £200 in all, say £2 per million gallons of sewage treated.

Although excellent results are obtained from the filter on which this distributor has been working owing to the highly efficient distribution which it secures, this does not seem to justify the heavy expense involved, while the fact that it is not applicable to rectangular filters precludes its general adoption at Hanley and many other places, where only a limited space is available for the works, as circular filters necessarily involve a separate wall to enclose each filter, and it is impossible to utilise the area intervening between the circles, whereas a larger area of rectangular filters can be more economically constructed in units of one acre or more without any division walls or waste space between.

The site of the new works at Hanley being in the centre of a populous district and the area of land available being only just sufficient to accommodate the works required by the Local Government Board, the necessity for avoiding the possibility of any nuisance and economising space rendered it very desirable that some form of travelling distributor should be adopted for use on rectangular filters, and whereas all previous attempts to accomplish this automatically had proved unsuccessful, Mr. Scott Moncrieff's circular distributor had demonstrated the advantages of using power if this could be applied at a reasonable cost.

The Author and his partner, Mr. Wilcox (as engineers for the Hanley works), were therefore confronted, in 1902, with the problem of either designing an entirely new apparatus that would satisfactorily comply with these special conditions, or else incurring a very heavy additional expense by endeavouring to acquire a larger area of land in another district, which would have resulted in serious delay and the possible risk of an injunction by riparian owners owing to the pollution of the river Trent from the totally inadequate sewage disposal works then existing.

In order to determine the best principle on which to construct a distributor to meet the above conditions it was decided to conduct a series of preliminary experiments, and the results having proved successful the first reversible power-driven distributor was built in 1902 for a rectangular filter about a quarter of an acre in area, on which it has been working constantly ever since with most satisfactory results.

This distributor consists essentially in a perforated iron pipe extending across the width of the filter (60 ft.) and fed with sewage from a central trough by means of syphons, the pipe being carried on wheels and drawn backwards and forwards from end to end of the bed by means of a wire rope driven from an electric motor provided with automatic gear, by which the motion of the driving rope is reversed at the end of each journey.

This experimental distributor having proved completely successful in fulfilling the purpose for which it was designed, namely the perfectly uniform distribution of sewage over a rectangular filter at a rate per acre which could be readily varied as required to suit special conditions, the Hanley Corporation decided to adopt this method of distribution for all the rest of the new works then contemplated, comprising about nine acres of percolating filters, and five one-acre filters

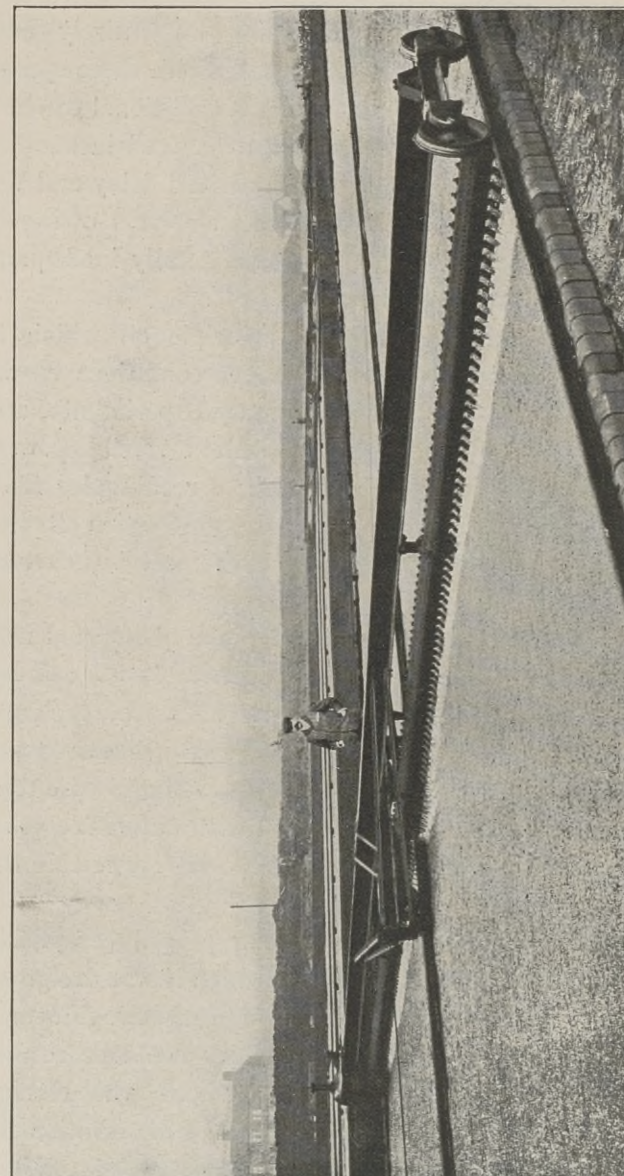

Fig. 60.—Hanley Distributor in Operation on ¼-Acre Rectangular Filter, Showing Sewage being Discharged in a Thin Film over the Whole Surface.

(Reproduced by permission of **Messrs. Willcox & Raikes, Westminster and Birmingham.**)

are now equipped with distributors constructed as shown in Fig. 60.

The details of this improved design are shown in Fig. 61, from which it will be seen that instead of having one continuous pipe right across the filter, each bed is divided into two half-acre plots, 208 ft. by 98 ft., each of which has a central supply carrier or trough extending from one end to the other, and from this trough two syphons discharge the sewage into separate distributing pipes on either side, which are made to travel over the filter with a reciprocating motion parallel with the trough by a continuous wire rope which is attached to the centre of each distributing pipe, and is taken round pulleys at each end of the filter to a winding drum in the motor house as shown in Fig. 62.

In order to secure a uniform interval of time between each dose of sewage discharged on to any particular part of the filter the distributors are arranged to discharge when travelling in one direction only, the valves on outlet of feed syphons being automatically turned off and on by means of a lever which is actuated by a stop fixed at each end of the iron trough, or at any intermediate point, so that any part of the bed may be readily thrown out of action when necessary for cleaning or repairs, and by adjusting the gear wheels attached to the motor the speed of the distributor may also be regulated as desired, though it is now found at Hanley that the best results are obtained when the distributor occupies about seven minutes in travelling from one end of the filter to the other and back again, this representing the interval between each dose of sewage.

Since there are 1,440 minutes in a day this gives about 200 doses per 24 hours, and when the filter is working at the usual rate of one million gallons per acre each dose equals one gallon per square yard, which represents a depth of

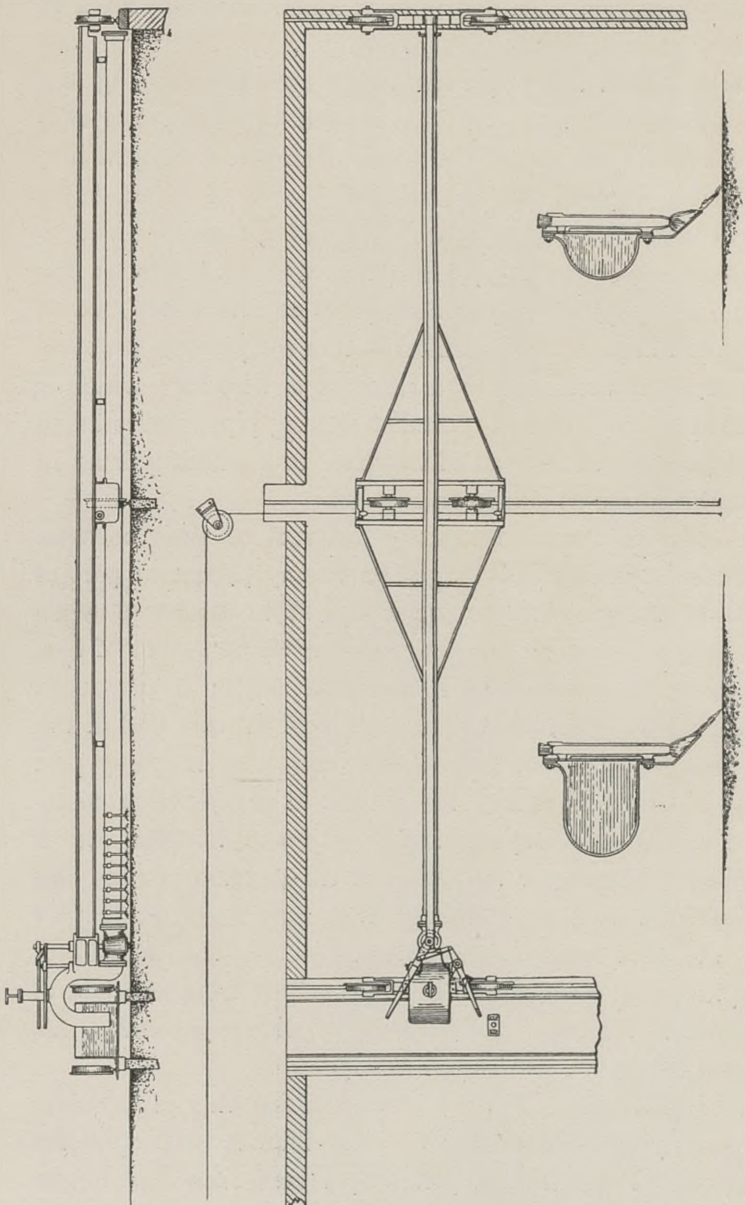

Fig. 61.—Section and Plan of $\frac{1}{4}$-Acre Hanley Distributor with Cross-Sections of Distributing Pipe at Each End, Showing Arrangement of Nozzles with Jets Impinging on Splash Plates.

(Reproduced by permission of Messrs. Hartley & Co., Stoke-on-Trent.)

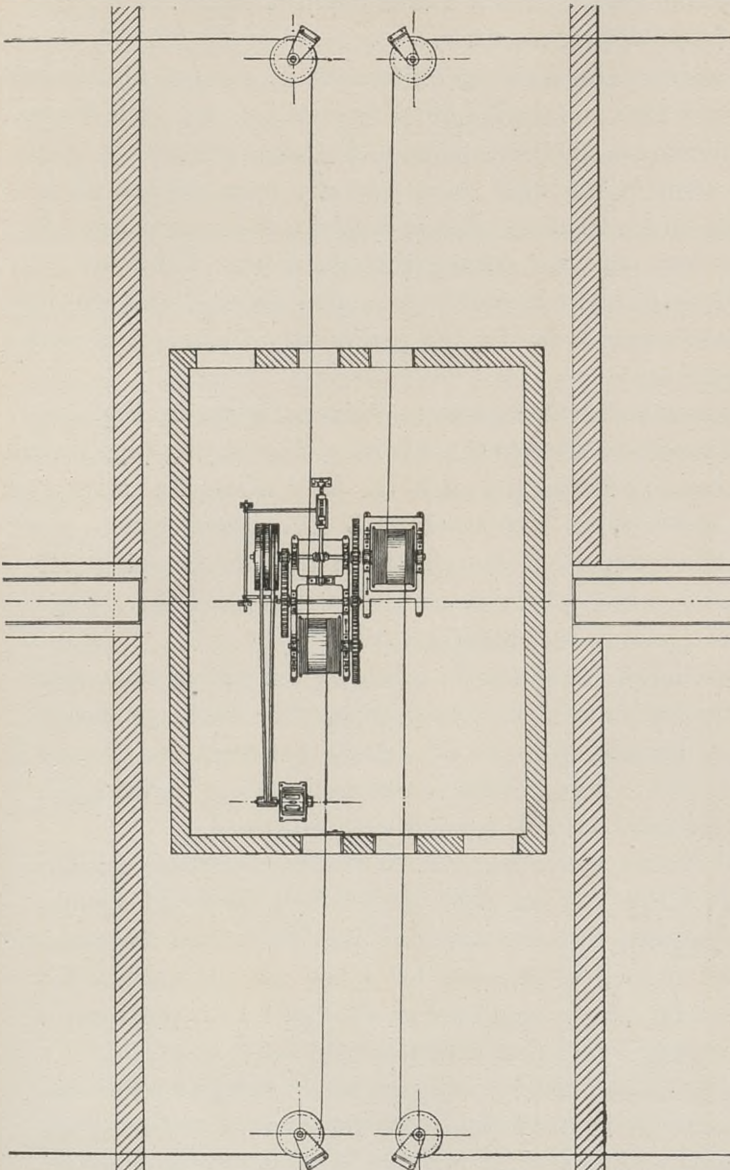

Fig. 62.—Plan of Motor House at Hanley, Showing One Electric Motor Driving Two Winding Drums with Wire Ropes Connected to Four $\frac{1}{4}$-Acre Distributors on Rectangular Filters.

(Reproduced by permission of Messrs. Hartley & Co., Stoke-on-Trent.)

$\frac{1}{5}$ inch 200 times a day, or a total depth of 40 ins. of sewage in 24 hours all over the filter.

In addition to securing uniformity in rate of filtration per super yard and the length of interval between each dose, special care has also been taken to discharge the sewage over every inch of the filter in a perfectly even stream while exposing it to the air as little as possible, and so avoiding the risk of any nuisance arising from the works, which are in close proximity to a thickly populated district, and which comprise septic tanks for the preliminary treatment of the sewage.

The means of accomplishing this is shown in Fig. 61, where it will be seen from sections of distributing pipe that the sewage is discharged on to the filter through a series of $\frac{3}{4}$-in. nozzle-tubes spaced about 3 ins. apart, which are slightly contracted at the outlets so that the escaping jets strike the splash plates below each nozzle, and the sewage is thus spread in the shape of a fan.

Each nozzle being fed by a hole in the side of tube near the top of main distributing pipe, the discharge ceases directly the supply is cut off, but as the main distributing pipe is always kept full the discharge instantly begins again when the inlet valve is automatically reopened.

The motive power for each half acre distributor consists in a $1\frac{1}{2}$ b.h.p. electric motor with a belt drive and counter shaft provided with fast and loose pulleys, so that the motor may be allowed to run free for a few seconds until it has attained the proper speed before the full load is put upon it by throwing it into gear with the distributor.

The greatest difficulty encountered in designing this distributor arose in connection with the gear for reversing the motion at each end of the bed, but this has now been accomplished quite satisfactorily by the use of a crossed belt, by means of which the motion of winding drum for driving rope is reversed, so that it revolves in the opposite direction after making a sufficient number of revolutions to draw the distributor from one end of the filters to the other, the proper number of revolutions being accurately governed by means of a screw attached to the drum with a travelling block, which engages with a lever after making a certain number of turns, and thus actuates the reversing gear.

Each of the motor houses is designed to accommodate the motors and driving gear for four quarter-acre distributors, as shown in Fig. 62, and they are placed underground in the space between the adjoining one-acre filters, so that the roadway is left clear, and as all the motors are the same size they can be readily changed or taken out and replaced when necessary for cleaning or repairs.

As a result of the experiments carried out with this type of distributor during the last five years, it is anticipated that when the whole scheme is completed the annual cost per acre of filter for maintenance will not exceed the following estimate, which is based on the assumption that although the scheme includes nine acres of bacteria beds, the average area in use will be about three acres.

	£	*s.*	*d.*
Renewals, repairs, oil, etc.	6	2	0
Electricity at 1.08*d.* per unit	16	10	0
Proportion of 3 men's time	20	6	0
Total	42	18	0

The reason why the whole of the distributors will not be working continuously is that the Local Government Board require the total area of filters to be sufficient to treat a volume of sewage equal to three times the dry weather flow in addition to a corresponding volume of storm water, whereas the average volume actually reaching the outfall works does not exceed about one and a half times the dry weather flow.

Since the Scott Moncrieff distributor erected at Hanley for experimental purposes has proved somewhat cumbersome and costly to maintain, it has now been replaced by a power-driven distributor designed by Messrs. Hartley and Son, of Stoke-on-Trent, for the quarter-acre circular filter, on exactly the same general principles as the distributors for rectangular filters described above, except that the motor is carried on the end of the distributor itself, so that no driving ropes are necessary, and the details of its construction are shown in Fig. 63, from which it will be seen that the nozzles are formed with short lengths of tube fixed in *échelon* to facilitate cleaning, and each connected to the main supply pipe by a separate plug valve, by which the rate of distribution can be accurately adjusted, according to the area of filter covered.

Power has also been used in a few instances for assisting the rotation of very large distributors designed on the "Barker's Mill" principle, but when power is available far more perfect distribution can be obtained by the use of large jets with spalsh plates, as shown in Fig. 60, instead of small jets alone, which discharge the sewage along a series of concentric circles instead of spreading it uniformly over the whole surface in a fine film.

The ordinary method of testing the efficiency of a distributor is by placing a number of shallow boxes or trays at different points on the surface of the filter, and if each box covers an area of, say, one square foot, a distributor which discharges uniformly over the whole filter should fill all the boxes at the same rate.

In testing distributors which discharge in jets (as distinct

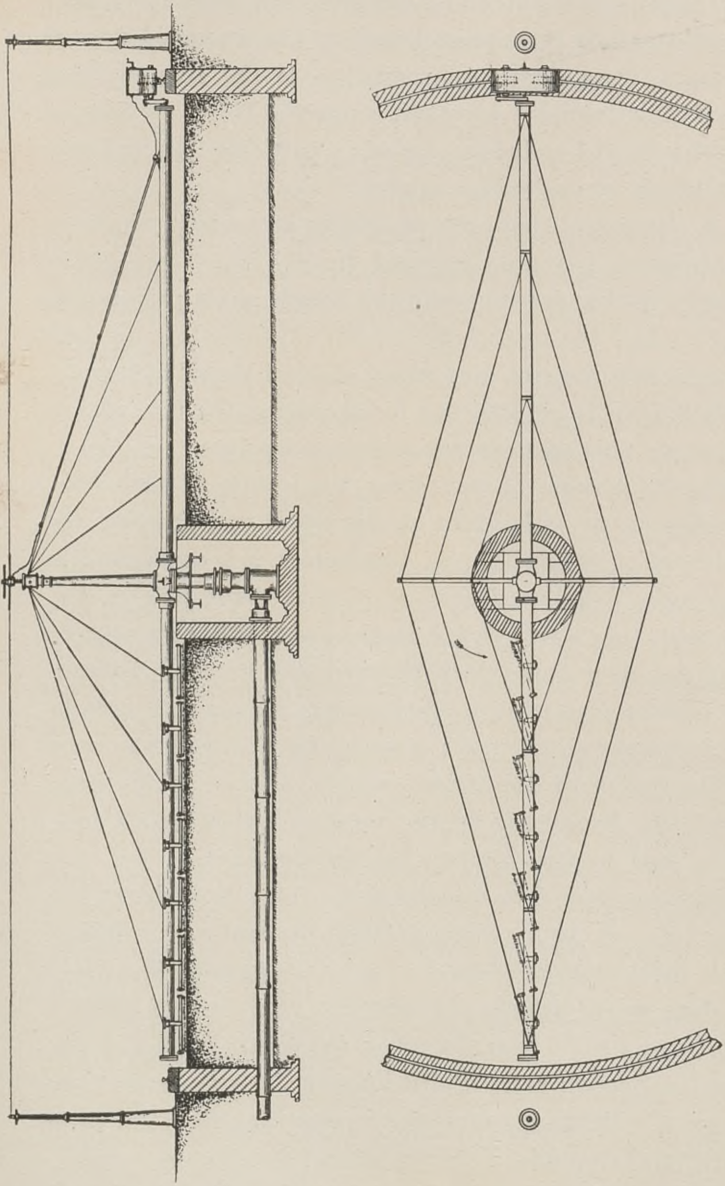

Fig. 63.—Distributor for $\frac{1}{4}$-Acre Circular Filter at Hanley, Driven by Electric Motor, Travelling on Rail Round Outside Wall.

(Reproduced by permission of Messrs. Hartley & Co., Stoke-on-Trent.)

from sprays) this method is, however, less satisfactory than a mathematical calculation based on the measured rate of discharge from each jet in relation to the area of filter which it is intended to cover, since the boxes may be so placed as to just include or exclude a particular jet, and may thus give very misleading results.

The discharge from each jet can be accurately calculated by observing the time required to fill, say, a one-gallon measure held under it; while the length of its path multiplied by half the space between the adjoining jets on each side will give the area over which each jet should distribute, so that there is no difficulty in computing the rate of discharge per unit area covered at different points.

For the purpose of comparing the results of such tests (whether made with boxes or otherwise) and showing the relative efficiency of different distributors, it is convenient to adopt some definite standard as a basis of comparison, and it is with this object that a method of plotting on squared paper has been employed at the Sanitary Research Laboratory of Massachusetts, in order to test the effect of vertical jets designed to discharge a spray over a circular area, but a similar system of comparison may be applied to the horizontal jets discharged by the rotary distributors so commonly used in this country for circular filters.

Having measured or calculated the rates of discharge per unit of area at varying distances from the centre of a circular filter, these may be plotted as abscissæ against the corresponding radial distances as ordinates on a sheet of squared paper, and a curve drawn through the points so plotted will show the relative rates of distribution along the radius, as compared with the straight line representing the ideal rates of distribution obtained with a perfect distributor.

Before concluding this chapter it may perhaps be of interest to briefly summarise the special conditions for which each different type of distributor is particularly suitable, so that their distinguishing characteristics may not be obscured by the somewhat detailed description which it has been necessary to give in explaining their method of construction and operation. It will, however, be understood that, although a particular kind of distributor may be mentioned as specially suitable for certain conditions, it does not necessarily follow that it is altogether unsuitable for other conditions.

Fixed Troughs are most suitable for small works, such as country houses, hospitals, etc., especially where ample filtering area but a limited amount of fall is available.

Fixed Pipes and Sprays are most useful where the absence of smell is not essential, and where the head is sufficient to make each jet cover a considerable area.

Automatic Rotary Distributors are employed where circular filters can be used with sufficient head to make the distributor work satisfactorily, and when it is desirable to avoid spraying the sewage near populous districts.

Power Driven Distributors are advantageous when it is desired to use rectangular filters or when fall is insufficient for distributors to work automatically under all conditions of the wind, etc., while at the same time affording the means of perfect control as regards both the rate and uniformity of distribution, as well as the interval of time between each dose.

As there has recently been a considerable amount of discussion regarding the effect of frost on the various types of distributors above referred to, it may be well to mention that so long as the distributors are kept in operation the natural warmth of the sewage is quite sufficient to prevent any serious trouble from frost in the English climate, but when the distributors are out of operation they should be kept empty during hard frost; while it is also advisable in some cases, when fixed syphons or other dosing apparatus is employed, to have this adequately protected, and it is important to keep all moving distributors high enough to clear any ice or snow which might accumulate on the surface of the filtering media.

CHAPTER X.

The Separation and Disposal of Storm Water.

Importance of provision for storm water—Pollution caused by storm overflows—Admission of storm water to sewers—When should storm overflows be permitted?—Effect of combined and separate system of sewerage—Desirability of treating all first washings—Quantity of storm water reaching sewers—Objection to adoption of a universal standard—Methods of treating storm water—Local Government Board requirements—Duration of rainfall annually—Equalising effect of long sewers—Storage of storm water—Storm overflows.

In considering the alternative types of works adopted for the disposal or purification of sewage in the preceding chapters no particular reference has been made to the storm water, for the treatment of which it is also necessary that sewage disposal works should provide, in order to prevent the pollution of natural water courses; but as storm water exercises such an important influence on the problem of sewage disposal, and frequently complicates the solution of it to a very material extent, its consideration deserves the most careful attention, and will therefore form the subject of this chapter.

To properly compare the efficiency of works from a river pollution point of view it is not only necessary to determine the degree of purification which it is reasonable to expect in the final effluent, but also to carefully consider the circumstances under which unpurified storm water may be discharged into water courses, for although the sewage disposal works may produce a perfectly satisfactory effluent, serious pollution may still take place through inadequate provision for the treatment of storm water containing putrescible organic matter.

When storm water is discharged direct into a water course without entering the sewers, its polluting effect is due to the foul washings from streets, yards, roofs, and other more or less impervious surfaces on which considerable quantities of organic matter accumulate in thickly populated districts; but it is very important to observe that the danger arising from such pollution is greatly increased when the storm water is first admitted to the foul sewers and then discharged by means of storm overflows, after becoming mixed with sewage which is liable to contain the germs of disease, and may therefore carry infection to the inhabitants of other districts deriving their water supply from the stream.

In order to minimise this danger it is highly desirable that the admission of storm water to the sewers should be so far restricted that the overflows shall only be brought into action on comparatively rare occasions during exceptionally heavy rain, when the stream will naturally contain a large volume of water, while the disposal works should, if possible, be designed of sufficient capacity to deal with the whole volume of sewage and storm water received by the sewers under all ordinary circumstances.

It is, however, a matter of very considerable difficulty to define the exceptional circumstances under which the use of storm overflows should be permitted, as it is impossible to ensure that the river or stream will always be in flood when a heavy storm occurs, and the degree of dilution resulting from a given intensity of rainfall is subject to very wide variations in different districts according to the system of sewerage and the extent to which the ground was previously saturated with water, while a certain rate of rainfall may be attained far more frequently at one place than another.

The proper solution of this problem must therefore involve a careful study of the circumstances affecting each particular case, and even assuming that the usual practice is then to be followed of fixing the capacity of disposal works at some multiple of the average dry weather sewage flow, and arranging the storm overflows accordingly, the actual extent to which the dry weather flow should be exceeded before the overflows come into action still remains to be settled.

As explained in Chapter I., the English Local Government Board have provisionally adopted an arbitrary standard, under which the sewage disposal works for inland towns are required to treat a volume of sewage and storm water equal to six times the average dry weather flow, without regard to the relative impurity of the sewage at different places when diluted to this extent, or the frequency with which this quantity actually reaches the outfall, so that whereas in some cases the works designed in accordance with this rule are really hardly sufficient to prevent river pollution to an appreciable extent, there are other cases where it is totally unnecessary to allow such a large margin for storm water in order to achieve this result, owing to the wide variation in local conditions, and although such variations may not be recognised by the Local Government Board, they cannot be safely ignored by those who are directly responsible for the economical construction and successful operation of sewage disposal works, so it may be well to briefly consider the effect which the application of this or any other similar standard has upon the results obtained in practice under different circumstances.

Assuming, for example, that the dry weather sewage flow in a certain district equals 20 gallons per head per day, and the disposal works are designed to deal with a volume of storm water equal to five times this quantity, which represents 100 gallons per head per day, or, say, 4 gallons per head per hour; then what rate of rainfall will be required on impervious areas draining to the sewers in order to bring the storm overflows into action?

The area of impervious surfaces per head of the population draining to the sewers will vary enormously according to local circumstances, but in the Author's experience of suburban districts which are fully built up about 40 super yards per house, or say 8 yards per head, is a fair allowance for back roofs and yards, while the area of front roofs and streets in the same district would be, say, 80 super yards per house or 16 yards per head.

Calculating on the basis of the above figures, it will be observed that since one gallon per super yard equals about $\frac{1}{5}$ in. (·217 in.) in depth, a rainfall of $\frac{1}{30}$ in. per hour over a total area of 8 plus 16 equals 24 yards will produce 4 gals. per head per hour, which represents the maximum capacity of disposal works, whereas the rainfall would have to exceed $\frac{1}{10}$ in. per hour, or three times the above rate, to produce the same quantity when only the back roofs and yards are drained into the sewers, so that the admission or exclusion of surface water from front roofs and streets must have an exceedingly important influence on the frequency with which the discharge of outfall sewer exceeds any given multiple of the dry weather flow which may be fixed upon as the capacity of disposal plant.

In districts which are not fully built over the area of impervious surfaces is usually assumed to be proportional to the length of streets, the width of streets, roofs and yards being estimated according to the nature of the district, while due allowance must in any case be made for any large open spaces or public buildings, and in calculating the rate of sewer discharge produced by a given rainfall it is essential that due allowance should be made for the time actually required for the storm water to flow through the sewers to the outfall, which has been well defined as the period of concentration.

A combined system of sewerage not only has the disadvantage of increasing the danger arising from the too frequent use of storm overflows, but it must also make a very appreciable difference in the total volume of storm water which the outfall works are called upon to purify annually, since they may have to be operated to their fullest capacity whenever the slightest storm occurs.

It therefore follows that if the overflows on sewers were only allowed to come into action during exceptionally heavy rain (say exceeding ·1 in. per hour) it would be far more economical and satisfactory to divert the surface water as far as possible by providing a separate system of drains to carry it off, instead of attempting to purify it when discharged at the sewage outfall, by increasing the capacity of disposal works, and possibly incurring additional heavy expense for chemical precipitants and pumping.

The relative frequency of storm overflows at different places has hitherto received but little attention, but the question as to how far the extra expense of constructing duplicate sewers and house drains is justified by the saving effected in cost of sewage disposal works has formed the subject of endless discussion, which has been by no means simplified by the introduction of various side issues, such as the possibility of connections being made to the wrong system, and the disadvantage of multiplying pipes in narrow roads and passages when the separate system is too strictly enforced in dealing with back drainage from small cottage property.

There can be no doubt that with the conditions of ordinary practice, if a given amount of sewage and a given amount of storm water have to be conducted along a particular street, through underground channels, it can be done cheaper in one channel than in two; but in laying out new schemes of sewerage for inland towns, where sewage cannot be discharged into tidal water and may have to be pumped or artificially treated, the Author would almost invariably recommend that all rain water should be rigidly excluded from the sewers, except that falling on back roofs and yards of small undetached houses, together with cab-stands, markets, and other paved areas from which the washings are likely to be exceptionally foul.

By thus restricting the admission of storm water to the sewers the volume of sewage and storm water discharged at the outfall will only on rare occasions exceed the quantity for the treatment of which it is possible to construct efficient disposal works at a reasonable cost, so that the brief duration and infrequent occurrence of storm overflows will not be likely to seriously pollute the water courses into which they discharge, since they will hardly ever occur, except when the streams or rivers are already swollen by exceptionally heavy rain.

It therefore seems fair to conclude that when new sewerage schemes have to be carried out the preference usually given to the partially separate system is fully justified on account of the far more effective protection which it affords against the pollution of water courses with sewage at a time when they may not contain sufficient water to thoroughly dilute it, of course assuming that the capacity of sewage disposal works must be approximately the same in any case.

The fact that the disposal works are at the same time enabled to purify the greatest possible proportion of foul first washings discharged by the sewers during the early stages of a storm is of special importance in a flat district, where the sewers cannot be laid with self-cleansing gradients, as they then become sewers of deposit in which large quantities of solids accumulate during dry weather, so that when a sudden rush of storm water comes an immense quantity of highly polluting matter may be discharged at the outfall, and if the works cannot deal with it, it must pass direct to the stream, where it may do far more harm than a corresponding quantity of ordinary dry weather sewage which is in a fresh state, and therefore much less offensive.

It has frequently been urged in favour of a combined system of sewerage that the first washings from streets in a thickly-populated district are of such a foul character that they cannot be safely discharged into a water course without some measure of purification, but it scarcely seems necessary to further emphasise the fact that the admission of road water to the sewers simply has the effect of transferring the pollution from one point to another, and, so long as the capacity of disposal works is a fixed quantity, it is far better to reserve these for sewage and leave the road water to take care of itself, rather than mix the two together and then to treat only part of the mixture.

This difficulty may, however, be overcome to some extent in hilly districts by the use of leaping weirs on the shallow surface water drains, by which the foul street washings may be automatically discharged into the sewers when the volume of storm water is small, at the commencement of rain, after a period of drought, or when the surfaces of streets are artificially washed with small volumes of water; but when the volume increases, and the water is consequently in a comparatively unpolluted condition, the whole of it is conveyed direct to the stream without entering the sewers at all.

This type of leaping weir is so arranged that when the surface water drain is at a higher level than the sewer the former is made to discharge into a small chamber or manhole, in which a narrow horizontal orifice is formed immediately under the inlet, so that when the flow of storm water is small it falls through this orifice into a channel underneath communicating with the sewer, but when the rate of discharge is increased the greater velocity of the storm water causes it to be projected beyond the orifice into a second channel discharging into the stream; it is necessary, however, in order to render this arrangement effective, that the storm water drain should have a fairly good gradient to give the required velocity of approach.

A somewhat similar arrangement is sometimes used in place of an ordinary storm overflow on the sewers, where it is desired to divert the whole contents of the sewer to the stream when a certain rate of discharge is reached, but this is only permissible under exceptional circumstances, as the discharge of unpurified sewage into water courses should only be allowed so long as the disposal works are dealing with their full capacity, when it is unavoidable.

There are cases, however, where it is necessary to pump all the sewage from a low level portion of the district to the outfall works, and in order to avoid surcharging the low level sewers during heavy storms it may sometimes be necessary to divert the whole rather than a portion of their contents at any point where the levels may permit of an outlet by gravitation, thus affording such relief as may be necessary to enable the pumping plant to deal with the remaining quantity without putting the sewers under pressure.

In estimating the probable quantity of storm water which is likely to reach the outfall, the effect due to the extent and configuration of the drainage area should not be lost sight of, as it is evident that the rain water will be carried off much more quickly in a hilly district than in a flat one, while it frequently happens in a large district that rain does not fall over the whole area at the same time; the nature of the soil also has an important influence, especially in the case of combined sewers, as an impervious subsoil causes a very large proportion of the rainfall to run off the surface which would soak into the ground on a porous gravelly soil, and rapidly melting snow may affect the sewer discharge even more than heavy rain.

The present requirement of the Local Government Board that all sewage works shall provide for treating a volume of sewage and storm water equal to six times the dry weather flow is also open to some criticism, on the ground that in taking the dry weather flow as a basis of calculation, no allowance is made for the wide variations in total volume per head of the population at different places, or the constant fluctuation in rate of discharge from sewers which takes place throughout the day and night, the minimum sewage flow in an ordinary sewer during dry weather being roughly about half the mean, while the maximum is usually about twice the mean.

It is evident that the adoption of an arbitrary standard may result in one local authority being called upon to purify a sewage which is far more dilute than that which another may be allowed to discharge without treatment, and in the event of a storm occurring simultaneously with the period of maximum sewage flow about mid-day the degree of dilution reached before any overflow takes place will be much less than if a similar storm took place at night.

In order to allow for such local variations it would be necessary to study their cause, and ascertain how far the sewage flow is augmented by the admission of subsoil water and trade waste to the sewers or extravagant use of water supplied for domestic purposes; but since all these causes of excessive sewage flow are usually capable of prevention, they would scarcely seem to justify a local authority in claiming any modification in their favour of the standard applied to other places with a smaller sewage flow per head, unless it could be shown that the cause of their difficulty was really unavoidable.

Although the quantity of storm water to be provided for in designing sewers or disposal works can be approximately estimated in the manner already described, it is an immense advantage if such calculations can be based on the actual observations of rainfall and sewage flow taken at a number of points in the district and extending over a considerable period, instead of adopting a purely empirical method; and as it is very necessary to know the rate or intensity of rainfall as well as the frequency and duration of storms, the use of automatic continuous recording gauges of the type described in Chapter XII. is to be strongly recommended in preference to ordinary observations of a more or less intermittent and casual character.

When such records are available on sewage disposal works, they provide the means of readily estimating the actual percentage of the total annual sewage flow which is discharged in an unpurified state during storms, and thus afford really reliable evidence of the efficiency or otherwise of the whole plant, when taken in conjunction with the analysis of purified effluent and observations of the river flow, as showing the relation between volume of sewage effluent or storm overflows and the water available for dilution in the river.

With regard to the method of treating storm water when it reaches the outfall, the present requirements of the Local Government Board have already been briefly stated in Chapter I., and it will be observed that the following provision must be made for disposal works where sewers are laid on the combined system.

"(1) Treating fully, as ordinary sewage, a volume of mixed sewage and storm water equal to three times the daily dry weather flow of sewage; and (2) Dealing with the excess of storm water up to six times the dry weather flow, either by passing it through a special and separate storm filter of sufficient extent, or by delivering it on to a special area of prepared land other than that in use for the treatment of the effluent from ordinary tanks and filters. If a special storm filter be provided for this purpose, it should be of sufficient extent to allow a rate of filtration of 500 gallons per square yard per diem."

The above requirements imply that a certain part of the works should be set apart for storm water, while the remainder should be reserved exclusively for the treatment of sewage mixed with storm water; but since the whole of the liquid discharged at the outfall during storms must be of an equally polluting character it is far better, in the Author's opinion, to treat it all in the same way and thus utilise the whole plant to its fullest capacity, while at the same time equalising the work done by every unit as far as possible.

So long as their requirements remain unaltered it is only natural that local authorities should endeavour to avoid unnecessary expense by constructing so-called cheap storm water filters, which are supposed to work at a much more rapid rate than that which is allowed for ordinary sewage filters, but which, owing to their inferior construction, are seldom of much real value, and it would be far better to spend the same amount of money in enlarging the ordinary sewage filters, which can be kept in regular work and maintained in the highest possible state of efficiency.

The term "storm water filters" is now quite commonly understood to mean an area of very roughly constructed filters, frequently unprovided with any adequate means of distribution or underdrainage, while the fact that they are only used occasionally during wet weather renders it impossible to maintain their bacterial activity, and they really act as little more than strainers to remove some of the grosser solid matters in suspension, having but little effect on the dissolved impurities.

It is, however, well known to anyone having experience of such works that the expense of constructing bacteria beds is mainly due to the cost of filtering media; and it would therefore seem obvious that if the same media must be used for storm water and sewage filters only a comparatively small saving can be effected by omitting floors, underdrains, walls, or distributors, and their omission is by no means economical in the end, as it is impossible to derive the best results from the expenditure incurred for filtering media unless the filters are properly constructed with efficient means of distribution and drainage, as explained in the preceding chapters.

In those cases where surface water is excluded from the sewers as far as possible and carried off by a separate system, the English Local Government Board are usually satisfied if the disposal works provide for fully treating as sewage a volume of storm water and sewage equal to twice instead of three times the dry weather flow, so long as the provision for storm water is increased to deal with the excess up to six times the dry weather flow, but they have not hitherto consented to any reduction in total area or capacity of filters, even when the whole of them are constructed in such a way that they can all be used for sewage in dry weather without the risk of causing pollution by a bad effluent, which would result from the use of ordinary storm water filters for the same purpose.

There can be no doubt that the question of what provision should properly be made for the treatment of storm water presents greater difficulties than any other which arises in designing sewage disposal works, and it is equally true that from a rivers pollution point of view the Local Government Board's present requirements are on the safe side; but when it is recognised that there are few places in England where the average aggregate duration of rainfall exceeds 30 days in the year, and it is therefore for only a comparatively short period annually that the sewage flow is increased by storm water, it certainly seems somewhat unreasonable that the additional works required for the treatment of the storm water should involve an expenditure which frequently exceeds the cost of the plant necessary for treating the dry weather sewage flow throughout the year; and yet this is precisely the present position when provision has to be made for the treatment of sewage and storm water at a rate equal to six times the dry weather flow.

No one will be likely to dispute the well-established fact that during the early stages of a storm after a period of drought the liquid discharged by the sewers will contain quite as much organic matter of a polluting character as the ordinary dry weather sewage, and the necessity for subjecting it to some process of purification before it can be safely discharged into any inland water course is generally admitted; but it is important to observe that, although these foul first washings may enter the sewers almost simultaneously all over the district, their arrival at the outfall may extend over a very considerable length of time when the storm water falling in a remote part of the district has to pass through a long length of sewers.

This fact undoubtedly makes it more difficult to provide for the treatment of first washings in a large district than a small one, but the difficulty is counterbalanced to some extent by the unequal distribution of rainfall over a large district, since it frequently happens that heavy rain only falls in a portion of a large area at the same time, and it is the average rate of rainfall over the whole district that governs the rate of discharge from outfall sewer at any given time, so that this local variation in rate of rainfall and the time occupied in passing through the sewers both tend to modify the effect of sudden storms, owing to the discharge of storm water at the outfall being spread over a much longer period than that in which it actually falls on the ground in the form of rain.

In this connection it is also worth noticing that nearly all the recorded observations seem to show that the maximum rate of rainfall increases as the duration of rainfall diminishes, so that heavy rain seldom lasts long, and the probable rate of discharge from outfall sewers cannot be even approximately estimated from the rainfall unless its duration exceeds the time occupied in its passage through the longest sewers in the district.

Having regard to the great variety of local circumstances affecting the rate of sewer discharge during storms, it is difficult to lay down any hard-and-fast rule which could be applied under all conditions as to the quantity of storm water for the treatment of which sewage disposal works may reasonably be expected to provide; but it certainly seems unnecessary in most cases to construct works capable of dealing with six times the dry weather flow, just as if this quantity had to be treated continuously, whereas it has already been pointed out that in most parts of England the total duration of rainfall seldom exceeds, say, one-tenth of the year, and when front roofs and roads are drained on the separate system the volume of sewage and storm water reaching the outfall works in any one year is never likely to exceed the dry weather flow for the same period by more than, say, 50 per cent., instead of the 500 per cent. for which provision is at present required.

The Author has therefore suggested in his evidence before the Royal Commission now sitting that the Local Government Board's present requirements might be considerably modified in regard to the treatment of storm water with a view to reducing the cost of sewage disposal works, while at the same time maintaining their efficiency for the purpose of preventing the pollution of inland water courses.

The present rule, that when bacteria treatment is adopted the bacteria beds shall have a sufficient capacity to treat a volume of sewage equal to twice the dry weather flow in the case of a separate sewerage scheme, or three times the dry weather flow for a combined scheme, cannot be regarded as unnecessarily stringent, and the Author has no fault to find with the distinction drawn between districts sewered on the separate and combined system, as it seems only reasonable that the extra expense involved by the former should be counterbalanced to some extent by reduced cost of sewage disposal works; but he is strongly of opinion that the Board's present requirements in regard to the treatment of storm water are excessive, and frequently involve an unnecessarily heavy expense.

The futility of expecting the highest efficiency from bacteria beds which are only used occasionally has already been emphasised, and in the Author's experience the results obtained from the so-called storm water filters usually provided for the purpose of complying with the Local Government Board's requirements are really insignificant when considered in relation to their cost, this lack of efficiency being frequently due to excessive economy in their construction as well as the unfavourable conditions under which they are worked, while a much smaller expenditure laid out in the provision of storage reservoirs to equalise the flow would enable the ordinary sewage filters to deal with practically all the storm water reaching the outfall without exceeding the maximum rate of working for which they are designed or detrimentally affecting the purity of the final effluent, which should, in fact, be improved rather than otherwise by keeping the beds in more constant use at a uniform rate of filtration.

These storm water storage reservoirs may be more properly called equalising tanks, and they should be so arranged that their contents can be gradually decanted into the ordinary sewage tanks as soon as the discharge from the sewers falls below the rate of two or three times the normal dry weather flow represented by the full capacity of bacteria beds.

This process of decanting from the equalising tank can be quite readily accomplished, when sufficient fall is available, by means of an automatic float valve fixed on the outlet, which limits the rate of discharge to a uniform quantity quite independent of the variable depth of liquid in the tank; but where the levels do not permit of this, and pumping must therefore be resorted to, the quantity of storm water to be raised during the year is usually small compared to the dry weather flow, and the additional cost should be well repaid by the greater efficiency of the plant which must result from the increased uniformity of its operation.

It may sometimes be found convenient to secure the same object of equalising the flow of tank effluent to the filters by placing an automatic valve on the outlet of the ordinary sewage tanks, which will limit the discharge to the required rate, and providing the necessary storage by increasing the depth of the tanks so that the surface of the liquid may rise to a considerable height above the outlet, which will become submerged whenever it cannot discharge at a rate equal to the flow of sewage and storm water entering the tank, the capacity of the tank above the outlet level representing the available storage.

An arrangement of this description was adopted some years ago for the liquefying tanks at Barrhead, where the outlet is about 18 ins. below the overflow at top water level, the storage capacity of the intermediate space being 67,500 gallons, or about one-third of the estimated dry weather flow for which the works were designed.

This arrangement has the advantage of occupying less space than an independent equalising tank, and may effect some slight saving in cost, but the fluctuating water level is undesirable in a liquefying tank, owing to the disturbance caused by the increased velocity of flow near the inlet and the difficulty of equalising the current near the outlet, since it is impossible to adopt the usual method of drawing off the effluent by a continuous weir as recommended in Chapter III., and in the Author's experience no other method is equally satisfactory.

With regard to the proper capacity of equalising tanks, this should properly depend, to some extent, upon the probable fluctuations in sewage flow and the particular method of treatment adopted; but assuming that it is desired to equalise the flow through liquefying tanks having a capacity equal to one day's dry weather flow, so that the sewage shall always remain in the tanks at least eight hours, it is evident that the outlet valve must be set to discharge at a rate not exceeding three times the dry weather flow.

If, under the above circumstances, an equalising tank is provided with a capacity of, say, half the daily dry weather flow, and this tank must be filled before the storm overflows come into operation, their action will be deferred for a period which will vary inversely with the rate of sewage flow: thus, with a discharge equal to six times the dry weather flow, the overflows will not come into operation for at least three or four hours after the beginning of a storm.

It will therefore be seen that the provision of such an equalising tank will enable the works to deal with all the foul first washings of the sewers for a certain length of time without excessive variations in rate of working for sewage tanks or filters, and even when the equalising tank is full the overflows will only come into action so long as the sewage flow exceeds the maximum capacity of the works, or, say, three times the average rate of dry weather flow, and their action will always be deferred for a period equal to the time occupied in filling the tank.

In cases where the sewers are laid out on the separate system, and the sewage filters are only required to treat twice the average dry weather flow, an equalising tank of the capacity suggested above would be capable of storing the surplus up to four, five, or six times the dry weather flow for periods of six, four, and three hours respectively, instead of twelve, six, and four hours in the case of a combined scheme, for which the capacity of the works is increased by 50 per cent., so that they are thus enabled to deal with a very considerable quantity of storm water without exceeding the normal rate of working for which the filters must in any case be designed.

It has frequently been suggested that the treatment of storm water beyond two or three times the average dry weather flow might be provided for by accelerated working in tanks and filters, but since it is not usually found necessary to provide ordinary septic or precipitation tanks with a greater capacity than one day's dry weather flow, it will be seen that the velocity through the tanks will be increased by more than 300 per cent. whenever the sewage flow exceeds three times the dry weather flow, and the duration of tank treatment will be reduced below eight hours, which, in the Author's experience, is the least with which a reasonably good tank effluent can be even temporarily obtained unless excessively large quantities of chemicals are used for precipitation.

By preparing comparative estimates for storm water filters as required by the Local Government Board and for equalising tanks having a capacity equal to half the dry weather flow, the Author has found that under ordinary conditions the cost of the tanks is less than half that of the filters in the case of a separate scheme, and but little more than half for a combined scheme where the tank can be filled and emptied by gravitation, so that even when pumping is necessary for this purpose the adoption of equalising tanks would seldom cost more than storm water filters, and their use would be decidedly preferable, as it enables the ordinary sewage filters to do more work and effect a far higher degree of purification than would be possible with storm water filters which are only used at irregular intervals, and are therefore never in a thoroughly efficient condition.

The fact that an equalising tank only provides for treating storm water beyond, say, three times the dry weather flow, for a period corresponding with the time occupied by filling it, is not a practical disadvantage, as the storm overflows need never come into action until the rate of flow exceeds six times the dry weather flow, or until the foul first washings from the sewers and drainage areas have been dealt with, and the water courses have become swollen with the rainfall extending over a considerable length of time, so that the liquid passing the overflows is not likely to cause serious pollution.

The length of time for which an equalising tank holding half the dry weather flow is capable of storing storm water is shown below in tabulated form for the purpose of clearly indicating the effect produced by the different bases adopted by the Local Government Board in calculating the capacity of ordinary bacteria beds for treating two or three times the dry weather flow, in the case of separate and combined schemes respectively, and assuming that their rate of working will never be allowed to exceed a certain fixed maximum.

For example, a case may be taken where the dry weather flow is, say, 10,000 gallons per hour, and the Local Government Board will, in that case, require bacteria beds to be capable of treating 30,000 gallons per hour for a combined scheme, and 20,000 gallons per hour for a separate system of sewerage; so that if the storm overflows are arranged so that the discharge of sewage and storm water at the outfall is limited to a rate of six times the dry weather flow, and the equalising tank holds 12,000 gallons, or half the daily dry weather flow, it is evident that it will be capable of storing the maximum quantity of storm water which can reach the outfall in excess of the filter capacity for at least three or four hours, and proportionately longer when the rate of flow is less than six times the dry weather flow, thus :—

Rate of sewage flow	3	4	5	6 times d.w.f.
Duration of storage	—	12	6	4 hrs. (combined)
,, ,, ,,	12	6	4	3 ,, (separate)

When the sewage and storm water must necessarily be raised to the outfall works by pumping, the storage capacity of pump-well may be arranged to answer the same purpose as an equalising tank, and if the works are designed to treat, say, three times the dry weather flow, the discharge from the pumps need never exceed this rate, any excess up to six times the dry weather flow being stored in the pump-well for a certain period, or until the rate of sewer discharge falls below the rate of pumping.

The cost of constructing underground pump-wells or storage tanks is, however, far greater than the cost of equalising tanks of the same capacity, which can be built at any convenient level, and it is therefore more economical (in large works at any rate) to allow for pumping at the maximum rate required by the Local Government Board, and provide storage at the outfall rather than the pumping station, where it is frequently a difficult and expensive matter to deal with the sludge deposited in an underground pump-well, and by pumping the sewage in a fresh state there is far less risk of causing a nuisance than when it is first allowed to become partially septicised and then subjected to violent agitation in passing through the pumps and rising main.

It therefore seems reasonable to conclude that if a sewage pumping plant is capable of raising six times the dry weather flow in 24 hours, it is only necessary to provide a pump-well with storage capacity equal to the estimated flow of sewage for the portion of each day in dry weather when the pumps are not working, and by arranging an automatic alarm bell to ring whenever the pump-well is nearly full, the man in charge of pumping station will have no excuse for not pumping when necessary at a sufficient rate to prevent the improper use of storm overflows, which should always be open to examination by duly authorised Inspectors of the County Council, Rivers Board, or other Public Authority responsible for the prevention of river pollution.

The arrangement and design of pumping plant is only indirectly connected with the problem of sewage disposal, and is therefore beyond the scope of this book, but it is worth while to observe that the plant should in all cases be divided into at least two units which can be worked independently or together, so that when repairs are necessary the whole plant need not be shut down.

For larger works the pumping plant would naturally be divided into a greater number of units, and the question then arises as to what variation, if any, should be made in their relative capacity, but as it is only by making all the units of the same size and capacity that perfect interchangeability can be secured, the use of pumps of varying sizes is rarely recommended, though it may be claimed for the latter arrangement that some advantage is gained by being better able to vary the rate of pumping to suit the sewage flow.

Chester and Worcester may be mentioned as instances of places where pumps of different sizes are used for raising varying quantities of sewage and storm water, and with three pumps having a capacity of one, two, and four times the dry weather flow respectively, it is possible to pump at the rate of one, two, three, four, five, or six times the dry weather flow without using more than two pumps at a time, whereas with three pumps of uniform size and the same total capacity, it is only possible to pump at the rate of two, four, or six times the dry weather flow, but in actual practice this is not likely to be a serious drawback, at any rate where equalising tanks are used in the manner already described.

The general principles affecting the design of works for the separation or disposal of storm water having been sufficiently explained, the actual construction of these works still remains to be considered, but since there is no essential difference between the works usually adopted for treating storm water and sewage, the descriptions of tanks and bacteria beds given in preceding chapters may be applied equally to either, and no further explanation is therefore necessary except in regard to storm overflows and automatic valves used for controlling the diversion of storm water from the sewers to the streams when the sewer discharge exceeds a certain fixed rate or multiple of the dry weather flow.

The Local Government Board have hitherto required that all storm overflows shall consist in some form of fixed weir by which the excess beyond, say, six times the dry weather flow may be discharged, while the remainder of the more or less diluted sewage shall be treated at the disposal works, regardless of the fact that the liquid allowed to escape direct to the stream will contain approximately the same proportion of polluting organic matter as that which is at the same time undergoing a process of purification, while the discharge from such an overflow during the early part of a heavy storm may be even more foul in character than the liquid which is being carefully purified at a later period when the streets and other surfaces have been washed clean.

The ordinary weir overflow usually consists in a horizontal sill or weir, either straight or curved on plan, which is fixed in the sewer at a height above the invert corresponding with the depth of sewage representing, say, six times the dry weather flow; but unless such an overflow can be constructed on a length of sewer having a uniform gradient for a considerable distance, it is a difficult matter to correctly estimate the depth of sewage corresponding with the required maximum rate of discharge, and even when this has been accurately determined, it is evident that when the sewage rises above the weir level, the overflow will only take a portion of the surplus, and the quantity passing on to the outfall works will exceed the required maximum on account of the greater depth and velocity of flow unless some kind of orifice or automatic valve is placed in the sewer just beyond the overflow.

In order to obviate this, a horizontal plate is sometimes fixed across the sewer at the overflow level, and only the sewage passing between the plate and the invert goes on to the outfall works, while everything above the plate goes direct to the stream, after passing an inclined screen by which all rags, paper, and other floating rubbish may be deflected down the foul water sewer.

An overflow of this description is illustrated in Fig. 64 which shows the method of construction recently adopted for relieving some of the main intercepting sewers in Birmingham, in which the deflecting screen is formed with No. 15 gauge wires $\frac{1}{2}$ in. apart, and this type of overflow is undoubtedly a great improvement on the ordinary weir, especially when the position of the sewer permits of the surplus storm water being carried straight on to the stream, while the dry weather sewage flows under the plate, and passes to the outfall works.

The large volume of storm water can thus follow a straight

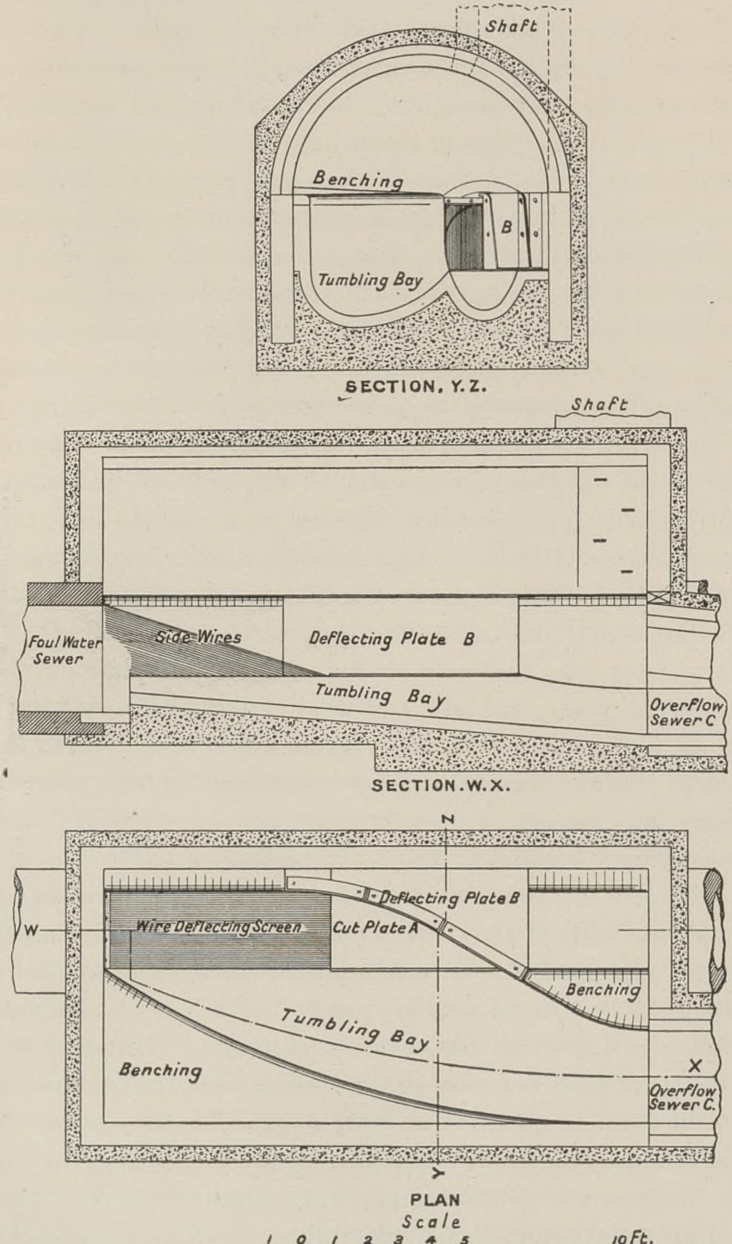

Fig. 64.—Details of Fixed Storm Overflow, with Deflecting Plate and Screen for Storm Water as Used at Birmingham.

(Reproduced by permission of the City Engineer, Birmingham.)

course without meeting the obstruction involved by any sharp change in its direction of flow, and since the bulk of the heavy suspended matter is carried along near the invert of the sewer very little of it will pass into the stream, while even if the screen is omitted, the small quantity of floating matter which is carried past the overflow plate with the storm water will be far less objectionable than the heavier solids, which would rapidly settle to the bottom in still water, and thus cause the accumulation of a highly offensive deposit in the bed of the stream, which is liable to produce a serious nuisance by its subsequent decomposition.

It is, however, found more convenient in most cases to divert the surplus storm water to one side of the sewer, so that the latter may be continued in a straight line, and this can readily be done with the type of overflow shown in Fig. 64 by forming a weir at the side of the sewer level with the separating plate, and the storm water can be deflected so as to pass over the weir by fixing a vertical plate on the top of the horizontal one, and, the vertical plate being fixed at an angle of about 30 degs. across the sewer, it turns the storm water to one side without causing any serious obstruction, and this type of overflow has also been adopted with satisfactory results in the Birmingham sewers.

No part of the above arrangement being movable, it complies with the requirement of the Local Government Board and several other authorities who object to any moving parts in a storm overflow, and since it can be used with slight modifications under most ordinary conditions, it is unnecessary to describe the numerous alternative types of storm overflows that have been designed for achieving the same object in other ways.

In cases where moving parts are permissible there is no difficulty in automatically controlling the flow of sewage to the outfall works by means of a penstock valve placed on the sewer below the storm overflow weir and operated by means of a float, which can be so arranged that when the dry weather flow is exceeded to any desired extent the penstock shall be closed and the whole contents of the sewers discharged direct into the stream by a storm overflow weir.

As an alternative, the penstock may be so arranged that when the rate of sewage flow exceeds the capacity of disposal works the penstock will be automatically raised or lowered to an extent sufficient to maintain a uniform discharge to the works, even when the sewage has to rise in the sewer to a considerable height above the normal level before reaching the overflow weir, which must be above the water course into which the surplus storm water is to be discharged, whereas the sewers may in many cases be at a considerable depth below it, and must of necessity be put under pressure by surcharging before the overflows can come into action.

It is, in fact, practically impossible to properly regulate the flow of sewage to the outfall without the use of a movable valve of this description when the sewers are much below the natural water courses, as any overflow weir must be placed above the top of the sewer, but the difficulty can be quite readily overcome by the means above described, and considerable saving may thus be effected by reducing the size and cost of main outfall sewers, though in cases where these are already large enough to carry all the sewage and storm water an overflow need only be provided at the outfall itself, or at any other points where an outlet is available at a lower level than the sewer.

In the case of pumping schemes the Local Government Board usually object to any overflow being provided at or near the pumping station, owing to the possibility of its being used for discharging insufficiently diluted sewage, which should be properly pumped to the outfall works for purification.

There are, however, many pumping schemes in which practically the whole of the sewers are below the only water courses available as outlets for storm water, and (in the absence of adjustable valves) whenever the sewer discharge

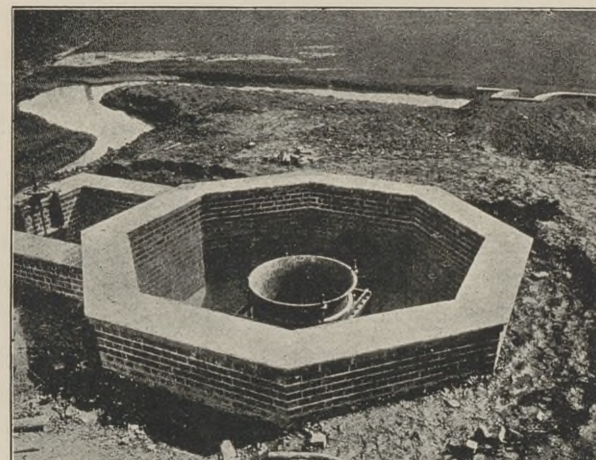

Fig. 65.—Adjustable Bell-mouth Overflow, with Telescopic Joint and Penstock Valve on Sewer to Outfall Works

(Reproduced by permission of Messrs. Willcox & Raikes, Birmingham.)

exceeds the capacity of the pumps the water level in pump-well will necessarily rise till it reaches the overflow, wherever this may be placed, and whenever the sewage flow exceeds the rate of pumping the surplus must either pass over the storm overflow or escape through the manhole covers on the sewers, so that in such cases the omission of an overflow at or near the pumping station is usually impracticable, unless the flow of sewage is restricted by means of a penstock or valve on the outfall sewer in the manner already described.

Fig. 65 shows an adjustable "bell mouth" overflow, which has the advantage of affording the greatest possible length of weir for use in a confined space where the overflow must discharge into a water course at a higher level than the sewer, and since the bell mouth is fitted with a telescopic joint its height can be adjusted by screws so as to give the head necessary for discharging any required quantity of sewage through a penstock or orifice placed in the sewer between the overflow and the outfall.

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CHAPTER XI.

Purification of Liquid Trade Wastes.

Treatment by manufacturers—Discharging into public sewers—Royal Commission Report No. 3—Powers and obligations of local authorities—Effect of trade waste on sewage treatment—Disputes between local authorities and manufacturers—Desirability of Central Authority—Special charges on manufacturers—Constitution of Central Authorities—Effect of mixing sewage with trade waste—Peculiarities of waste from wool scouring, bleaching, and dye works, paper mills, galvanising, breweries, and tanneries.

In dealing with this subject from an engineering point of view, the Author does not propose to go very fully into the somewhat complicated questions of chemistry which frequently arise in determining the most suitable method of treating various kinds of liquid trade waste before it becomes mixed with domestic sewage, but prefers to direct attention to the circumstances under which trade wastes may properly be admitted to the public sewers or discharged into natural water courses, together with their effect upon the arrangement and capacity of sewage disposal works.

Liquid trade waste may be defined as the water which has been used in manufactories, together with all the waste products of manufacture which are capable of removal by the water carriage system, and which are liable to injuriously affect any natural water courses into which they may be discharged, either by polluting the water or obstructing the channel with solid deposit.

Although trade waste is usually free from the germs of disease which are found in domestic sewage, the impurity which it contains may have an equally injurious effect upon public water supplies or fish life, owing to its liability to offensive decomposition or its naturally poisonous character, while the deposit of solid matter may be highly objectionable in the interests of navigation and riparian owners.

In the case of inland towns, at any rate, the purification of trade waste containing organic impurities or chemical poisons may therefore be regarded from a river pollution point of view as hardly less important than the treatment of domestic sewage; and it is for this reason that the subject is now receiving so much attention at the hands of engineers, chemists, and bacteriologists, while the Royal Commission on Sewage Disposal has also devoted a considerable amount of time to its consideration

Since manufactories are usually situated in the vicinity of populous places, where works must in any case be provided for the purification of sewage, the question at once arises as to whether the manufacturing waste should be admitted to the sewers and treated with the sewage at the public expense, or whether it should be dealt with by the manufacturer independently; and as this question has been very fully dealt with by the Royal Commission, the following abstracts from their Third Report will serve to clearly explain the present position of the matter.

"4. The main statutory provisions in regard to this matter are contained in Section 21 of the Public Health Act, 1875, and Section 7 of the Rivers Pollution Prevention Act, 1876. These provisions are as follows :—

Section 21, *Public Health Act*, 1875.—'The owner or occupier of any premises within the district of a local authority shall be entitled to cause his drains to empty into the sewers of that authority on condition of his giving such notice as may be required by that authority.'

Section 7, *Rivers Pollution Act*, 1876.—' Every sanitary or other local authority having sewers under their control shall give facilities for enabling manufacturers within their district to carry the liquids proceeding from their factories or manufacturing processes into such sewers.

Provided that this section shall not extend to compel any sanitary or other local authority to admit into their sewers any liquid which would prejudicially affect such sewers, or the disposal by sale, application to land, or otherwise of the sewage matter conveyed along such sewers, or which would from its temperature or otherwise be injurious in a sanitary point of view.

Provided also that no sanitary authority shall be required to give such facilities as aforesaid where the sewers of such authority are only sufficient for the requirements of their district, nor where such facilities would interfere with any order of any court of competent jurisdiction respecting the sewage of such authority.'

6. According to the opinion of the Law Officers of the Crown, Section 21 of the Public Health Act, 1875, has no application to trade effluents.

9. Under the provisos of Section 7 of the Rivers Pollution Act, 1876, the local authority may refuse to allow trade effluents to enter sewers on any of the following grounds :—

1. That they would injure the sewer.

2. That they would prejudicially affect the disposal of the sewage.

3. That their volume is too great for the capacity of the sewers.

4. That their admission to the sewer would interfere with some order of a court of competent jurisdiction.

12. It is obvious, therefore, that while the existing law is apparently precise, the difficulties attendant on its application in any particular case render uncertain the position and rights of any particular manufacturer.

One of the results of this uncertainty has been that the work of enforcing the purification of manufacturing effluents has been considerably hampered and delayed.

A manufacturer when requested to put down purification works has replied that he is in negotiation with the local authority with a view to discharging his effluents into the sewer.

The local authority then frequently 'drift along for years without giving any definite answer one way or another.' They doubt their liability in the matter, and often allege great difficulty in deciding whether the purification of the mixture of ordinary sewage and the manufacturing effluent will be practicable or not.

Moreover, we find as a fact that the attitude of local authorities towards manufacturers has differed widely, and that many manufacturers have been seriously handicapped.

Some authorities definitely refuse to allow any manufacturing effluent to enter their sewers, others have allowed connections subject to the manufacturer observing conditions and adopting preliminary treatment, while others have allowed connections without conditions.

From the table handed in by the West Riding District Councils Association, it appears that in twenty-nine of the districts represented by that Association in which trade effluents occur, the Councils refuse to allow trade effluents to enter the sewers, in four they are admitted subject to conditions, in sixteen they are admitted unconditionally.

15. In addition to the difficulties attendant on the application of the existing law in any particular case,

the following further causes of differential treatment are important.

1. Only those manufacturers who happen to have a sufficiently large sewer near their premises have any claim to discharge their effluent into the sewer, and

2. A local authority in constructing a system of sewerage have the absolute right to elect that they will not construct the sewers of sufficient capacity to take trade effluents.

16. We are satisfied that unless the law is altered differential treatment of manufacturers will continue, and that, as a consequence, trade will continue to be seriously hampered, if not, indeed, injured.

We fully share in the view which has been pressed upon us from all sides, that as far as practicable all manufacturers should be placed on an equal footing. This is desirable, not only in fairness to manufacturers, but also in the interest of river purification.

We think that it is practicable to secure far greater uniformity than at present exists, and we therefore now proceed to indicate by what means this end may be secured.

17. In considering what remedies are available, it has been necessary to determine whether the purification of sewage, when mixed with trade effluents, is practicable.

On this question we have taken a considerable amount of evidence from officers and others representing local authorities who have had actual experience in the matter.

We find that sewage containing trade effluents is generally more difficult to purify than ordinary sewage, and that the following are the chief causes of difficulty :—

1. The trade effluents may be turned into the sewer at irregular intervals, so that the composition of the sewage

as it arrives at the sewage works varies considerably throughout the day.

2. The trade effluents may contain large quantities of solids in suspension, which tend to choke the purification plant.

3. The trade effluents may be very acid or very alkaline, or otherwise chemically injurious.

The general opinion of these witnesses, however, is that it is practicable, in the great majority of cases, to purify mixtures of sewage and trade effluents if the manufacturers adopt reasonable means for removing the solids, equalising the discharge, and, when necessary, neutralising the trade effluent.

Moreover, there is some evidence to indicate that even if the manufacturers do not adopt such means the purification of the mixture of sewage and trade effluents is still practicable, though the difficulties and cost are much greater.

But the evidence clearly shows that, wherever practicable, the manufacturer should adopt means for removing the bulk of the solids in suspension from his effluents, for neutralising it, and for delivering it into the sewer in a fairly uniform manner. And, further, it would seem probable that in some cases the cost to the manufacturer of adopting these preliminary measures would be less than the additional cost which would be thrown on the local authority if the measures were not adopted. Indeed, there is evidence to show that occasionally the removal of the solids has been a source of profit to the manufacturer.

We have examined a large number of effluents from works where sewage containing trade refuse is being treated, and our results fully support the view that it is practicable in the great majority of cases to purify mixtures of sewage and trade effluents if the manufacturers adopt reasonable preliminary measures.

18. We have not yet examined in detail the methods available for the purification of trade effluents, but from an inspection of some manufactories where considerable sums have been expended on purification plant which is inefficient, and also from the evidence, we are satisfied that in some cases at least the purification of the trade effluent by itself would be very difficult to accomplish.

Moreover, the evidence shows that the separate purification of trade effluents is generally more difficult and more costly than their purification when mixed with the ordinary sewage of the locality.

And it has been proved by the evidence and by our own inspection of manufactories that there are many cases, especially in towns, where the manufacturer has not sufficient space on which to erect purification works.

20. The position therefore is as follows :—

Purification of trade effluents by the local authority is in the great majority of cases practicable; purification by the manufacturer is in some cases difficult, if not impracticable; while purification by the manufacturer would generally be more costly than purification by the local authority. It also appears that the local authorities as well as the manufacturers are of opinion that there should be laid on the local authority a distinct obligation to receive trade effluents.

21. Further advantages which would follow from such a change in the law would be that the average standard of purification which would be reached throughout the country would be higher than if each manufacturer separately attempted to purify his own trade effluent, and also that the work of preventing the pollution of rivers would be

greatly assisted, in that the number of purification works to be kept under observation would be diminished.

22. We are therefore of opinion that the law should be altered so as to make it the duty of the local authority to provide such sewers as are necessary to carry trade effluents as well as domestic sewage, and that the manufacturer should be given the right, subject to the observance of certain safeguards, to discharge trade effluents into the sewers of the local authority if he wishes to do so.

We do not think it possible to provide by direct enactment what these safeguards should be. In each district it would probably be desirable that the local authority should frame regulations which should be subject to confirmation by a Central Authority. In most cases, however, these regulations could provide definite standards for the different manufacturers as regards preliminary treatment, and it appears from the evidence that manufacturers would much prefer to have standards to work to.

Power to vary the standards or to dispense with them altogether in special cases would be necessary.

23. Although the duty of receiving trade effluents should, we think, be imposed on the local authority, cases may arise in which they should be wholly or partially relieved of it.

For example, we find that in some instances the effluent discharged from the manufactory is of a composite character, the greater part of which might with advantage be easily dealt with by the manufacturer if it were kept separate. In such cases we think the manufacturer would generally be willing to adopt this course, but provision is necessary for those cases in which the local authority and the manufacturer could not agree.

Further, although we have received no conclusive evidence to show that there are trade effluents which could not be purified by the local authority, we do not deny the possibility of such cases arising.

And it is possible that in some cases, as, for example, of a large manufactory being newly established in a small district, it might be necessary to relieve the authority of the obligation to treat the trade effluent or to enable them to exact some special contribution from the manufacturer, not only for the cost of treatment but also towards capital expenditure.

24. It is obvious therefore that some tribunal will be required for settling differences between the local authority and the manufacturer, and for relieving the local authority in exceptional cases, either wholly or partially, of their obligation to provide sewers and disposal works of sufficient capacity for trade effluents as well as ordinary sewage.

We shall explain in a later section the plan which we think should be adopted. (See section 40.)

25. In many cases a part or the whole of the water which the manufacturer uses in his business is obtained from a stream, and must therefore be returned to the stream.

We do not propose that the manufacturer should by statute be relieved of this liability. If he is able to relieve himself from the obligation by obtaining the necessary consents from other riparian owners, or by providing compensation water, then he might discharge his effluent into the sewer; but the responsibility must rest entirely on the manufacturer: the local authority should be expressly exempted from any liability for the infringement of riparian rights by the discharge into the sewer of water obtained from a stream.

26. We have taken a considerable amount of evidence on the question whether the manufacturer who discharges his

trade effluent into the sewer should be required to pay something beyond his ordinary rates, and, as might be expected, the views expressed are divergent.

It appears that in some few cases manufacturers have, by agreement with the local authority, purchased the right to discharge crude trade effluents into the sewer.

27. The chief argument which has been used against a special charge being made is that a manufacturer who is heavily rated in respect of his premises is therefore entitled to the free use of the sewer.

This argument raises a general question of rating, into which we do not propose to enter, but we may observe that other manufacturers producing little or no trade effluent are rated equally, and that, speaking generally, the amount of the trade effluent is not proportional to the rateable value of the premises.

Moreover, it has been stated in evidence that the amount paid in rates by the manufacturer would in some cases not be equal to the cost of treatment entailed on the local authority.

28. We have carefully considered this question from all points of view, and much may be said in support of the opinion that each manufacturer should be charged with the cost of the purification of his trade effluent.

We cannot, however, disregard the following considerations :—

(*a*) Under the existing law the local authority are not empowered to make a special charge.

(*b*) The evidence shows that, though it would be practicable were such a charge made to ascertain what the charge should be, it would involve a very large amount of labour to settle the charge in respect of each manufactory.

(*c*) In the interests of the community it is desirable that most trade effluents should, subject to certain safeguards, enter the sewers and be purified by the local authority.

(*d*) In the interests of the manufacturers no new restrictions which are not essential should be imposed.

(*e*) A distinction ought to be made between the cases where the manufacturer complies with the regulations as to preliminary treatment and the cases where he does not; and many important witnesses representing local authorities, including Sir Bosdin Leech and Alderman Dreyfus (Manchester), Mr. Hopkinson (Keighley), Mr. Jones (Pudsey), Mr. Beeley (Hyde), Mr. Platt (Rochdale), and Mr. Morgan (Bolton), have strongly expressed the view that no special charge should be made in the former class of cases.

29. Having regard to these considerations, we are of opinion that generally no special charge should be made on the manufacturer in those cases in which the regulations as to preliminary treatment are complied with.

As we have already stated, it is desirable that wherever practicable some preliminary treatment should be carried out by the manufacturer.

But where the manufacturer is unable to comply with those regulations we consider that the local authority should be empowered to make a special charge.

Power should also be granted to make a special charge, even when preliminary treatment is adopted, where there are exceptional circumstances as regards volume, quality, or otherwise.

30. We should leave the actual amount of the charges to be fixed by agreement between the manufacturer and the local authority.

In default of agreement the amount should be settled by a superior authority in the manner hereinafter explained.

31. In those cases in which a manufacturer is precluded

from discharging his effluent into the sewer by reason of the fact that the water which he uses is obtained from a stream, and must therefore be returned to the stream, the duty of purification will still rest with him.

But we do not consider that this will be a serious grievance, as he obtains his water without charge, and this advantage may be set against the cost of purification.

Moreover, it would be open to him to acquire the right to use the sewer by getting his water from some other source or by obtaining the necessary consents of riparian owners below him on the stream.

32. At present a manufacturer discharging trade effluent into a stream can only be compelled to provide "the best practicable and reasonably available means" for purifying his trade effluent.

Proceedings can only be taken against him with the consent of the Local Government Board, and that Board are expressly precluded from giving their consent unless they are satisfied that no material injury will be inflicted on the interests of the industry by such proceedings.

With this general principle we agree, and although we think that in most cases the additional cost of treatment thrown on the local authority by reason of the manufacturer not complying with the regulations as to preliminary treatment, or in consequence of the exceptional character of the trade effluent, would not be a serious burden on the manufacturer if exacted from him, we are of opinion that in cases where the local authority and manufacturer do not agree, and the case has to be settled by a superior authority, power should be vested in the superior authority to reduce the charge below the actual cost, or to postpone it in any case in which they are satisfied that the actual cost would be so great as to inflict a material injury on the manufacturer.

In such a case the onus of proof should rest on the manufacturer.

We think that generally it would be in the interests of the community that a portion of the cost should be met out of the rates, rather than that either the pollution of the river should be allowed to continue or that the works should be closed.

33. Many trade effluents already flow into sewers and are dealt with by the local authority.

In some cases these are first partially purified by the manufacturer, while in others they are subject to no preliminary treatment.

In regard to this point, Dr. Maclean Wilson, the Chief Inspector of the West Riding Rivers Board, stated: 'I think very strongly that the manufacturer will feel aggrieved, and justly so, if the law is not made applicable to cases of old connections, as well as to all cases of new connections'; and other witnesses have expressed the same views.

34. We find that many of these old connections were made before the duty of purifying sewage was enforced on the local authority, and that some have been made without the knowledge of the local authority.

We consider that all manufacturers should be placed on the same footing, and that the proposals which we have made as to preliminary treatment by the manufacturer, and as to a special charge being made upon him by the local authority in certain cases, should apply equally to the manufacturer whose trade effluent already passes into the sewer and to the manufacturer who is only proposing to obtain a connection.

35. In those few cases in which the manufacturer has by agreement with the local authority purchased the right to

discharge trade effluent into the sewer the rights and position of the parties should, we conceive, be governed by the agreement.

36. Mr. Brotherton, M.P., urged upon us the importance of giving manufacturers reasonable time to carry out any requirements which may be imposed upon them. This consideration should, we think, have special weight in the case of existing connections.

37. It appears that in some cases the borrowing powers of the local authority might not be sufficient to enable them to raise the loan necessary to defray the cost of enlarging their works so as to provide for trade effluents as well as ordinary sewage.

Such extensions of the borrowing powers as may be required for this purpose should, we think, be conferred on the local authority.

38. It may also sometimes be necessary for the local authority to construct a sewer for the reception of trade refuse alone, and, in certain circumstances, it may be desirable that the local authority should provide a separate system of trade sewers and also works for a partial treatment of trade effluents before they are mixed with the ordinary sewage for final purification.

If powers to construct such works are not already possessed by local authorities they should be conferred upon them.

39. The evidence shows that manufacturers would generally be willing to adopt reasonable means for the removal of solids from their effluent before passing it into the sewer.

It has, however, been represented to us that the disposal of these solids, which would be in the form known as sludge, is sometimes a serious difficulty to the manufacturer. At Salford the Corporation undertake the work of collecting and disposing of such sludge, and under the Public Health (London) Act, 1891, Section 33, the manufacturer is empowered to require the sanitary authority to remove any trade refuse from his premises, the manufacturer paying a reasonable sum for such removal.

We think it desirable that power to undertake the disposal of sludge at the expense of the manufacturer should be conferred on the local authority. We do not think, however, that the manufacturer should be empowered to compel such removal. If compulsion is necessary, this should be exercised by a superior authority in the manner hereinafter explained.

40. In an earlier section of this Report (see Section 24), we have referred to the necessity of providing machinery for the settlement of differences between local authorities and manufacturers.

The chief questions upon which differences may arise are the following :—

1. The refusal of a local authority to allow a particular trade effluent to enter their sewers.

2. The refusal of a local authority to construct or enlarge sewers for the purpose of a particular manufactory.

3. The question of varying general conditions as to preliminary treatment by the manufacturer.

4. The amount of the special charge to be imposed on the manufacturer.

5. The removal of sludge.

42. The balance of opinion is strongly in favour of the view that for the settlement of these questions it is necessary to constitute a Central Board possessing adequate technical knowledge, such as the Supreme Rivers Authority, which we recommended in our Interim Report. Some witnesses, while agreeing with this view, have expressed the

opinion that the questions should in the first instance be referred to the Local Rivers Board, and that the Central Board should be an appellate tribunal only.

Only a few witnesses consider that the questions can properly be determined by the ordinary Courts.

44. In our opinion a properly equipped Central Authority is essential, and we unhesitatingly recommend the creation of such an authority.

In the interests of river purification as well as the trade of the country, we consider it is of the highest importance that the changes in the law which we have recommended should be made. But these changes would not, in our opinion, be of much use apart from the creation of a Central Authority for the determination of differences between the local authority and the manufacturer.

If the settlement of these differences be left to the ordinary Courts, differential treatment of manufacturers, with all the objections to it, will be certain to continue.

46. The officers of the Central Authority must be clothed with the necessary powers to conduct inquiries, to call witnesses, to enter premises to take samples of the trade effluent, and generally to do such acts as are necessary for the proper performance of their duties.

48. The work of the Central Authority will be so intimately connected with the work of the Local Government Board that it will be desirable to make it a new department under the Local Government Board rather than an entirely separate department.

51. The following are the only Rivers Boards at present in existence :—

The Mersey and Irwell Joint Committee, formed in 1891, and having jurisdiction over so much of the River Mersey, and any tributary thereof, above the point of intersection by the Southern boundary of the Borough of Warrington, as passes through the Counties of Lancaster and Chester, or between them, or through, or by any of the County Boroughs of Bolton, Bury, Manchester, Oldham, Rochdale, Salford, and Stockport.

The Ribble Joint Committee, formed in 1891, and having jurisdiction over so much of the River Ribble, and any tributary thereof, and of the Rivers Darwen and Douglas, and the streams running into the Crossens Channel, as passes through the County of Lancaster, or through or by the County Boroughs of Blackburn, Burnley, Preston, and Wigan.

The West Riding Rivers Board, formed in 1893, and having jurisdiction over so much of every river or tributary thereof as passes through or by the County of the West Riding of Yorkshire, and through or by any of the County Boroughs of Bradford, Halifax, Huddersfield, Leeds and Sheffield.

55. As might be expected, some of those against whom action has been taken by Rivers Boards have complained. But we find that, generally speaking, both the local authorities and the manufacturers recognise that the Rivers Boards are taking effective action for the improvement of the rivers in their district, and several witnesses have expressed confidence in these bodies as a first court to which differences between the local authority and the manufacturer might be referred.

56. In our opinion it is desirable that such differences should be settled by the Rivers Boards whenever this can be done, and having regard to the valuable experience which these bodies have accumulated, to the fact that they represent large areas and possess capable officers, and to the confidence which they command, we think the following cases

might very properly be referred to them in the first instance, power being given to either party to appeal to the Central Authority.

1. Differences between the manufacturer and the local authority as to variation of the general regulations respecting preliminary treatment to meet particular cases.

2. Differences as to the amount of the special charge to be imposed on the particular manufacturer.

3. Disputes as to whether the preliminary treatment adopted by the particular manufacturer complies with the regulations.

4. Differences as to the removal of sludge.

57. We think, however, at any rate for the present, that the following cases should be dealt with by the Central Authority alone :—

(*a*) Refusal of a local authority to allow a particular trade effluent to enter their sewers.

(*b*) Refusal of a local authority to construct or enlarge sewers for the purpose of a particular manufactory.

As regards (*a*) the difficulty would in most cases arise in consequence of the unusual nature of the effluent, and it is undesirable that each Rivers Board should be put to the expense of providing such a staff of skilled advisers as would be necessary to investigate such special problems as would be involved.

As regards (*b*) these complaints are already dealt with by the Local Government Board, so far as they relate to a failure of a local authority to provide sufficient sewers for ordinary requirements, and we think it is better to leave this matter entirely in the hands of the Central Authority.

58. Differences arising in those parts of the country for which Rivers Boards have not yet been formed must, for the present, be referred to the Central Authority.

59. It will be seen, however, from the next section of this Report, that we consider further Rivers Boards should be set up. The Central Authority should therefore be empowered to confer on the new Rivers Boards from time to time jurisdiction similar to that which we propose should at once be given to the existing Rivers Boards."

The broad principles affecting the prevention of river pollution by trade waste are so clearly indicated in the Royal Commission's Third Report, from which the foregoing abstracts are taken, that any further comment regarding this part of the subject seems superfluous; but before any agreement can be reached as to how much or how little should be done by the local authority and manufacturer respectively, it is necessary to consider the peculiar difficulties that are likely to be encountered in connection with different trades, and the alternative means by which these difficulties may be overcome, together with the various practical questions that should be taken into account in attempting to arrange an equitable compromise between the conflicting interests of public economy and commercial enterprise.

It may therefore be desirable to conclude this chapter with a few general observations regarding some of the more important points referred to in the Report quoted above, and the arguments which must influence the conclusions of the Rivers Boards or any other Central Authority appointed to deal with such questions.

The necessity for some more effective means of preventing the pollution of our rivers and streams with the enormous volumes of trade refuse which is poured into them in most manufacturing districts has recently become much more generally recognised owing to the growing density of population and the ever-increasing demand for more hygienic conditions of life; for although the general reduction in pollution resulting from the purification of sewage has undoubtedly effected a very great improvement in many inland water courses, much still remains to be done before their condition can be regarded as entirely satisfactory or even inoffensive.

It should also be observed, however, that although the waste from many trades is of a very highly polluting character, it is seldom likely to contain the germs of infectious diseases, and its effect may therefore be far less dangerous in streams used for domestic water supply than the imperfectly purified effluent from a sewage works; so that it is highly undesirable to admit trade waste to the sewers if this is likely to impair the efficiency of sewage purification.

On the other hand, the independent treatment of trade waste by manufacturers may frequently be almost out of the question, owing to the limited space available for the necessary works and the risk of their causing a nuisance in thickly populated districts, while there can be no doubt that the purification of trade waste can, as a rule, be far more efficiently accomplished when mixed with domestic sewage than when treated independently, and its presence in the sewage is seldom likely to increase the cost of treating the latter by an amount equal to the expense involved by independent works capable of effecting the same degree of purification on the trade waste alone.

Assuming, therefore, that the disposal of trade waste can be most economically effected by discharging it into the sewers and treating it with the sewage, the special contribution, if any, which should be made by the manufacturer towards the cost of its disposal still remains to be settled, and as this must largely depend upon the nature of the waste and its effect upon the sewage disposal works, it is essential that each individual case should be considered on its merits.

Since certain kinds of trade waste may contain precipitants which will materially assist in the removal of suspended matter from the sewage their presence may sometimes be an advantage rather than otherwise, and it frequently happens that although the waste from different trades may be strongly acid or alkaline, and therefore detrimental to sewage purification by bacteria treatment, the effect of each may be counteracted by the other when mixed together in the sewers, while any excess of acid or alkali can, if necessary, be neutralised by the addition of chemicals at the outfall works; but so long as the trade waste does not exceed, say, 10 per cent. of the sewage flow, its presence seldom causes any great difficulty.

Even when the volume of trade waste to be treated is far greater than the sewage, the presence of the latter even in small quantities will materially assist in promoting bacterial fermentation, and it has for this reason been found that the introduction of sewage sludge containing anaerobic bacteria will have the effect of setting up rapid fermentation in many kinds of trade waste, especially in those containing starch, which would otherwise become sour.

The mixture of sewage with trade waste may also have a coagulating effect on the suspended matter, and thus tend to reduce turbidity, while at the same time facilitating the removal of dissolved impurities by subsequent treatment in bacteria beds.

It is not only necessary to consider each trade separately, but also to study the peculiarities of each manufactory, as the composition of the waste from similar trades may be subject to wide variations, owing to some slight difference in the process of manufacture, and when the waste from a certain part of a process is particularly difficult to deal with, it may be better to separate it in a concentrated form and apply some preliminary system of chemical treatment for the purpose of removing its specially objectionable qualities.

Owing to the constant fluctuation in the character and volume of trade waste, and the fact that the waste from different departments of a manufactory may be discharged at a number of different points, it is frequently a very difficult matter to obtain samples which may be taken as fairly representative of the bulk, and it is therefore important that when samples are taken for analysis their collection should be spread over a considerable period, and when several samples are mixed the quantity of each should bear an approximate proportion to the total volume of waste which they are respectively intended to represent.

The antiseptic effect of strongly acid or alkaline trade waste has already been referred to, but the presence of acid may also cause damage to the sewers by attacking the cement joints, while excessive quantities of lime are liable to form an incrustation which will gradually reduce the capacity of the sewer.

Although most of the impurities are usually held in solution, it is the removal of solids in suspension together with grease and oil which presents the greatest difficulty, and as the treatment of any sewage or other waste is greatly complicated by the presence of grease it is important that it should be extracted as far as possible before the waste is discharged into the sewers.

For example, the woollen industry produces a waste containing large quantities of grease and soap which can be readily separated by preliminary treatment of the concentrated liquor, and as the cost of extraction should be practically covered by the value of the grease obtained, a number of different processes have been invented for its recovery; but, Bradford being the chief centre of this industry, it will be sufficient to briefly describe the method of treatment adopted there, though a more detailed account of these works and experiments is given in a Paper read before the Association of Managers of Sewage Disposal Works in June, 1904, by Mr. Garfield, the Sewage Works Engineer of Bradford.

After the removal of detritus and floating solid matter by settlement and screening, the sewage receives a dose of sulphuric acid (which neutralises the alkali decomposing the soaps), and is then passed through precipitation tanks of special construction on the continuous flow system, the capacity of tanks being about one quarter the dry weather flow.

The sludge, which contains about 80 per cent. of moisture, is allowed to accumulate in the tanks until they are full, and is then discharged into sludge vats containing about five tons each, where it is acidified with sulphuric acid and heated up to the boiling point of water by means of steam.

From the vats the sludge is forced through filter presses by compressed air under 60 lb. per square inch pressure, the presses being meanwhile kept hot by means of steam, so that the grease flows away with the press liquor, from which it is easily separated by skimming it off the top, and after purifying and cooling it is barrelled for sale.

It is found, however, that by the above process only about 20 per cent. of the grease in the sludge is recovered, and as the large amount of grease still remaining in the pressed cake renders it unsuitable for manure, a plant has now been put down for extracting this grease by a process of distillation, which consists in heating it in retorts to a temperature of 600 deg. F., when the grease volatilises and can then be again condensed, leaving the cake in the form of a dry powder.

The liquid waste from bleaching and dye works contains a great variety of objectionable matter both in suspension and solution, including starch, lime, and greasy resinous matters, in addition to soluble soaps and salts of lime and soda, as well as the waste liquors from dye-becks and the thickenings washed out in calico printing; but the suspended matters can be readily precipitated by lime or alumino-ferric, and by treatment in continuous flow precipitation tanks a clear effluent is usually obtained, from which the dissolved impurities can be removed with little difficulty by filtration, so that the final effluent can be again used for the various processes of manufacture, the removal of colouring matter being due to the mechanical effect of coagulation in the tanks and the straining action of the filters rather than oxidation. The increased cost of precipitants and sludge disposal is therefore the chief disadvantage of treating waste of this description at the sewage works.

The particularly foul character of the waste from paper manufactories renders it one of the worst causes of pollution when discharged into water courses in a crude state, but if the suspended solids are removed by precipitation with sulphate of iron and lime the clarified tank effluent can be dealt with on filters with little difficulty, so that the method of treatment above referred to for bleachers' waste is equally suitable for the refuse from paper mills, and the increased cost of purifying sewage containing such waste depends mainly on the quantity and price of chemicals used, together with the extra expense of sludge disposal.

Since the introduction of wood pulp as a substitute for ordinary fibre in paper-making, the amount of washing required, and consequently the volume of liquid waste, has been very much reduced; but when the waste contains excessive quantities of lime this is liable to be deposited in the sewers in the form of incrustation, and may also require neutralising before it can be dealt with by bacteria treatment.

The galvanising of iron is another trade which causes very serious pollution in the districts where this industry is followed in the neighbourhood of Birmingham, the objectionable character of these wastes being mainly due to the large quantities of acid which they contain and which is highly detrimental to the bacterial treatment of sewage with which they are mixed, though the presence of iron oxide may sometimes assist precipitation.

The waste from galvanising works consists in the contents of the sulphuric or hydrochloric acid baths which are used for cleaning the iron plates before they are dipped in the molten zinc, and when the contents of these acid baths becomes ineffective through saturation with iron salts it is no longer economical to use it.

The admission of this strongly acid waste to the sewers should be avoided if possible, owing to its effect upon the cement joints; and owing to the large quantities of lime required in order to neutralise the acid its treatment at a sewage disposal works involves considerable extra expense.

In the case of breweries a large quantity of water is used for cooling, but as this is free from pollution it cannot properly be described as a trade waste, and should be kept separate from the highly offensive liquid which results from the washing of barrels, fermenting vats, and cooling tanks, and which is very liable to cause a nuisance owing to its high temperature and its tendency to rapid souring, which renders it very difficult to purify by bacterial treatment, and when brewery waste represents a large proportion of the sewage flow, as at Burton-on-Trent, the enormous quantities of lime required for precipitation is very prejudicial to subsequent bacterial treatment unless the free lime is neutralised with copperas.

There can be no doubt, however, that treatment of brewery waste is immensely simplified when it is mixed with sewage, as the presence of anaerobic bacteria counteracts the tendency to souring due to starch or starch products, and Stratford-on-Avon may be mentioned as an example of a strong brewery sewage which is purified with complete success by bacteria treatment alone in the new works completed in 1906, which comprise liquefying tanks and percolating filters followed by land treatment.

Tannery waste may practically be regarded as a very concentrated sewage and can usually be dealt with by similar methods, but when it cannot be diluted with a much larger volume of ordinary sewage its purification by bacterial treatment may be greatly facilitated by first precipitating the solid suspended matter with sulphate of iron and lime, the latter being usually obtainable in the form of refuse from the lime pits at the tannery.

This class of waste is difficult to treat separately owing to the highly-concentrated character of its impurities and the large quantities of highly-offensive sludge which has to be disposed of, the very rapid decomposition of which is liable to cause a considerable nuisance, so that it should undoubtedly be discharged into the sewers wherever this is possible, and the cost of the additional works necessary for treating it when mixed with sewage will be far less than independent works to effect the same object, though it is in any case desirable to first reduce the quantity of suspended matter by preliminary precipitation.

The town of Kenilworth may be taken as a typical case where the sewage contains a large proportion of tannery waste, but it is found that this can be successfully purified by bacterial treatment so long as the waste is discharged at a fairly uniform rate, so as to avoid the wide variations in volume and composition of sewage which otherwise results.

The importance of carefully regulating the discharge of trade wastes where these are admitted to the sewers cannot be too strongly emphasised, as this is the only means of ensuring its thorough mixture with the sewage, and when the wastes from different parts of a manufactory vary in their composition it is usually a great advantage if these can be thoroughly mixed together, so that the stronger liquors may be diluted with the less foul water used for washing, etc.

In the foregoing pages no attempt has been made to describe the details of works for the preliminary treatment of trade waste, as the design of these must be varied to suit each individual case, and the endless variety of processes that are now in use for treating the wastes from different trades render it impossible to do more than give a very brief outline of the essential points to be observed in dealing with the liquid refuse from some of the more important industries.

It should, however, be observed that, although in the great majority of cases trade waste can be most economically disposed of when mixed with sewage and should therefore be admitted to the sewers as a matter of principle, the terms and conditions to be applied in each case can only be determined after a careful study of all the local circumstances, such as the position of the works, the quality of the waste, and the necessity for pumping or otherwise, in addition to endless other details affecting the question.

With a view to encouraging trade at Leeds, the Town Council undertake to receive practically all trade wastes into their sewers so long as their regulations are complied with in regard to the following conditions, which have been applied in the case of many important works where the volume or composition of trade waste is such as would be likely to materially affect the process of sewage purification, and as these conditions will serve to show the special points to which attention should be directed in arranging such matters, they are given below as published in a report by Colonel F. W. Harding and W. Harrison, M.Sc. :—

(1) Effective means being taken by traders to precipitate the solids in their refuse.

(2) The discharge being so regulated that there should be no sudden rush of a considerable volume, but rather a gradual and steady flow spread over the 24 hours.

(3) That an inspection manhole shall be provided on the drain by which trade waste is discharged into the sewer.

(4) That no discharge should be allowed which, either by its temperature or other character, would injure the sewers, promote decomposition, or prejudicially affect the treatment of the sewage.

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CHAPTER XII.

Maintenance and Management of Sewage Disposal Works.

Importance of good management—Necessity for experiments and observations—Qualifications of a sewage works manager—Characteristics of good sewage effluents—Necessary knowledge of chemistry and bacteriology—Desirability of agricultural experience—Duties of a sewage works manager—Gauging volume of sewage treated—Self-recording rain gauges—Taking samples for anaylsis—Tests and standards of purity—Forms used for manager's records and reports—Central control of sewage works.

Attention has been repeatedly directed in the preceding chapters to the very great care and consideration required in designing Sewage Disposal Works in order to render them capable of producing the best results at the minimum of expense; but it seldom seems to be sufficiently recognised that the management of a modern sewage purification plant also requires quite as much care and attention as the most delicate piece of machinery in order to maintain it in a state of the highest efficiency, and it is the more surprising that this fact should not be better appreciated, having regard to the large sums of money invested in the construction of such works, and the heavy expense involved by their restoration when allowed to become partially or totally ineffective through neglect, apart from the risk of litigation and damages on account of any nuisance resulting therefrom.

The frequency with which more or less untrained men are appointed to fill the very responsible post of Sewage Works

Manager clearly shows that among the Local Authorities making such appointments, as well as the applicants for them, there is no adequate understanding or appreciation of the duties appertaining to such a position, or the qualifications which are necessary to fulfil them successfully; so it is the Author's intention to emphasise the folly and false economy of appointing incompetent men to take charge of important works by briefly indicating in this chapter some of the principal duties which a good Manager should be capable of undertaking, and at the same time explaining some of the qualifications which he should possess in order to avoid the risk of ultimate failure, which becomes inevitable when sewage works are persistently mismanaged, no matter how perfect their design and construction may be.

It has already been explained that the design of Sewage Works first involves the adoption of some more or less arbitrary standard of efficiency, and then their capacity is determined by estimating the quantity and quality of the sewage, trade waste, and storm water to be dealt with; but since it by no means follows that the actual working conditions will correspond even approximately with those originally assumed for the purpose of calculation, it is quite futile to expect the best results from the universal application of any hard-and-fast rules, and in order to prescribe the best method of operating any particular plant, it is a Manager's first duty to collect reliable information as to the capabilities of the works by constantly conducting experiments and systematically observing the results obtained, together with all the circumstances by which they are affected.

In order to devise and properly carry out such experiments it is essential for a Manager to clearly understand the theoretical principles on the application of which all the different systems of sewage purification depend, and he must possess sufficient practical experience to know how best to utilise the information so obtained as a guide in conducting further experiments, or altering the method of operation from time to time so as to always avoid overworking or wasting any portion of the plant, thus maintaining the whole of it in the highest possible state of efficiency without incurring any unnecessary expense for renewals or repairs.

The proper technical training of a competent Manager is therefore a gradual process, since it should include both a theoretical and practical knowledge of the whole sewage disposal problem, which can only be gained by constantly reading all the available literature on the subject and carefully studying different types of sewage works in actual operation; but in addition to this he should possess some knowledge of agriculture, chemistry, and bacteriology, as well as hydraulic and mechanical engineering, before he can be considered technically qualified to undertake the control of the costly works now required for purifying the sewage from our larger towns.

It can hardly be expected, however, that the sewage works of small communities should receive the undivided attention of a fully qualified Manager, and in such cases the difficulty arising through the inability of a partially trained man to take full responsibility may be largely overcome by appointing a competent Consulting Specialist to exercise a general control of the works, who would make periodical inspections, and whose experience would enable him to advise as to the best means of checking any tendency to deterioration which he might detect, either in the works themselves or the quality of the effluent, thus preventing the permanent damage which would otherwise ensue and ultimately involve considerable expense to rectify.

A similar course might also be adopted with advantage in the case of many larger communities, where difficulties frequently arise through local authorities expecting their surveyor to undertake the whole responsibility involved by the maintenance of sewage works in addition to all the other duties of his office, which may be more than sufficient to occupy his full time and attention, and by occasionally obtaining the opinion of a Specialist, who would emphasise the importance of improved methods or any structural alterations necessary, the disastrous results of false economy might be averted, to the mutual benefit of all concerned.

In towns of, say, 10,000 inhabitants and upwards the maintenance of efficient sewage disposal works should afford ample employment for a Manager's whole time, and it is in the interest of true economy to pay a good salary to a competent man, who will appreciate the fact that agricultural and other considerations are of very secondary importance compared to securing a uniformly satisfactory degree of purity in the effluent, so that it can always be safely discharged from the works without danger of polluting water courses.

A good sewage effluent may be roughly distinguished from a bad one by the fact that it should be colourless, free from smell, and after shaking up in a glass bottle or test tube for one minute all bubbles should disappear in three seconds; but for the purpose of determining the degree of success attained in sewage purification it is necessary that samples of effluent from every portion of the works should be regularly analysed to obtain the accurate data necessary for comparing the work done from day to day and showing the results produced by all the different units, so that supposing any particular portion of the works begins to show signs of decreasing efficiency a period of partial or complete rest may be allowed till its normal condition is restored, while it is also necessary that reliable evidence should be available as to the purity of the final effluent for the purpose of satisfying any riparian owners or public authorities interested in preventing the pollution of the water courses into which it may be discharged.

The chemical tests applied to sewage effluents usually comprise the determination in parts per 100,000 or grains per gallon, of the solids in suspension and solution, chlorine, albuminoid ammonia, free ammonia, nitrates, nitrites, and oxygen absorbed; so that although it is not suggested that an expert chemist is required to control sewage works, it is important that the Manager should study chemistry sufficiently to make the most of the above determinations when required, and to properly interpret the results obtained by his own or other people's analyses.

The increasing attention now being devoted to the study of bacteriology in connection with sewage disposal also renders it highly desirable that a Manager should understand the methods of cultivating, counting, and distinguishing the different kinds of bacteria to be found in sewage, so that he may be able to observe the conditions that are favourable or unfavourable to their growth, and thus ascertain the best means of developing the growth of those which are useful for decomposing the sewage while at the same time destroying the pathogenic or disease-breeding bacteria, which may sometimes constitute an even greater source of danger in the final effluent than chemical impurity.

The methods adopted in the chemical analysis and bacteriological examination of sewage having been already referred to in Chapter I., and very fully described in several recent books written by eminent Scientific Authorities, it is unnecessary to deal with them in detail here; but it should be observed that the work of analysis can now be immensely simplified by the use of standard solutions of the various chemicals required, many of which can be very conveniently prepared by dissolving tabloids of known strength in a given quantity of water, while the measurement of organic matter by the oxygen absorbed or incubator test presents no difficulty whatever.

Although land irrigation is being gradually superseded by the more up-to-date methods of bacteria treatment in artificial works, almost all disposal schemes still include an irrigation area, the extent of which should properly depend on the degree of preliminary purification accomplished in tanks or bacteria beds before the sewage is discharged on to the land, but in any case the Manager will require some experience of practical agriculture in order to understand the proper methods of keeping the land in good order and cultivating the crops which are found to be most successful under the somewhat unfavourable conditions frequently existing on a sewage farm, where the land has to be continually irrigated with sewage with the shortest possible periods of rest throughout the whole year.

It therefore happens very frequently that sewage has to be discharged on to the land when the growing crops would be far better without it; but since the primary object is the purification of sewage, the interests of agriculture must always be regarded as a secondary consideration, and every Manager should be thoroughly impressed with the fact that the production of a uniformly good effluent is of far greater importance than showing a profit from crops grown on the farm, which should only be looked upon as a means of facilitating the disposal of sewage.

Owing to the very rapid growth of weeds as well as crops on land irrigated with sewage, the employment of far more labour is necessary for cleaning, planting, and harvesting than would be required for the cultivation of a corresponding area of arable land under ordinary conditions; and as the wages bill represents the chief expenditure on a sewage farm, the efficient management of the men is of the greatest importance, since the absence of proper organisation and discipline must always result in a serious waste of time, which is fatal to economical working.

The duties of a Manager usually include the control of the machinery required for a variety of purposes, such as pumping sewage, cleaning screens, driving distributors, pressing sludge, and many other operations directly or indirectly connected with sewage disposal works; and since such machinery may comprise the whole plant necessary for the development of power by steam, gas, or oil engines, including boilers or gas producers and all their various fittings, together with all kinds of pumping plant, air compressors and pneumatic machinery, it is obvious that the efficient management of such works requires considerable mechanical knowledge and experience.

Although it would be out of place to enumerate here all the endless details requiring constant attention in the maintenance of machinery, it should be observed that it not only involves the erection, working, and repair of all the different kinds of machines in use, but also the selection and measurement of fuel, together with the examination and cleaning of boilers, as well as the periodical testing of the whole plant to ascertain that a proper degree of efficiency is secured.

The apparatus used for regulating the distribution of sewage over the different types of bacteria beds has already been fully described in Chapters VII. and IX., but it will be the Manager's duty to see that all such apparatus is kept in good working order by regular cleaning and oiling of working parts when necessary, and this remark applies equally to all valves and penstocks used for controlling the flow of sewage from one part of the works to another, as no such apparatus can be expected to work satisfactorily if neglected.

Reference has been made to the control of mechanically driven screens or rakes for removing screenings; these should be thoroughly washed down at least once a week, and all the moving parts should be kept properly adjusted and well oiled to prevent excessive wear, while the removal and disposal of floating garbage and sludge from screens and sewage tanks respectively require constant attention as a matter of routine.

Where chemicals are used for precipitation good results can only be secured at a minimum cost by seeing that the quality of chemicals is up to the specified standard and by very carefully adjusting the quantity used according to the volume and composition of sewage treated; so a good Manager should thoroughly understand how to select and apply the chemicals to the best advantage, as well as the best means of periodically emptying and cleaning the sewage tanks so as to interfere as little as possible with the uniform working of the plant.

The management of artificial bacteria beds should include the regular observation of results obtained from each, as well as the frequent examination of filtering media, so that any tendency to clogging may be immediately checked by a period of rest, or in case this proves ineffective the material may need forking, screening, washing, or renewing, all of which require the most careful supervision on the part of a Manager in order to ensure that the work is properly done and none but the best material is used.

For the purpose of gauging the work done by each tank or bacteria bed the quantity of sewage passing through it should be carefully measured every day, while the amount of purification should also be ascertained by frequent analysis of the crude sewage and effluent; but in order to derive the full advantage from these observations it is essential that the results should be carefully recorded in tabulated form for future reference; and as the preparation of these records constitutes certainly one of the most important, if not the most important, of a Manager's duties, they deserve some special consideration.

The keeping of such records is not only of the utmost value to the Manager himself, as affording the means of closely watching the operations of the whole plant under his control and comparing the results obtained from day to day, but their production as evidence of the work done is by far the best answer to the complaints so frequently made by irresponsible people, who are always ready to magnify the injury resulting from the slightest smell or pollution of water courses in the neighbourhood of sewage works, and when such evidence is always available to disprove exaggerated statements it saves an immense amount of trouble and expense which might otherwise be involved by meeting claims for imaginary damages.

Even in cases where a nuisance really does exist owing to inadequate works, and legal proceedings are taken against the Local Authority to procure an injunction, a Manager may to a great extent save the situation, while at the same time protecting his own reputation, by being able to prove conclusively that the sewage has been purified to the fullest possible extent, having regard to the means at his disposal, and reliable evidence as to facts must always tend to stop frivolous litigation, or at any rate shorten the proceedings, and thus materially assist the Local Authority by keeping down costs even when they cannot win their case.

The composition and volume of sewage discharged at the outfall being subject to constant variations, for which it is necessary to make provision in operating the works, it is practically indispensable to efficient management that the Manager should have the means of accurately recording the quantity treated as well as the frequency, intensity, and duration of rain by which storm overflows may be brought into action.

For this purpose it is not only necessary to gauge the flow of sewage at frequent intervals, but to note any marked change in its appearance which may be taken to indicate the presence of trade waste or storm water in exceptional quantities, the particular cause of such changes in appearance being usually identified without much difficulty by the colour of the sewage, which is known to correspond with certain changes in composition as shown by previous analysis, though a fresh sample should be taken and analysed whenever unusual changes are observed which cannot be accounted for by the data already available.

Although the total volume of sewage discharged at the outfall can be estimated with a fair degree of accuracy from gaugings taken by hand at regular intervals of, say, half an hour for one or more days, it is far better for large works, at any rate, to use an automatic recording instrument driven by clockwork, which can be so arranged as to mark all fluctuations in rate of discharge on a diagram attached to a revolving drum, the pen being actuated by the movement of a float on the surface of the sewage above the gauging weir.

The arrangement of this apparatus is shown in Fig. 66, from which it will be seen that as the drum revolves the pen marks an irregular line on the diagram, and as the height of this line from the bottom of the sheet indicates the rate of discharge over the gauge weir the

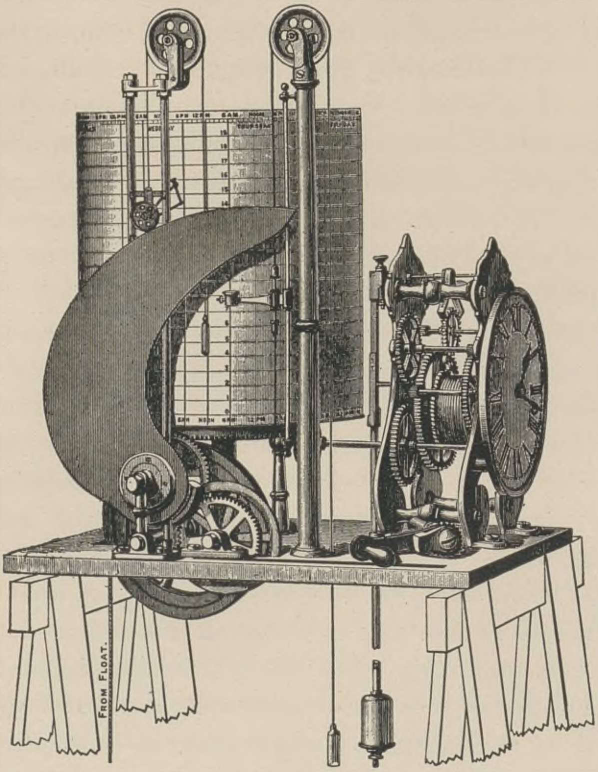

Fig. 66.—Hutchinson's Recording Instrument for Registering Quantity of Sewage Passing over Gauging Weir.

(Reproduced by permission of Messrs. Glenfield & Kennedy, Ltd., Kilmarnock.)

diagram is ruled with horizontal lines drawn to scale at varying heights, one inch representing, say, 500 cubic feet per minute, so that maximum, minimum, and average gaugings can be very readily ascertained with little or no calculation and recorded in a book each time the diagram is renewed, which is usually done once a week, the drum making one complete revolution in this time.

Since the cost of such an apparatus is about £35, it is often necessary on small works to rely upon gaugings taken by hand at intervals, or when it may be noticed that the discharge is exceptionally great or unusually small, and it is quite possible to derive a considerable amount of useful information even from intermittent gaugings of this description if they are occasionally supplemented by gaugings every half-hour for a whole day for the purpose of checking the estimated dry weather flow, which may be used as a basis in comparing abnormal fluctuations.

As crude sewage frequently contains large pieces of floating garbage which are liable to obstruct the gauge weir, it is desirable if possible to fix this in such a position that the sewage passes through screens before reaching it, and in order to avoid the error so frequently caused by the sewage approaching the weir with a considerable velocity, the gauge should not be placed in a narrow channel, while it is also important that the sill should be at least three inches above the surface of water on lower side of it, so that it may discharge quite freely, though in case these conditions cannot be secured the consequent error may be corrected by making a proper allowance in calculating the discharge.

When the quantity and composition of sewage to be dealt with are known it is simply a matter of experience and judgment to determine the best kind and most suitable quantity of chemicals to use for precipitation; but in order to ensure that their application is properly adjusted from time to time a Manager should also see that the chemicals used each day are carefully weighed, so that by comparing their weight with the volume of sewage treated the exact proportion can be ascertained and recorded in grains of chemical per gallon of sewage, and from these records the cost of chemicals per million gallons can also be calculated.

In addition to measuring the total quantity of sewage discharged at the outfall, it should also be the Manager's duty to know the approximate quantity treated in each tank, bacteria bed, or irrigation area provided for its purification, so that he may be able to equalise the work as far as possible between all the different units, and in case of any deterioration in the effluent his records should show whether the inefficiency of any particular tank or bacteria bed is due to an excessive accumulation of sludge or overwork, thus enabling him to apply the proper remedy.

In the absence of such measurements and records the reason of any failure must often be merely a matter of conjecture, and the haphazard application of a remedy without first knowing the cause of the trouble must always prove unsatisfactory, for although it is true that a bad effluent generally means that a tank requires cleaning or a bacteria bed requires rest, prevention is far better than cure, and it is decidedly bad policy to wait until all the damage is done before applying the remedy.

A bad effluent may sometimes be due to purely accidental or temporary causes, such as a sudden rush of sewage through a septic tank carrying an excessive quantity of solid suspended matter on to one particular bacteria bed, or some difference in the kind of media used in the beds may quite easily account for different results which might be eroneously attributed to inequality of distribution or imperfect ventilation unless the work done by each unit is very carefully observed from day to day, so that due allowance may be made for any difference in their construction or method of operation.

Although the necessity has been so strongly emphasised for recording the volume of sewage treated by each section of the plant for the purpose of ensuring an equal division of the work, it is no less important that the purity of the effluents should be regularly tested every day and analysed at least once a week on works of any importance, though in cases when this is impracticable it is an excellent plan to, at any rate, take a sample of the final effluent every day, which can be kept on the works for, say, one month, and so long as these samples remain clear and bright they show that the works have been producing fairly satisfactory results, of course assuming that the results are representative.

The measurement and occasional analysis of the sludge removed from each tank is another matter which demands the Manager's attention in order that he may be able to check the efficiency of precipitation or septic action, while he should, at the same time, keep a careful record of all expenses connected with the disposal of the sludge, so that he may be able to calculate the cost per ton, and by comparing this and the composition of the sludge with the corresponding figures obtained at other places he will be in a position to show whether his methods are economical and effective.

For the purpose of facilitating reference to the various records of gaugings and analysis recommended in this chapter it is very necessary to adopt some systematic method of entry in a specially ruled book, with spaces for remarks on any special circumstances affecting the comparative value of the figures, as well as notes as to the state of the weather, together with the date and hour when the observations were made. The different sections of the works referred to in the records should be clearly identified by numbers or letters on a suitable block plan showing all underground pipes and carriers as well as the tanks, filters, and other works with which they are connected.

If a Manager is to derive the fullest benefit from these records of his observations, it is essential that he should not only keep them neatly, accurately, and regularly, but he must constantly make it his duty to study them and compare his results from day to day with those previously obtained, always endeavouring to secure the highest possible efficiency from the works under his control by adopting every little improvement in his system of management which experience may suggest, while at the same time qualifying himself to assist in the solution of the sewage disposal problem by evolving logical conclusions from the evidence at his disposal.

In order to properly interpret the various records above referred to, it is necessary to bear in mind that most of the important fluctuations are due either directly or indirectly to the influence of rainfall, which not only affects the volume and composition of the sewage reaching the outfall, but at the same time reduces the purifying capacity of the works themselves by disturbing the contents of open tanks, and sometimes so materially reducing the capacity of bacteria beds and irrigation areas as to cause them to become temporarily saturated and more or less ineffective.

The daily measurement of rainfall in the drainage area by means of one or more rain-gauges is therefore of the utmost value in enabling a Manager to thoroughly understand his other records, and since the rate at which the rain falls is of even greater importance than its total volume, the equipment of every large sewage works should include a good self-recording rain-gauge, such as that illustrated in Fig. 67, by which the rate of rainfall is automatically registered on the diagram attached to a revolving drum, similar to that already described for the measurement of sewage discharged over a gauging weir.

The comparison of all these different records is immensely

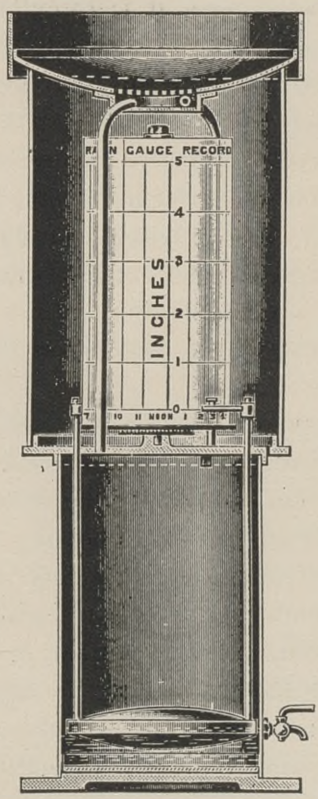

Fig. 67.—Self-registering Rain Gauge with Recording Instrument Driven by Clockwork.

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facilitated by plotting the results to scale on squared paper, so that the fluctuations from day to day may be seen at a glance without the necessity of making calculations or referring to figures on several pages of a book, while the relation of one set of observations to another can be much more readily seen when the results of both are plotted on the same sheet.

There are many other matters of which an intelligent Manager will find it necessary to keep a record, but as these chiefly consist in miscellaneous notes and memoranda, their arrangement must be left to his discretion, though they can as a rule be embodied in the account of each day's work, which should be regularly entered up in the form of a diary, so that if complaints are made of a nuisance arising from the works on any particular date the exact cause, if any, can be readily ascertained.

Fig. 68 shows a general plan of the new sewage disposal works at Stratford-on-Avon, comprising preliminary treatment in four detritus and liquefying tanks with eight circular percolating filters, and one acre of specially prepared land filters for the final treatment of effluent before discharging it into the River Avon, these works being capable of efficiently purifying a volume of sewage and storm water up to three times the dry weather flow from a population of about 10,000, while four contact beds are provided for treating a further volume of storm water up to six times the dry weather flow, and about ten acres of land are available for irrigation and sludge disposal.

This plant having only been quite recently completed may be taken as a typical example of modern English practice, and Fig. 69 shows the headings used in the Manager's Monthly Report to the Sewage Works Committee, which includes a summary of the more important records kept, though a large amount of special research work has also been undertaken by the Managing Chemist, Mr. H. D. Bell, for the purpose of determining the best means of securing the highest possible efficiency from all the different systems of treatment employed on these works for dealing with a highly concentrated sewage containing a large proportion of brewery waste.

The particular form in which all these records can be

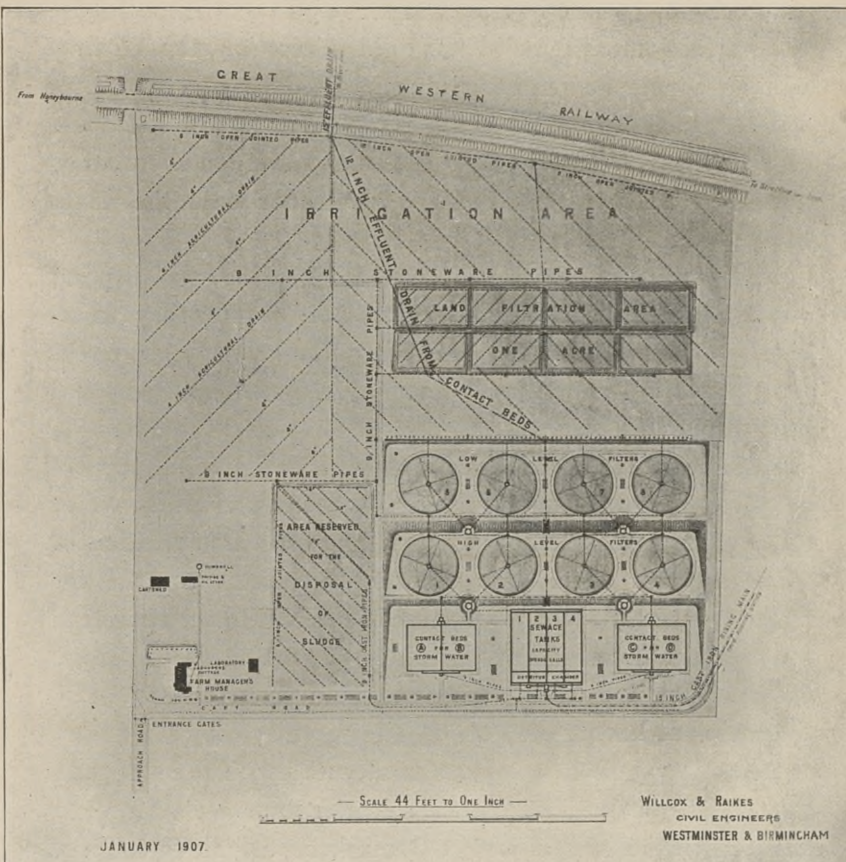

Fig. 68.—General Plan of Sewage Disposal Works at Stratford-on-Avon, Showing Eight Circular Filters for Sewage and Four Contact Beds for Storm Water, also Method of Laying Out Land Filters and Irrigation Area.

(Reproduced by permission of Messrs. Willcox & Raikes, Westminster and Birmingham.)

Borough of Stratford-on-Avon. Sewage Works. Manager's Report. No. .... Date .... 19 ....

Date	Rainfall in inches.	Pump Revolutions				Quantities in Gallons per 24 Hours					Sludge removed from Septic Tanks		Results of Analyses in Grains per Gallon (1 Part in 70,000)																				
						Pumped to Works	Method of Treatment						4 Hours Oxygen Absorption							Albuminoid Ammonia							Solids in Suspension						
							Circular Filters.																										
		1	2	3	Total		High Level	Low Level	Land Filters and Irrigation Area	Contact Beds	Weight in Tons of Wet Sludge	Percentage of Moisture.	Raw Sewage	Septic Tank Effluent	High Level Filters	Low Level Filters	Contact Beds	Land Filters and Irrigation Area	Final Effluent	Raw Sewage.	Septic Tank Effluent	High Level Filters	Low Level Filters	Contact Beds.	Land Filters and Irrigation Area	Final Effluent.	Raw Sewage.	Septic Tank Effluent.	High Level Filters.	Low Level Filters	Contact Beds	Land Filters and Irrigation Area	Final Effluent
Total																																	
						Average	...	...	...	...	...																						
						Percentage of Purification on Raw Sewage.																											

Fig. 69.—Headings of Forms used at Stratford-on-Avon for Records kept by Sewage Works Manager.

(Reproduced by permission of Messrs. Willcox & Raikes, Westminster and Birmingham.)

most conveniently kept must depend on the circumstances of each individual case, but Fig. 71, showing the headings used for the tabulated records at Hanley, may serve as another instance of a system designed for works dealing with the sewage from a population of about 65,000, the general arrangement of the works being shown in Fig. 70.

Having determined the maximum rate of filtration with which it is possible to obtain the most satisfactory results with sewage containing different degrees of impurity by means of actual experiment, the next step is to decide upon the best means of applying the conclusions arrived at, and in the case of comparatively small works, where it is not necessary or economical to keep a man constantly employed, it is usually desirable to adopt some automatic system of control by which the work of different filters may be equalised, and the apparatus commonly adopted for this purpose is fully described in Chapters VII. and IX.

It is found, however, that in larger works the automatic apparatus referred to does not fulfil all the requirements, as they necessarily act without regard to the varying composition of the sewage, and in the case of the works at Manchester and many other extensive schemes it is found better to employ two or three men to regulate the various valves by hand, three men being able to look after the distribution of sewage to 26 acres of contact beds at Manchester.

Where the extent of the works justifies the employment of a highly trained Manager, it is evidently desirable that they should as far as possible be brought under his personal control, so that he may not only watch the results obtained but may also be able to personally regulate the operation of the works, instead of being dependent on manual labour, which may or may not be reliable, besides involving con-

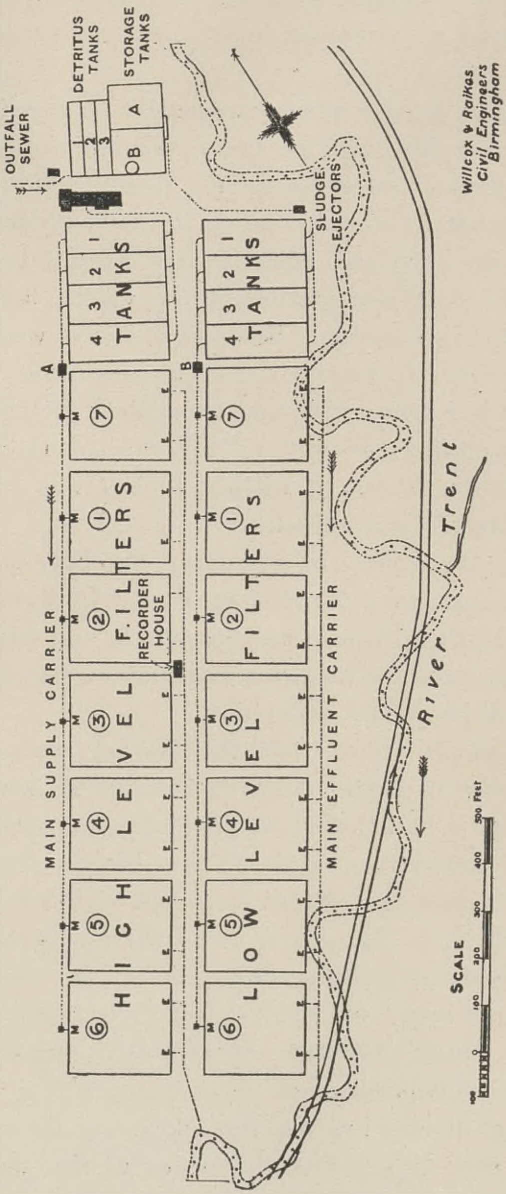

Fig. 70.—General Plan of Hanley Sewage Works, Showing Proposed Position of Recorder House and Venturi Meters on Two Main Supply Carriers at A and B.

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siderable expense in doing work which may be quite as efficiently done by a mechanical means under a system of central control.

The Author has been so much impressed with the importance of central control that he has devoted his attention to the development of a scheme for use in connection with the Hanley Sewage Works, by which it would be possible for one man in a central office to not only take and analyse samples from any portion of the works, but also to examine the crude sewage discharged at the works at any particular time, to have a record of its volume automatically registered before him, and to regulate the number of filters in operation, as well as the rate of filtration, without leaving his office and without in any way relying upon the assistance of subordinates.

In designing the apparatus necessary, he has received very great assistance from Mr. George Kent,* by whom the details shown in Fig. 72 have been prepared, and with the assistance of these and the following explanation, the method of operation will be readily understood.

It should first be stated that the Hanley works will ultimately consist of septic tanks and about 12 acres of percolating bacteria beds, which are divided equally between the high and low level, as shown in plan in Fig. 70, and so arranged that the effluent from the high level beds can, when desired, be discharged on to the low level beds for keeping these in working order during dry weather, though it will be seen from analysis on page 254 that the effluent from single filtration is perfectly satisfactory, showing 97 per cent. purification.

The filters are divided into one acre plots, and the sewage is distributed over the surface by means of the specially

* Mr. George Kent, 199, High Holborn, London, W.C.

Quantity of Sewage treated in Detritus and Septic Tanks, in Gallons.

Four Weeks ending ....

Date	Discharged by Outfall Sewer	Treated in Detritus Tanks	No. of Detritus Tanks in use	Pumped into High Level Tanks	No. of High Level Tanks in use	Treated in Low Level Tanks	No. of Low Level Tanks in use	Rainfall in Inches

Tons of Sludge from Detritus and Septic Tanks disposed of by Pressing.

Four Weeks ending ....

Date	Detritus Tanks and Reservoirs A and B										High Level Tanks								Low Level Tanks							
	No. 1 Tank		No. 2		No. 3		Reservoir A		Reservoir B		No. 1		No. 2		No. 3		No. 4		No. 1		No. 2		No. 3		No. 4	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	D

Septic Tank Effluent, treated on High Level Bacteria Beds,
IN MILLIONS OF GALLONS

Four Weeks ending ....

Date	½ Acre Bed No. 1		1 Acre Bed No. 2		1 Acre Bed No. 3		1 Acre Bed No. 4		1 Acre Bed No. 5		1 Acre Bed No. 6		Total
	½ Acre	½ Acre Experimental Bed	A	F	A	B	A	B	A	B	A	B	
Total													
Average per Bed per Day													

Septic Tank Effluent, treated on Low Level Bacteria Beds,
IN MILLIONS OF GALLONS.

Four Weeks ending ....

Date	½ Acre Bed No. 1		1 Acre Bed No. 2		1 Acre Bed No. 3		1 Acre Bed No. 4		1 Acre Bed No. 5		1 Acre Bed No. 6		Total
			A	B	A	B	A	B	A	B	A	B	
Total													
Average per Bed per Day													

ANALYSES OF SEPTIC TANK EFFLUENTS.

Four Weeks ending ....

	Temperature of sewage in deg. F.	HIGH LEVEL TANK EFFLUENT						LOW LEVEL TANK EFFLUENT					
		Temperature in deg. F	Opacity in inches	Solids in suspension	Solids in solution	Oxygen absorbed before incubation	Oxygen absorbed after incubation	Temperature in deg. F.	Opacity in inches	Solids in suspension	Solids in solution	Oxygen absorbed before incubation	Oxygen absorbed after incubation

ANALYSES OF BACTERIA BED EFFLUENTS.

Four Weeks ending ....

Date	Temperature of air in deg. F.	HIGH LEVEL BACTERIA BEDS						LOW LEVEL BACTERIA BEDS					
		Temperature in deg. F.	Opacity in inches	Solids in suspension	Solids in solution	Oxygen absorbed before incubation	Oxygen absorbed after incubation	Temperature in deg. F.	Opacity in inches	Solids in suspension	Solids in solution	Oxygen absorbed before incubation	Oxygen absorbed after incubation

Maintenance Expenses.

Four Weeks ending

Date	COST OF PUMPING						
	Wages	Coal	Repairs	Lighting	Oil and Waste	Sundries	Total Cost

Maintenance Expenses.

Four Weeks ending

COST OF SLUDGE DISPOSAL					MAINTENANCE OF BACTERIA BEDS			
Cleaning out Tanks	Pressing Sludge	Lime used	Sundries	Total Cost	Wages	Electric Power	Sundries	Total Cost

Fig. 71.—Headings of Forms used at Hanley for Records kept by Sewage Works Manager.

(Reproduced by permission of Messrs. Willcox & Raikes, Westminster and Birmingham.)

designed distributing apparatus which is fully described in Chapter IX., the sewage being pumped to the high level works, while that dealt with on the low level is delivered by gravitation.

The sewage on its arrival at the works is first screened and then passes over a rectangular plate weir, where the depth is automatically measured by a float, and the corresponding rate of discharge registered in gallons on a drum by means of the automatic recording instrument already described, Fig. 66, in which the motion of the marking pen is actuated by the movement of a cam having a curve which ensures that the correct discharge is accurately indicated on the diagram in gallons, in spite of the fact that the volume does not vary in direct proportion to the depth of sewage flowing over the weir. This apparatus is quite independent of the general system of central control above referred to, and is only used as a check on the various other methods of measurement, the results of which can be compared with it at the end of each week.

For the purpose of measuring the total quantity of tank effluent discharged on to the high and low level filter beds respectively, a 30-inch "Venturi" meter will be fixed on each of the main carriers at A and B, as shown on plan, Fig. 70, and the pressure pipes from these meters are connected with the recording apparatus placed in the central office, as shown in detail drawing Fig. 72, the variation in flow being thereby recorded on the diagram in the office itself, so that the quantity to be dealt with is constantly under observation and can be provided for accordingly.

In order to measure the quantity of sewage discharged on to each of the filter beds, the scheme provides for a 15-inch "Venturi" meter at the inlet of each of them, and the pressure pipes from these are also connected with a

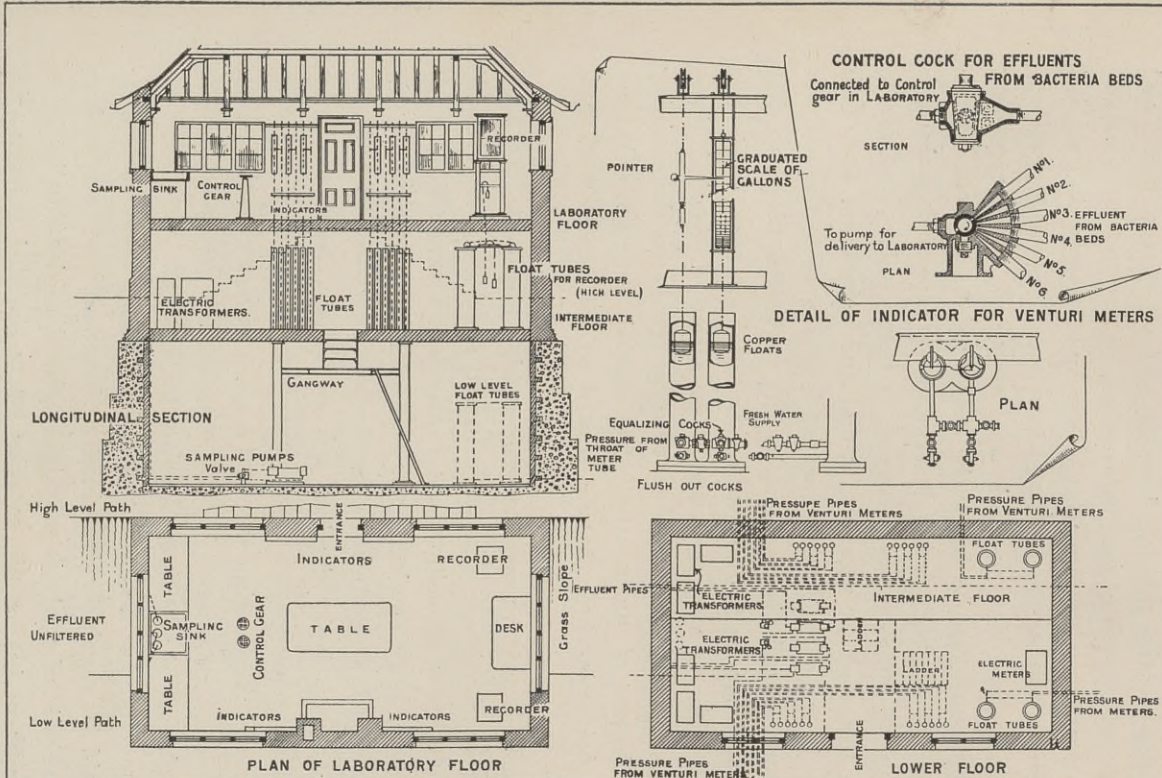

Fig. 72.—Details of Laboratory and Recorder House for Proposed Scheme of Central Control for the Hanley Sewage Disposal Works.

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series of indicators in the office; but since it is only necessary to measure the rate of flow on one filter at a time, and since the recording instruments are by far the most expensive portion of the apparatus, only one recorder is provided for the whole of the high and low level beds respectively.

By means of a multiple-way stop-cock these recording instruments can be instantly connected to any one of the meters at the high or low level, and the rate of flow through it can be immediately observed, it being only necessary to turn this cock by means of a dial and pointer on the office table in order to obtain exact information as to the amount of work actually being done by any particular filter, so that a record can be kept showing the total quantity of sewage dealt with on any particular area within a specified time, which is frequently a very valuable guide in determining the degree of purification that should be expected from any particular bed, having regard to the amount of work done.

As it is well known that any sudden change in the composition of sewage is usually accompanied by a corresponding change in its colour, and as any defect in the working of a filter at once results in the effluent becoming more or less discoloured, arrangements can be provided whereby a stream of sewage (tank effluent) can be drawn from the inlet carriers by means of a small centrifugal pump driven electrically and discharging through a glass cylinder in the office, where any variation can be immediately observed, and a sample can at any time be taken for analysis.

As it is also necessary that the effluent from each filter should be regularly examined at frequent intervals, and as the results of analysis may be rendered misleading by carelessness in taking the samples by unqualified persons, the advantage of the analyst being able to take all samples himself, either by night or day, is obvious, and for this purpose a small centrifugal pump may be provided under the office, on the North and South side for high and low level filters respectively, its construction and operation being similar to that used for the sewage mentioned above.

In order that the same pump may be used for all the filters a separate suction pipe is taken to the outlet chamber of each, so that by merely turning the multiple cock a sample may be drawn off from any particular filter and discharged for the purpose of inspection through a glass cylinder similar to that used for the sewage, and a sample can at any time be taken in the office by drawing off the quantity required through a tap provided for the purpose over a basin on the analyst's table, the position of a pointer attached to the valve indicating on a dial the particular filter from which the sample is taken. It would, however, be necessary that the pump should be kept working for a few minutes before taking the sample in order to ensure that the water standing in the suction pipe is first drawn off, but since the apparatus is practically automatic this presents no difficulty or disadvantage.

The centrifugal pumps referred to have been specially designed by the Jewell Filtration Co., their dimensions being only about 9 ins. diameter by $1\frac{1}{2}$ ins. thick, and since they are driven by an electric motor, which is also of the smallest dimensions, the whole apparatus can be placed in a very limited space, and by building the office on the first floor a good view of the works may be obtained from the windows, while the whole of the recording instruments and other apparatus can be easily accommodated on the ground floor and basement.

The management of sewage farms has formed the subject of inquiry by the Royal Commission now sitting, and the following special note in the form of an appendix is attached to the end of their Fourth Report, Volume IV., Part I.

"There can be no doubt that even the best sewage farms, with the most suitable soil, will under continued bad management fail to turn out a satisfactory effluent.

"The question of whether or not a particular farm is going to purify the sewage efficiently depends mainly upon the manager, assuming, of course, that the farm has been properly laid out in the first instance, that it has a reasonable volume of sewage to treat, and that the manager has (within certain limits) a free hand in the supervision of sewaging operations. The fact, however, must not be lost sight of that he has often a most difficult post to fill, especially with regard to the crops.

"The effectual purification of sewage, even with suitable land, can only be accomplished when the farming operations are relegated to the background, and the production of a good effluent considered of primary importance. On the other hand, the manager knows that the crops will probably form an important item in his receipts at the end of the year, and he not unnaturally wishes it to appear that the farm is being worked economically under his supervision.

"Hence there is a temptation to grow remunerative crops, *e.g.* cereals, that cannot be sewaged (at all events for the greater part of the year), or to refrain from the further sewaging of crops which may be damaged thereby; meanwhile, the land which is under sewage must needs yield, owing to the lack of rest, increasingly unsatisfactory effluents. There may, of course, be some farms where the large area at command in proportion to the volume of sewage to be treated renders the growing of grain crops justifiable, but these are exceptions to the general rule. Land is usually too expensive in the immediate vicinity of towns to allow of this, and the tendency is to take too little rather than too much land for a sewage farm.

"Speaking generally, large farms are better managed than small ones, this being in great measure due to the fact that the salary attached to the latter does not always offer sufficient inducement to a competent man to undertake the duties. In many instances there are small districts fairly near together, each with its own sewage farm. In such cases a combined scheme would appear to be advantageous; by adopting this course an adequate salary could be paid so as to secure an efficient manager, while the annual cost of treating the sewage would also be lessened. On the other hand, it is possible to have a sewage farm so large as in a sense to be unwieldy.

"It seems desirable that managers should employ day by day some simple chemical test or tests to enable them to follow the results of the working of the farm to the best advantage. It is probable that attention to this point would do much to foster the desire on their part to turn out the best effluent possible at the expense, if necessary, of the crops. This question is raised quite apart from the larger one of appointing a qualified chemist in connection with all large sewage disposal works.

"In the case of a new farm it would seem advisable, if practicable, that the prospective manager should be on the spot while the works were being carried out, as he would thereby obtain an insight into details which otherwise it might take him some time to discover (*e.g.* the nature of the soil and subsoil on different parts of the farm as disclosed by drainage operations). In connection with this, it may be remarked that the soil and subsoil are rarely uniform in nature throughout a farm, and that therefore the various plots cannot all take the same quantity of sewage.

"We are unable to recommend the abandonment of farming operations even in connection with filtration sewage farms, because, if intelligently pursued, they make for profit with increased efficiency of the land. The farming operations, however, should always be under the control of the authorities responsible for the proper working of the farm, and the manager should receive written and explicit directions to regard the crops as of secondary importance to the uniform and satisfactory purification of the sewage.

"It would be invidious to attempt to arrange in order of the excellence of the management the various farms which by the courtesy of the Local Authorities and their officers we have been enabled to keep under observation, but Nottingham Sewage Farm cannot be passed over without special comment. There can be no question that here the excellent management of the farm largely contributed to the remarkably good quality of the effluents."

The above abstract from the Commissioners' report may be taken to fairly represent the general opinion expressed by the witnesses who have given evidence before them, as well as the result of their own observations in relation to sewage farms, and there can be no doubt that these conclusions as to the necessity for good management apply with even greater force to the various forms of tank treatment and bacteria beds, in which a far higher efficiency is required owing to their comparatively small capacity in proportion to the quantity of sewage dealt with.

The Engineers responsible for the design and construction of sewage disposal works may often be heard to deplore the fact that directly the works are finished their management is too frequently handed over to an untrained man, who really only gains experience from the mistakes he makes, while the works are blamed for the disappointing results obtained, when they are chiefly due to mismanagement; but the increasing demand for qualified Managers is a sure sign that the value of their services is becoming more generally recognised, and the old idea that any intelligent labourer can look after a sewage works, without competent supervision, is rapidly dying out.

Many Managers of sewage works are also very frequently entitled to much more sympathy than they generally receive when subjected to unfair criticism for not producing results as good as those obtained elsewhere from similar works, where the conditions may be much more favourable; but since the formation of the Sewage Works Managers' Association in 1903 their position and responsibility have become much better appreciated by Local Authorities, and it is in their power to exercise an enormous influence in improving the condition of our rivers, while at the same time benefiting their own interests by creating a better understanding among themselves and their employers of the conditions which are essential to successful sewage purification.

When sewage works effluents cannot be conveniently analysed every day their quality may sometimes be sufficiently indicated by applying the simple physical tests previously referred to, but the organic matter present can be so easily estimated by the oxygen absorbed test that there is no reason why this should not be regularly employed to show the amount of impurity still remaining in the effluent, which is still capable of further decomposition.

This test may, however, be applied in several different ways, and as the results obtained by different methods cannot be properly compared, greater uniformity in this respect is to be hoped for in future, there being apparently no very strong reason why the time allowed for this test should in some cases be three minutes, while in others it is four hours, or why it should not always be made at the same temperature.

When it is only necessary to ascertain whether the oxygen absorbed exceeds a certain arbitrary limit, without estimating the actual amount of organic matter present, the following rough test has been employed by Mr. O. J. Kirby, the Borough Engineer of Batley, and is thus described in his Paper on Sewage Disposal read before the Association of Managers of Sewage Disposal Works in 1906 :—

"One hundred and forty cubic centimetres of effluent are put into a glass cylinder, to which 20 cubic centimetres of acid permanganate are added. If the colour does not completely disappear in fifteen minutes a fairly good effluent is indicated. If it does not disappear under an hour and a half it is equivalent to .18 grain per gallon in a three minutes' quantitative analysis. If the colour does not disappear under two and a half hours it is equivalent to .07 grain per gallon in the three minutes' test."

The acid permanganate solution is made in the manner recommended by Dr. Gilbert J. Fowler as follows :—.395 gramme of permanganate of potash dissolved in 200 cubic centimetres of water added to 800 cubic centimetres of 3 to 1 sulphuric acid solution make up 1 litre of permanganate solution.

The best system of collecting daily samples for analysis is very fully dealt with in the reports on the large scale experiments at Columbus (referred to in the Introduction), where it has been found convenient to omit every eighth day, so that the analyst is given an opportunity of completing his records once a week, but no one day is omitted from the sampling schedule twice in succession, the system adopted being as follows :—

The samples are collected at half-hour intervals and placed in 4-oz. bottles, which are completely filled, tightly stoppered, and placed at once in an ice chest kept at a temperature of 10 deg. C. About 32 hours after the collection of the first sample the contents of the 48 small bottles are mixed in equal proportions in a large bottle and the chemical analysis is then immediately proceeded with, while the samples for bacterial analysis are not stored for more than about an hour.

Although the oxygen absorption test is undoubtedly very valuable for the purpose of measuring the organic matter present, it is important to observe that this does not necessarily show whether a sample is likely to undergo so-called "secondary decomposition" or not, as this must largely depend on the amount of nitrate and dissolved oxygen present and whether this is sufficient to oxidise the organic matter, so that, in order to make this test complete, a determination should be made of the dissolved oxygen and nitrate* present both before and after the period of incubation, and any change in the appearance of the sample should be carefully noted.

When the dissolved oxygen and nitrate are ignored it seems clear that with two samples containing an equal amount of impurity, as shown by the oxygen absorbed test, one may undergo rapid putrefaction owing to the

* The determination of nitrate after incubation is not necessary except for research purposes, because if a filtered effluent contains at least .4 grain per gallon, or .57 part per 100,000 of nitrate in terms of ammonia before incubation, it is very unlikely to putrefy unless there is a large amount of suspended organic matter present.

absence of sufficient dissolved oxygen and nitrate, while the other may gradually improve through being more perfectly aerated, so that the results of this test are liable to be misleading unless they are very carefully conducted.

It should be observed that the so-called "secondary decomposition" of inferior effluents is really due to a process of putrefaction resulting from the absence of available oxygen, whereas the term decomposition should properly be applied to fermentation in which large quantities of oxygen are absorbed, and the more complex compounds are converted into such stable products as water, ammonia, carbonic acid gas, marsh gas, sulphuretted hydrogen, sulphides, free hydrogen, and free nitrogen.

With regard to standards of purity for sewage effluents, the conclusions of the present Commission are given in their Fourth Report, Vol. I., Part I., from which the following abstracts are taken for the purpose of showing the general result of their investigations in relation to the standards hitherto adopted in certain districts, and the difficulty of devising any absolute standard which would be capable of universal application regardless of local conditions.

"The standard of purity for effluents recommended by the Rivers Pollution Commission for 1868 has already been given (Section III.). So far as regards matter in suspension and organic matter in solution, it is :—

"(*a*) The liquid shall not contain, as solids in suspension, more than three parts by weight of dry mineral matter, or more than one part by weight of dry organic matter in 100,000 parts of effluent.

"(*b*) It shall not contain in solution more than two parts by weight of organic carbon, or more than .3 part by weight of organic nitrogen per 100,000.

"The Mersey and Irwell River Board's provisional standard (converted into terms of nitrogen and into parts per 100,000) is :—

" .12 part albuminoid nitrogen per 100,000, and 1.43 parts oxygen absorbed from permanganate in four hours at 60 deg. F. (15.6 deg. C.). At the same time this Board also takes into account the rate at which an effluent takes up dissolved oxygen and nitrate from water.

"Dr. Barwise, County Medical Officer for Derbyshire, recommends the following :—

	Parts per 100,000.
Total suspended matter	less than 3.0
Oxygen absorbed at 80 deg. F. in 4 hrs.	1.5
Albuminoid ammonia	0.15
(Equal to albuminoid nitrogen 0.12)	
Nitrogen as nitrates	at least 0.25

"This last approximates to the Mersey and Irwell standard (excepting that the 'oxygen absorbed' test is done at 80 deg. F. instead of 60 deg. F.), but with the addition of a small quantity of nitrate as a safeguarding factor.

"The West Riding Rivers Board has not published any standard, but we understand from Dr. Wilson that it relies mainly upon the 'oxygen absorbed' test at 80 deg. F., and at the same time allows for the presence of nitrate in an effluent.

"The Thames Conservancy has likewise not published any standard.

"The Ribble Joint Committee has not officially fixed upon any standard, but uses provisionally the following figures as a rough working classification :—

"Albuminoid ammonia, if under 0.1 part per 100,000, effluent good.

"Albuminoid ammonia, 0.15 to 0.2 part per 100,000, unsatisfactory.

"Albuminoid ammonia, over 0.2 part per 100,000, bad.

"Without quoting further opinions, it is thus evident that the views upon standards held by acknowledged authorities on the subject of sewage purification differ considerably from one another.

"We do not propose at present to touch upon the question whether or not the chemical standard of purity for an effluent might be allowed to vary within certain limits, according to the volume of the stream into which the effluent flows, but merely to consider upon what principles a standard might reasonably be based, supposing the Commission were ultimately inclined to recommend one.

"A standard may be either (1) one of the non-putrescibility of an effluent, without any regard to the rate at which the effluent takes up oxygen; or it may be (2) one of non-putrescibility, having regard also to the rate at which oxygen is taken up. It is, of course, obvious that the second must be the higher standard of the two. In both cases it is assumed that the suspended solids are either absent, or at all events are not present in larger quantity than allowed for by the Rivers Pollution Commission.

"Any more or less 'absolute' standard like the provisional one of the Mersey and Irwell Board, therefore must necessarily press more hardly upon places which have to deal with strong sewages than upon those which treat weak ones.

"It seems, therefore, reasonable to suggest that, if any chemical standard of purity is to be ultimately proposed by the Commission, it should be one depending, at all events partially, upon the rate at which oxygen is taken up, all the more since the diminution of the dissolved oxygen in brook and river waters by effluents is one of the main things which we have actually to guard against.

"The main objection to a standard depending, in part at least, on the rate of absorption of dissolved oxygen, is that we cannot imitate in the laboratory the ever-changing conditions of a natural stream, and that therefore any dissolved oxygen absorption test that might be recommended for adoption must be an arbitrary one.

"Without making any definite or final statement on the subject at present, we think it would probably be found that any effluent which did not within the 24 hours after drawing take up more than about 3 to 4 c.c. of oxygen per litre (when kept in a full bottle at, say, 18 deg. C. or 65 deg. F.), would be found to be chemically satisfactory. The test might have to be taken in conjunction with the permanganate 'oxygen absorbed' test, to provide against the (unlikely) contingency of an effluent being a sterilised one; and in the present state of our knowledge, it might also be advisable to safeguard it further as regards a maximum of nitrogenous organic matter to be allowed in any effluent at any time (measured, say, by the albuminoid nitrogen), though this additional precaution might in the end be found unnecessary.

"We think there can be no doubt that, if it could be satisfactorily and easily worked out in practice, a standard based upon the above principles would deal equably between effluents from strong and weak sewages, not favouring the one at the expense of the other."

The following passage in the First Report of the Rivers Pollution Committee (Vol. I., p. 20) also has an important bearing on the same subject:—

"The oxidation of the organic matter in water is effected chiefly, if not exclusively, by the atmospheric oxygen dissolved in the water, such dissolved oxygen being well known to be, chemically, much more active than the gaseous oxygen of the air."

And it has been shown by Dr. Dupré that the amount of dissolved oxygen taken up by natural waters in which bacteria are active is very much greater than the amount of oxygen which the same waters take up from a solution of permanganate employed for laboratory test, so that the results obtained by the latter do not necessarily show the rate of oxygen absorption from brook water under natural conditions.

Prof. Dunbar, of Hamburg, has also drawn attention to the various sources of error in forming general conclusions from the results of chemical tests applied to determine certain characteristics of sewage and sewage effluents without a complete analysis and due allowance for the circumstances under which such results are obtained, both as regards the method of conducting the tests and the similarity of results which may be derived from entirely different causes.

For example, the oxygen absorbed figure may be affected by certain inorganic substances as well as organic matter, so it cannot always be accepted as an absolute measure of the latter, the permanganate of potash being discoloured by ferrous salts, nitrites, sulphites, sulphides, ammonia, etc., while some organic bodies are much more readily oxidised than others, and the oxygen absorbed is not in proportion to their molecular weight.

It does not follow therefore that, when the oxygen absorbed figure in two samples is the same, they are equally liable to putrefaction, as the organic matter in each sample may vary considerably as regards stability, and although the effluent from a strong sewage may absorb a larger proportion of oxygen than the effluent from a weak sewage, this does not necessarily mean that the former is more liable to putrefaction, as this depends on the stability of the organic matter present as well as its quantity, so that an effluent which absorbs two or more grains per gallon may still be non-putrescible and not harmful to fish.

The albuminoid ammonia test may be equally inconclusive, since many effluents from very concentrated sewage will not undergo putrefaction when this figure is .3 grains per gallon or even more; and Prof. Dunbar has therefore suggested that, instead of attempting to fix a standard based on the absolute figures obtained by any analytical test, it would be quite sufficient if the impurity originally present in the sewage is reduced by a certain percentage, which could be adjusted according to local conditions, and for estimating this percentage purification the determination of either albuminoid ammonia or oxygen absorbed would usually give sufficiently reliable results, as the percentage reduction shown by different determinations in the same sample is usually about the same.

It will thus be seen that, although an effluent which complies with any or all of the alternative standards previously referred to is not likely to undergo putrefaction under ordinary circumstances, the adoption of any absolute analytical standard must involve unnecessary expense whenever the degree of purity required in a sewage effluent is greater than that which would, in fact, be sufficient to prevent injurious pollution in the river or estuary into which it is discharged, and a considerable saving might in many cases be effected by spending, say, one year's interest on the estimated cost of new sewage disposal works in preliminary experiments and the thorough investigation of local conditions.

No reliable substitute is likely to be found, however, for expert knowledge and experience in estimating the value of analytical tests and determining the degree of purification that may be reasonably insisted on in each individual case, as well as the nature and capacity of the works necessary to produce the required result at the least possible cost; and if Rivers Boards are formed for the different watersheds they will, in the Author's opinion, be far better able to deal with such questions than any Central Authority, though the latter would, no doubt, be useful as a court of appeal in case of dispute, besides exercising a general control over the subordinate Authorities, while seeing that their powers are properly applied for the more effective protection of our rivers and streams, which is a matter of urgency and great national importance.

INDEX.

NOTE.—In order to facilitate reference the index is arranged alphabetically under separate headings as follows:—

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