Investigations on the purification of Boston sewage made at the sanitary research laboratory and sewage experiment station of the Massachusetts institute of technology, with a history of the sewage-disposal problem / By C.E.A. Winslow and Earle B. Phelps.


LONDON·SCHOOL·OF·HYGIENE·AND·TROPICAL·MEDICINE·

Water-Supply and Irrigation Paper No. 185 Series L, Quality of Water, 15

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

INVESTIGATIONS
ON THE
PURIFICATION OF BOSTON SEWAGE

Made at the Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

WITH A

HISTORY OF THE SEWAGE-DISPOSAL PROBLEM

BY

C.-E. A. WINSLOW AND EARLE B. PHELPS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

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INVESTIGATIONS ON THE PURIFICATION OF BOSTON SEWAGE.

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Systems of water carriage, or sewerage, are now almost universally employed for the quick and inoffensive removal of fluid wastes and human excrements from thickly settled communities. These fulfill fairly well that first and most imperative requirement of scientific sanitation—the prompt and efficient removal of the more dangerous excreta. As often happens, however, the solution of one problem has given rise to another scarcely less difficult, namely, in this case, the sanitary and economic disposal of vast quantities of contaminated liquids known as sewage. The volumes of sewage discharged by modern communities are so large, especially in the United States, where water is liberally supplied, freely used, and frequently wasted, and the character of all kinds of sewage is always so objectionable, that the so-called sewage-disposal problem becomes, from the economic as well as the sanitary point of view, one of the most serious with which modern communities have to deal. Nor is this merely a public or community problem. Isolated private houses of the better class are now almost invariably abundantly fed with running water—a supply which has become one of the greatest necessities as well as one of the greatest luxuries of civilized life. In such houses the water-carriage system for the disposal of household wastes of all kinds has found favor no less than in crowded communities. Here, also, it entails a difficult problem, i. e., the ultimate disposal of large quantities of noxious sewage; and for the house no less than for the community it is important to secure this ultimate disposal in such a way as to avoid the creation of any insanitary focus or foci in the environment, or any infringement of the laws of hygiene and sanitation.

Moved by the magnitude and gravity of the sewage-disposal problem as it concerns householders and communities, an anonymous friend of the Massachusetts Institute of Technology, in 1902, presented to that institution the sum of $5,000 a year for three years, for the purpose of making experiments on sewage purification and of giving the widest possible publicity to means or methods by which the present too often crude and imperfect systems may be improved. In a letter which constituted a virtual deed of gift, the donor designated a preference for the following lines of activity:

1. For keeping up with the investigations of the best workers in all countries.
2. For utilizing this knowledge in the work of the Massachusetts Institute of Technology.
3. For original experiments.
4. For distributing all over the country the results of the work in such words that he who runs may read.
5. For inciting students to make plain and simple statements of the results of their studies.

The gift thus made was gratefully accepted by the authorities of the Massachusetts Institute of Technology, and the planning and organization of the work to be done were assigned by them to the writer, head of the department of biology, who had for some years served as lecturer in the Institute on sanitary science and public health, and had also gained considerable experience in sewage purification during a connection of several years with the work of the State board of health of Massachusetts. In view of the limited means available and the long-continued and well-known investigations of the Massachusetts State board of health at the Lawrence experiment station, dealing chiefly with the sewage of an inland city; in view, also, of the increasing use of harbors for the disposal of the sewage of seaboard towns, with the growing dangers of contamination of shellfish, pollution of bathing beaches, and the like; and especially in view of the desirability of making the new work of practical educational value to the students of the Institute of Technology, who might carry away with them into active life and to all parts of the country the results of personal knowledge of the work, it was decided to establish a sanitary research laboratory and sewage experiment station on the main trunk sewer of the south metropolitan system of the great seaboard city of Boston. The precise point finally chosen, near the corner of Massachusetts avenue and Albany street, has proved very convenient and favorable. Here a piece of land formerly occupied by a livery stable was secured on a long lease, the stable itself was turned into a tank house, and a smaller building on the premises was fitted up as an office, with chemical and bacteriological laboratories connected. Open space enough remained for the construction later of outdoor filters and a large trickling filter. Permission was obtained for making connections with the main trunk sewer of the south metropolitan system on its way to the sea at a point where it contained the sewage of a contributing population of about half a million people, and for drawing sewage from this sewer as needed. A pump was installed, tanks were constructed for tests of various methods of sewage purification, and a working organization was effected by the formal appointment of the writer as director, of C.-E. A. Winslow as biologist in charge of the laboratory and station, and of Earle B. Phelps, a graduate of the Institute in the department of chemistry, and for some years assistant at the Lawrence experiment station of the Massachusetts State board of health, as research chemist and bacteriologist. A full description of the laboratory and experiment station is given on pages 97–107, illustrated by figs. 10–14.

The elaborate and long-continued experiments of the State board of health of Massachusetts at the Lawrence experiment station on intermittent sand filtration as a means of sewage purification made it advisable to set up only three filters of this kind, largely for demonstration purposes and for the benefit of students. To the so-called septic-tank method it was felt necessary to give somewhat more attention, the value of this process under various conditions being still somewhat problematical; and to the contact system much attention was given for the same reason. More recently, continuous filtration by means of trickling filters has come to the front, particularly in England, and this system of disposal has therefore required especially careful consideration and study.

As a prerequisite for all these investigations it was plainly necessary to make, in the first place, careful examinations of the character and amount of the sewage actually discharged by the south metropolitan system of Greater Boston. The results of these examinations have already been published, together with other papers, in vol. 1 of "Contributions from the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology," of which the present work is volume 2. Volume 1 appeared originally in the "Journal of Infectious Diseases," volume 1, supplement No. 1, Chicago, 1905, and was also reprinted as a separate brochure. This latter was in large demand and is now unfortunately out of print, but a limited number of the copies of the "Journal of Infectious Diseases" containing these papers may still be purchased from the publishers. As a matter of record the titles of the papers may here be given, as follows:

The chemical and bacterial composition of the sewage discharged into Boston Harbor from the south metropolitan district. C.-E. A. Winslow and E. B. Phelps.

The number of bacteria in sewage and sewage effluents determined by plating upon different media and by a new method of direct microscopic enumeration. C.-E. A. Winslow.

The mode of action of the contact filter in sewage purification. E. B. Phelps and F. W. Farrell.

A critical study of the methods in current use for the determination of free and albuminoid ammonia in sewage. E. B. Phelps.

The determination of the organic nitrogen in sewage by the Kjeldahl process. E. B. Phelps.

Test of a method for the direct microscopic enumeration of bacteria. C.-E. A. Winslow and G. E. Willcomb.

The present volume contains, first, a careful and elaborate historical review of the whole sewage-disposal problem from its origin in the wide adoption of the water-carriage system up to the present time, when that system has become practically universal. This interesting review can not fail to be of the highest value to expert engineers, sewage commissioners, and communities all over the United States, especially those numerous small communities which are confronted, perhaps for the first time, with a problem which means so much for the health as well as the finances of the citizens.

Following the historical review is a full description of the experiments thus far made on the sewage of a great American seaboard city, together with comparisons with similar work done elsewhere, with practical conclusions which have been drawn from the experiments and specific statements concerning the comparative merits of various systems of purification tested. These are by no means applicable merely to large cities or to seaboard cities, but contain lessons of practical value for all sorts of communities having to deal with the ever present sewage-disposal problem.

This report is by no means final, for experiments are still in progress not only along these lines but also along others more recently developed. In particular, the percolating, trickling, or continuous filter method is being more extensively tested, with results which it is hoped may be ready for publication by the end of another year.

The donor of the original gift has consented to continue the work for the fourth and fifth years—an immense advantage in work of this kind, which grows in interest and value with the lapse of time as well as with the experience gained by the workers on the problems involved. In consonance with the wishes of the donor as expressed in the deed of gift, it is the intention of the director to prepare a brief popular statement of the facts contained in this volume, in language so simple that citizens, boards of health, and sewerage commissions may readily avail themselves of the information here contained, and so that, as desired by the donor, "he who runs may read."

The work here described and the results here recorded have no connection with the well-known work of the State board of health of Massachusetts and no official connection with the city of Boston or any of its departments. They proceed entirely from an educational institution—the Massachusetts Institute of Technology—and all the officers and workers at the laboratory and station have been either officers, graduates, or students of the Institute.

If, however, as is quite within the bounds of possibility, it should ever become necessary to purify the sewage of Greater Boston, or of any part of it, before discharging it into the waters of Boston Harbor, there is reason to believe that these studies may have a practical local value in proportion to their cost. Meantime, it is the wish of the director no less than of the donor that they may be found immediately serviceable to numerous American communities confronted with the sewage-disposal problem and seeking means for its solution.

In addition to those persons already mentioned, the working staff of the laboratory and station has included, for longer or shorter periods, Prof. S. C. Prescott, of the Massachusetts Institute of Technology; Prof. E. G. Smith, of Beloit College; Miss Anne F. Rogers, and Messrs. George R. Spalding, Frederick W. Farrell, George C. Bunker, George E. Willcomb, James A. Newlands, William H. Beers, and William T. Carpenter, all of whom have contributed directly or indirectly to the discussions and results contained in this volume.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
Boston, April, 1906.

HISTORY OF THE SEWAGE-DISPOSAL PROBLEM.

NATURE OF THE PROBLEM.

The disposal of waste is a fundamental problem for all living organisms. As the body takes in food and builds it up into its own peculiar structure, so it must continually break down and give off waste products, which, as a rule, if they accumulate, prove poisonous to the organism itself. This is the case with the individual; it is still more the case when large numbers of organisms are closely congregated together in communities. The political body resembles the organisms of which it is composed in no merely fanciful sense. It is subject to the laws of organic life; it has its income and its outgo; and a failure to remove the waste products of its life processes is inevitably dangerous to the units of which it is composed.

In spite of these facts, the attempt at scientific waste disposal is comparatively recent. The Cloaca Maxima and the other so-called sewers of antiquity were rather drains than sewers, and their function was to lower the ground-water level and not primarily to remove excretal wastes. Until 1815 the discharge of any waste but kitchen slops into the drains of London was prohibited by law, and the same regulation persisted in Paris up to 1880. Sewerage and sewage disposal proper really date from the epoch-making report of the health of towns commission of Great Britain in 1844,[a] which revealed the accumulation of such an astonishing amount of decomposing organic matter and filth of all kinds in the cities that it aroused British sanitarians to a strong movement for the amelioration of these conditions and led to the development of the filth theory of disease—the theory that disease is bred in heaps of decomposing filth. This pythogenic theory of Chadwick and Murchison we now know to be wrong in its essential assumption that infective material is created de novo by decaying organic matter; yet it was right in laying emphasis on filth as a carrier of disease. The wonderful administrative work of the British sanitarians, acting on this partially erroneous theory, effected the greatest sanitary progress which has probably ever been known. Public and private cleanliness was taught and practiced as never before. The midden system and the pail system rapidly gave way to the water-carriage system. Whereas in 1815 the sewers of London were simply drains to carry off the storm water—the discharge of sewage into them being forbidden by law—in 1847, only three years after the report of the health of towns commission, it was made obligatory to discharge all sewage into those drains.

In other countries the example set in England was more or less promptly followed. In the United States numerous drainage systems existed, one in Boston, for example, dating from the seventeenth century; but the first comprehensive sewerage project was designed

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[a] Frequent reference will be made to the investigations of the royal commissions of Great Britain, and in order to avoid confusion the following chronological summary of the work of those commissions which have dealt with sewage disposal and allied subjects is quoted from A. J. Martin:

1843. Royal commission appointed "to inquire into the present state of large towns and populous districts" (health of towns commission).
1844. First report of health of towns commission.
1845. Second and final report of health of towns commission.
1857. Royal commission appointed to inquire as to the best means of distributing the sewage of towns (sewage of towns commission).
1858. Preliminary report of sewage of towns commission.
1861. Second report of sewage of towns commission.
1865. Commission appointed to inquire in the best means of preventing the pollution of rivers (rivers pollution commission).
Third report of sewage of towns commission.
1868. Second rivers pollution commission appointed.
1870. First and second reports of rivers pollution commission.
1871. Third report of rivers pollution commission.
1872. Fourth and fifth reports of rivers pollution commission.
1874. Sixth and final report of rivers pollution commission.
1882. Commission appointed to inquire into the effects of the discharge of the sewage of the metropolis into the river Thames (metropolitan sewage commission).
1884. First report of metropolitan sewage commission.
1885. Second and final report of metropolitan sewage commission.
1898. Commission appointed to inquire and report what methods of treating and disposing of sewage may properly be adopted (royal sewage commission).
1901–2. Interim report of royal sewage commission.
1902. Second report of royal sewage commission.
1903. Third report of royal sewage commission.
1904. Fourth report of royal sewage commission.

by E. S. Chesbrough for the city of Chicago in 1855. On the continent of Europe a sewer system was constructed at Hamburg after the great fire of 1842, by Lindley, an English engineer. Berlin began her sewerage in 1860 and other German systems quickly followed. France and the Latin countries, though still somewhat inadequately sewered, are making progress. No law of sanitation is now more clearly recognized than the principle that the wastes of human life must be diluted with an adequate supply of water and quickly removed from the region of habitation.

With the establishment of the water-carriage system the difficulty was shifted from the individual to the community. The insanitary conditions surrounding the dwelling were relieved, but at some point on the outskirts of the city the concentrated filth from its entire population must be disposed of. The vast volume of water in which the excretal elements are distributed makes the problem only more difficult. In England the average daily flow of sewage is about 25 gallons per capita. In London it is 34 gallons (R. S. C., 1902 b[a]). In the United States, on the other hand, the flow in several small Massachusetts cities is estimated at about 100 gallons (Fuller, 1903), while for the south metropolitan district of Boston it is over 250 gallons (Winslow and Phelps, 1905). In the latter case the yearly flow of sewage amounts to 46 billion gallons—a fair-sized river. The organic matter to be treated includes during the year over 1,500,000 kilograms of nitrogen in the form of free ammonia alone. The treatment of such a volume of waste material offers a problem in applied chemistry of no mean magnitude.

The undesirable constituents in sewage may be considered under two heads—living germs and dead organic matter. The first create disease; the second breeds nuisances. The germs of almost any disease of man or the lower animals may gain access to sewage, and, in the case of typhoid fever in particular, the infection may be transmitted through its agency so as to cause epidemics on a disastrous scale. The experiments of Jordan, Russell, and Zeit (1904) and of Frost (1904) indicate that typhoid bacilli in water, and particularly in sewage-polluted water, for the most part die in a few days. Yet the statistics of Lowell, Lawrence, Chicago, Philadelphia, Pittsburg, and Newark indicate that the typhoid germs which survive a sojourn in sewage and water are sufficiently numerous to produce serious results. Therefore where shellfish are taken from an estuary into which sewage is discharged it is desirable to subject the sewage

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[a] Complete references to all literature cited in this report will be found in the bibliography at the end. References in the text include the name of the authority (the initials in the case of the British commissions) and the date of publication, with a distinguishing letter in case more than one volume appeared in a single year. This serves simply to identify the article or book, the full title of which is given in the bibliography.

to some process—such as sand filtration—which effects a considerable reduction in bacterial content; and the sterilization of an effluent after its complete oxidation might, under certain conditions, prove desirable. As a rule, however, if the effluent from a sewage plant as discharged into a stream is clear and nonputrescible, the process is considered to be satisfactory. It is becoming more and more clearly recognized that all polluted waters, perhaps all surface waters, should, before they are used for drinking, be treated by water filters designed for the special purpose of removing disease germs. If such filtration as this is to follow, it is unnecessary to place on the sewage-purification works the extra burden of bacterial removal. The immediate and pressing need at the sewer outfall is the disposal of the organic matter, which threatens to create a nuisance by its decomposition. This organic matter may often be rendered harmless by means quite different from those calculated to effect high bacterial removal. When such is the case, it is scarcely fair to hamper the essential task of sewage disposal by demanding a bacterial purification which can be better attained by subsequent special treatment in water filters. All sewage-purification processes, as a matter of fact, materially reduce the number of bacteria present; but this must in general be regarded as incidental, the success of the process being gaged chiefly by the fate of the organic matter.

Where the waste from manufacturing processes is abundant, certain special problems are introduced. The material to be handled may be greatly increased in amount and the added material may be organic matter of a specially refractory kind, such as is found in wool-scouring waste, tannery waste, and brewery waste. Furthermore, the presence of mineral poisons may interfere with the very processes which bring about the purification of the organic matter present. The acid-iron sewage of Worcester is an example of this sort, the biological processes of purification being appreciably hampered by the waste liquors from wire mills. The waste from the sulphite-pulp mills offers a notable example, carrying vast amounts of refractory organic matter, together with antiseptics which prevent any bacterial treatment until they are removed. Such industrial wastes require specific treatment in each case, generally along mechanical and chemical lines. They offer special problems quite distinct from the main question of sewage treatment, to which it is desired to limit the present paper.

In the disposal of ordinary domestic sewage it is primarily dead organic matter which must be dealt with. The products of the metabolism of men and animals and the partially decomposed waste materials from the preparation of food are largely made up of unstable organic compounds. They must be further decomposed, and the decomposition may follow either of two different courses. Under ordinary conditions a rapid reduction of any available oxygen first takes place, followed by an incomplete anaerobic putrefaction, accompanied by the evolution of methane, carbon dioxide, nitrogen, hydrogen, and various ill-smelling gases, such as hydrogen sulphide and the mercaptans. Such a process is likely to create a nuisance objectionable from economic as well as esthetic grounds. The odors of decomposition may even become so objectionable as to menace the public health.

The history of the organic matter is quite different if its decomposition takes place in the presence of an abundant supply of oxygen. If dry organic matter is burned, it is converted into water and the oxides of carbon and nitrogen. If moist organic matter is allowed to ferment in the presence of an ample supply of oxygen, a slow oxidation is accomplished by the activity of certain micro-organisms, and the end products are again water, carbon dioxide, and nitrates. This aerobic fermentation is free from odor, and its end is the complete conversion of the decomposition products into harmless inorganic constituents. Such an oxidation alone can finally dispose of the excretal products and prevent the obnoxious conditions attendant on anaerobic putrefaction. This is the rational aim of all processes of sewage disposal, which may be defined as methods for the conversion of the waste products of organic life and death into their oxidized and mineral forms.

COMPOSITION OF SEWAGES.

Chemically considered, sewage is a dilute solution and suspension of certain organic and inorganic substances in water. The statement, originally made in 1890 by Hiram F. Mills and often quoted by subsequent writers, that "a sewage stronger than ordinary would contain, say, 998 parts of pure water, 1 part of mineral matter, and 1 part of animal and vegetable matter," serves its intended purpose in fixing an upper limit for the constituents of sewage, but is excessive for the sewage of American and English cities in its estimate of solids. From the data available it may be stated that 800 parts per million of total solids, as against 2,000 parts given by the standard mentioned, is a liberal figure for American cities and is exceeded by few; English cities may average about twice as much, while the continental European cities vary widely, but in few cases exceed 2,000 parts.

Of the total solids in a sewage it may be said roughly that from 60 to 70 per cent is in solution, either true or colloidal, the remainder being insoluble matter in suspension. Measured by the nature of the solids, about one-half, as a rule is volatile on ignition, representing in the main organic matter, while the remainder, called the fixed solids, represents the mineral matter originally present, as well as the mineral ash of the organic matter. The fact should be emphasized in this connection that many mineral substances are lost on ignition and that the combustion of nearly all organic substances occurring in nature leaves a greater or less amount of mineral ash. By far the larger part of the fixed solids is found dissolved, this amount on the average reaching about 75 per cent of the total, most of the remainder being sand or other insoluble matter, largely derived from street washings. The division of the organic matter is about equal between dissolved and suspended matter.

Concerning the character of the mineral matter present, it may be said that the portion in solution is of little consequence in relation to sewage treatment. It consists largely of sodium chloride. In certain special cases dissolved mineral matter may be precipitated during treatment and become burdensome. This is especially the case where iron salts are present in considerable amount. The insoluble mineral matter and the mineral residue from organic matter concern the present discussion more immediately, since in many processes of treatment these materials will accumulate to the detriment of filters. They normally amount to perhaps 10 per cent of the total solids and in the case of cities sewered on the separate system will not vary materially from that proportion. Combined sewers, however, admitting storm water from the streets, deliver an immense amount of sand and similar material during a storm, for the care of which some provision must be made at the disposal plant. No estimate can be made of the amount of such material likely to be delivered. It will depend entirely on local conditions, especially on the nature of the streets and the soil and on the severity of storms.

The character of the organic matter is of much greater importance. It is customary to speak of nitrogenous and carbonaceous matter, although the nitrogenous matter contains as a rule more carbon than nitrogen. Since, however, organic matter containing nitrogen gives rise on decomposition to products offensive to the senses, and since the various products of its oxidation are readily determined by simple analytical methods, much greater stress has always been laid on the nitrogen in sewage than on any other element. The total nitrogen value for American city sewages may be roughly placed at from 15 to 35 parts per million. Of this amount from one-third to one-half, depending on the condition of the sewage, will be in the form of free or saline ammonia, largely as ammonium carbonate. The remainder, say from 10 to 25 parts per million, exists in combination as organic nitrogen. The nitrogenous organic material present in part results from the breaking down of proteid or albuminous material in digestion and in part represents unaltered proteid material. Albumin contains about 16 per cent of nitrogen, while its decomposition products—leucine, tyrosine, and various other amido-acids—

contain from 8 to 10 per cent, so that 10 per cent may perhaps be taken as an average value for the nitrogen in the nitrogenous material. This gives an amount of such material equal to from 100 to 250 parts per million in the sewages under discussion. Roughly, about one-half of this nitrogenous material is carbon in organic combination, giving from 50 to 125 parts per million of carbon. The total carbon of such sewages may be expected to be between 100 and 300 parts, say 200 for an average, of which perhaps 75 parts are found in the nitrogenous material. This leaves 125 parts of carbon as carbonaceous (nonnitrogenous) material, of which the greater part is cellulose or some other carbohydrate and fat. From the rather meager data available as to the amount of fat in sewage, it may be concluded that 50 parts per million is perhaps a fair average figure. Seventy per cent of the fat, or 35 parts, is carbon, which, deducted from the 125 parts previously mentioned, leaves about 90 parts of carbon as carbohydrate. The proportion of carbon in carbohydrates being taken at 46 per cent, this gives 200 parts per million of carbohydrate. The figures thus deduced may be taken as fair average figures for American sewages. Considerable variation from the estimates may be found, amounting to perhaps 50 per cent on either side, but the relative amounts seem to be fairly constant as far as can be judged from available data. For the sake of clearness these typical figures are tabulated below:

Composition of an ideal sewage.

[Parts per million.[a]]

	Total.	In solution.	In suspension.
Residue on evaporation	800	500	300
Mineral and ash	400	300	100
Organic and volatile	400	200	200
Nitrogenous	150		
Nitrogen	15		
Carbon	75		
H, O, S, P, etc	60		
Nonnitrogenous	250		
Fats, etc	50		
Carbon	35		
H, O	15		
Carbohydrates	200		
Carbon	90		
H, O, etc	110		
Total carbon	200		
Total nitrogen	15		
Total H, O, S, P, etc	185		

[a] All analytical results in this report are expressed in parts per million. Data cited from other authorities have been converted to the same basis.

In order to change these figures to grams per capita per day it is only necessary to multiply by 0.38, a daily flow of 100 gallons per capita being assumed.

The sewage of English cities is in general stronger than the figures given here for a typical American sewage. Analyses previously compiled (Winslow and Phelps, 1905) indicate that the total solids in

European sewages will average about 1,500 parts per million, with a range of from 500 to 2,100 parts. The organic constituents also, as measured by total organic nitrogen, indicate that European sewages are twice as strong as American. Values for oxygen consumed are not comparable on account of differences in analytical methods, but those for free ammonia are much more nearly equal in the two cases.

The amount of oxygen required to convert these organic substances into the mineral form is considerable. Dibdin, as shown in Table I, estimates it at from one to three times the weight of the organic substance to be acted on.

TABLE I.—*Parts of oxygen required to oxidize one part of various organic substances (Dibdin, 1903).*

Substance.	Oxygen required.				Oxygen already present.	Difference, or additional oxygen required for complete oxidation.
	By the nitrogen.	By the hydrogen.	By the carbon.	Total.		
Gelatin	0.523	0.528	1.333	2.384	0.251	2.133
Chondrin	.411	.568	1.310	2.289	.294	1.995
Albumen	.457	.568	1.414	2.439	.220	2.219
Cellulose, woody fiber		.496	1.184	1.680	.494	1.186
Starch		.496	1.184	1.680	.494	1.186
Fat, stearic acid		1.016	2.025	3.041	.113	2.928

The problem of sewage disposal is to supply this required oxygen and to supply it under such conditions that it will unite with the organic matter to be eliminated.

DISPOSAL OF SEWAGES BY DILUTION IN LAKES, RIVERS, AND THE SEA.

The most obvious way to dispose of sewage is to empty it into the nearest body of water. Before true sewers existed the natural drains discharged into the nearest watercourse, and when the drains became filled with polluting matter the same plan was followed. Within certain limits the process proved a success. When the volume of sewage was not too great it disappeared by dilution and was finally removed by the agencies involved in the "self-purification of streams." The dilution is, of course, only an aid to purification and not in itself an active agent in the process. A drop of ink in a barrel of water is still existent, though invisible. Sedimentation, too, is scarcely in itself a process of purification, although it performs a most important part, separating the solids and storing them so that other agencies may have time to act. Oxidation of the organic matter is the real purification process, and it is by virtue of this process that streams are able to dispose of organic pollution when they do so successfully.

The oxidation of organic matter in a stream or pond may be partly due to direct chemical action. In the main, however, it is carried out by the activity of micro-organisms. The larger microscopic forms, the crustacea, the rotifera, and the protozoa, play a part the exact importance of which is hard to estimate, especially in the consumption of the solid particles. The algæ and other green plants exercise an important influence, as shown by Bokorny (1897) and others. The chief agents, however, are the bacteria, particularly those metatrophic and prototrophic forms which liquefy proteids, liberate free ammonia from more complex compounds, and oxidize it to the mineral form.

The process of self-purification of streams, though a real process, is a slow one. The rivers pollution commission of Great Britain concluded in 1874 that sewage mixed with twenty times its volume of pure water would be two-thirds purified in flowing 168 miles at a rate of 1 mile an hour. Long, in 1889, made a careful study of this process in the Illinois and Michigan Canal. A large part of the sewage of Chicago, diluted with the water of Lake Michigan, at that time flowed through the canal for a distance of 29 miles at a rate of about 1 mile an hour. Analyses from Bridgeport and Lockport, at the beginning and end of the canal, as shown in Table II, gave a purification of 23 per cent as measured by albuminoid ammonia and 27 per cent measured by oxygen consumed, with a removal of 46 per cent of the matter in suspension.

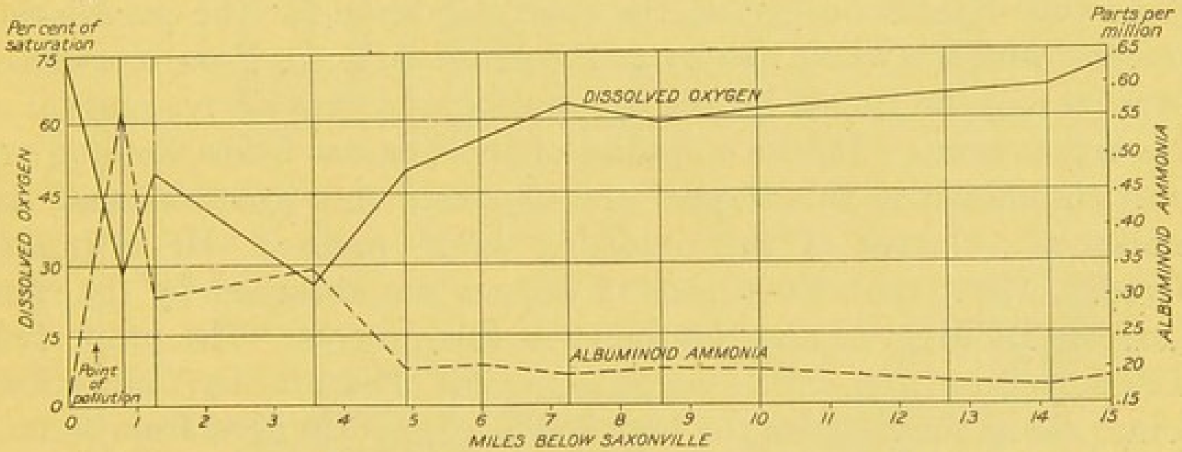

FIG. 1.—Diagram illustrating self-purification of Sudbury River.

TABLE II.—*Analyses of water from the Illinois and Michigan Canal at Bridgeport and Lockport (Rafter and Baker, 1894).*

[Parts per million.[a]]

Place collected.	Total solids.	Matter in suspension.	Nitrogen as nitrates.	Chlorine.	Hardness ($CaCO_3$).	Nitrogen as—		Oxygen consumed.
						Free ammonia.	Albuminoid ammonia.	
Bridgeport..........	471.2	129.2	0	46.8	201.3	10.1	2.1	22.1
Lockport............	431.2	69.8	0	46.1	207.7	8.9	1.6	16.2

[a] Free and albuminoid ammonia values throughout this paper are expressed as nitrogen. The method by which oxygen-consumed determinations were made is stated whenever it could be ascertained from the original reports.

Streams with more sluggish flow will naturally exhibit a greater purification in a short distance, since sedimentation will be greater and since the time during which the nitrifying organisms act is one of the chief factors involved. Sudbury River in Massachusetts, for example, is heavily polluted at Saxonville by the wastes from a woolen mill. It flows rapidly for about 3 miles below the mill and then enters an area of meadows where it winds along through a weedy channel at a rate not more than one-fourth mile an hour. In an investigation by Woodman, Winslow, and Hansen (1902) it was found that 3 miles below the entrance to the meadows and 6 miles below the mill the chemical constituents of the stream had fallen to their normal. The relations of albuminoid ammonia and dissolved oxygen on one of the days studied is indicated in fig. 1, in order to illustrate the progress of the purifying process. It will be noticed that below the point marked "Point of pollution" the albuminoid ammonia is greatly increased, and the dissolved oxygen, being absorbed by the organic matter, is correspondingly diminished. Gradually, however, normal conditions reassert themselves, more oxygen is absorbed, and the albuminoid compounds settle out and are oxidized. At the station 6 miles below the point of pollution both constituents have been restored to their original value. Throughout, the reciprocal variation of the oxygen and the oxidizable nitrogen are striking.

Next to the time element the amount of available dissolved oxygen is, as this diagram suggests, the chief condition for the purification process; and the whole history of the pollution and self-purification of streams may be traced by the diminution and gradual restoration of this constituent. Dibdin's studies of the Thames below London are most significant in this respect and illustrate on a practical scale the enormous volumes of the oxidizing agent needed. He estimates (Dibdin, 1904) that 2,000 tons of oxygen are absorbed by the river between Teddington and Southend in this process. The proportion of dissolved oxygen, expressed as "Per cent of saturation," at various points along the river on the high tide is plotted in fig. 2 from figures given by Dibdin (1904) for 1893–94. As the river enters the city between Kew and Battersea its oxygen content falls from 70 per cent to 43 per cent, and the progressive pollution continues until at Woolwich the oxygen value is only one-fifth that of saturation. Below Barking Creek the heavy pollution ceases, absorption of oxygen overbalances its consumption, and the normal conditions are gradually restored. The same general relations are shown in Table III, quoted by the Connecticut State sewage commission (1899). The ratio of oxygen to nitrogen, which changes from 1:2 at Kingston, above London, to 1:62 at Greenwich, is most significant.

TABLE III.—*Dissolved gases in the Thames above and below London, England (Connecticut, 1899). Analyses by Roscoe and Schorlemmer.*

[Cubic centimeters per liter.]

	Kingston.	Hammer-smith.	Somerset House.	Green-wich.	Wool-wich.	Erith.
Total volume of gas	52.7	....	62.9	71.25	63.05	74.3
Carbon dioxide	30.3	....	45.2	55.6	48.30	57.0
Oxygen	7.4	4.1	1.5	.25	.25	1.8
Nitrogen	15	15.1	16.2	15.4	14.5	15.5
Ratio of oxygen to nitrogen	1:2	1:3.7	1:10.8	1:62	1:58	1:8.6

When in any river the proportion of organic matter is slightly increased over that in the Thames at Woolwich, the small proportion of dissolved oxygen may be quite consumed. Conditions change and instead of aerobic nitrification, anaerobic putrefaction is set up. Foul-smelling gases are produced, and in place of a self-purifying stream a septic tank or open cesspool is produced.

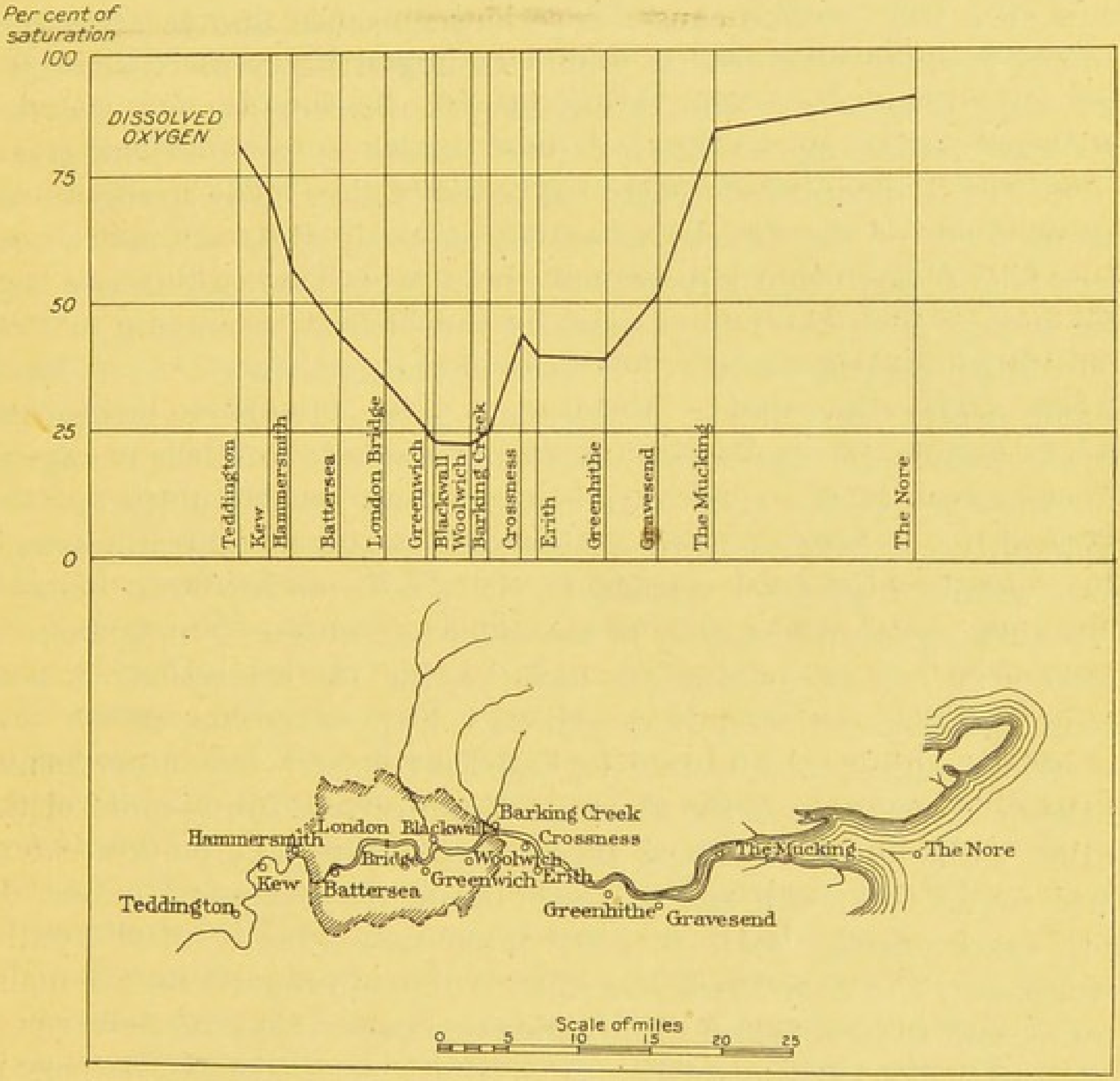

FIG. 2.—Diagram illustrating self-purification in the Thames, England.

There is evidently a critical point in the purification of sewage by discharge into water. Up to a certain point the organic matter is successfully nitrified. As soon, however, as the material to be oxidized exceeds the available oxygen, aerobic purification stops and putrefaction takes its place. Rideal has attempted to express the relation between the various factors involved in the form of an equation, $XO = C(M - N)S$, where X = flow of a stream, O = parts of dissolved oxygen in the water of the stream per unit flow; S = volume of sewage or effluent; M = parts of oxygen consumed by a unit volume of sewage; N = parts of available oxygen in the form of nitrites and nitrates, and C = a constant. When the available oxygen exceeds the demand all goes well; when it does not, trouble ensues.

The ocean furnishes seaboard cities with the most favorable possible conditions for disposal in water. At New York and many other places small sewers discharge at frequent intervals into tide water. In Boston this method caused a serious nuisance, and as a result a somewhat more elaborate system was begun in 1876. Since 1895 two main sewers have discharged into the harbor, serving the city and surrounding metropolitan district, which includes 25 cities and towns with a territory of nearly 200 square miles. The sewage of the region north of the Charles flows continuously from an outlet near Deer Island Light and amounts to about 50 million gallons per day. The sewage from the region south of the Charles, averaging in 1904 100 million gallons per day, has been discharged since 1884 at Moon Island, nearer the center of the harbor. Here, in order to protect the adjacent shores, it has been thought necessary to hold the sewage in four masonry basins and to discharge it only on the outgoing tide. September 19, 1904, a third outlet was opened to take the sewage from certain high-level regions in the south metropolitan district. This discharges continuously in the outer harbor near Nut Island and delivers 20 million gallons per day, leaving the diminished flow at Moon Island about 80 million gallons. Experience has shown that no serious nuisance is caused by the Deer Island and Moon Island outlets. The sewage in the first case disappears within 1¼ miles of the outlet, while off Moon Island the sewage stream may be traced outward round the south end of Long Island for perhaps 2 miles. In both cases passing boats find the immediate vicinity of the outlet unpleasant, and near Moon Island the value of property on the mainland is said to be affected. No serious menace to health, however, is involved. The sewage apparently produces no permanent damage in the harbor, and recent investigations carried out by J. H. McManus and A. W. Walker in the laboratories of the Massachusetts Institute of Technology indicate that even in high winds there is no tendency for sewage bacteria to be carried into the air and blown shoreward. So popular is the method of disposal in the sea that according to a review made by the Massachusetts State board of health in 1902

(Massachusetts, 1903) nearly one-half the population of that State is tributary to such systems. In general they have proved successful, although a serious nuisance is created in some places, as at Lynn, where the sewage is discharged in shallow water and over tidal flats. In any case it is certain that such methods of disposal will prove less and less satisfactory from year to year as the volume of sewage and the concentration of shore population increase. The presence of shellfish beds in locations affected by the discharge of sewage into tide water is a special problem of a serious nature in some localities. It has been exhaustively treated by Fuller (1905 b). The royal sewage commission, in an extensive report on the shellfish question in 1904 (R. S. C., 1904 c), concluded that this evil is a grave one, but that it must be met less by restricting sewage disposal than by regulating the taking and storing of shellfish.

The discharge of sewage into inland waters is less likely to be successful than disposal in the sea. The gravest dangers with large lakes and rivers have arisen from their simultaneous use for sewage disposal and water supply, as in the case of Chicago before the opening of the drainage canal, and to some extent since. In such a case the water supply should always be subjected to its own process of purification; yet where water for drinking is to be taken below the sewage outlet some treatment of the sewage before it discharges furnishes an additional safeguard that is eminently desirable. With smaller bodies of water the increasing proportions of sewage sooner or later exceed the purifying capacity of the stream or pond, and once this point is passed conditions rapidly become intolerable. Just such a condition existed in the Thames, England, prior to the treatment of the sewage of London by chemical precipitation in 1890. In a night trip down the river during one of the investigations of the metropolitan sewage commission of 1882 three of the five members of the commission and their clerk were nauseated by the odor. Gross nuisances of this sort have been created in many streams, both in this country and in England. Blackstone and Neponset rivers, in Massachusetts; Naugatuck River, in Connecticut, below Waterbury; Passaic River between Paterson and Newark, in New Jersey, and Chicago River before the opening of the drainage canal are notorious examples.

By the examination of various rivers it has been possible to fix fairly well the practical limits within which a stream can purify sewage with success. Stearns (1890) estimated that a stream flow of 7 second-feet could safely carry the sewage of 1,000 persons, while if the flow were reduced to 2.5 second-feet a nuisance would result. Hering (1888) set the lower limit at 2.5 to 3.3 second-feet. Goodnough (1903), after a careful study of various Massachusetts streams in connection with the proposed Charles River dam, placed the certain danger line at 3.5 second-feet per 1,000 persons and found that with 6 second-feet trouble rarely follows. Johnson (1905) converted these figures into dilution volumes as follows:

TABLE IV.—*Proportions of sewage which can be discharged into a stream with safety (Johnson, 1905).*

Authority.	Nuisance probable.	Nuisance improbable.
Hering	1 in 16	1 in 45
Goodnough	1 in 23	1 in 36

Roughly, then, it may be said that a stream will purify one-fiftieth of its volume of sewage, but not much more. In summer, when the volume of diluting flow is least, the high temperature accelerates bacterial action and makes an abundant supply of oxygen specially necessary. Table V shows for Merrimac River, above Lawrence, the monthly ratios of stream flow to the sewage-contributing population, estimated at 185,000, together with the mean monthly temperatures and the dissolved oxygen in the river water. The data are graphically shown in fig. 3 and bring out clearly the much greater demand on the purifying power of the river during the summer months. The curve for November and December, 1899, is worthy of special notice, since with no increase in dilution a fall in temperature, with its consequent slackening of fermentation processes, shows a marked rise in dissolved oxygen. Although at the lowest points the dilution does not fall below Goodnough's minimum of 6 second-feet and although the dissolved oxygen averages do not show complete exhaustion, the river

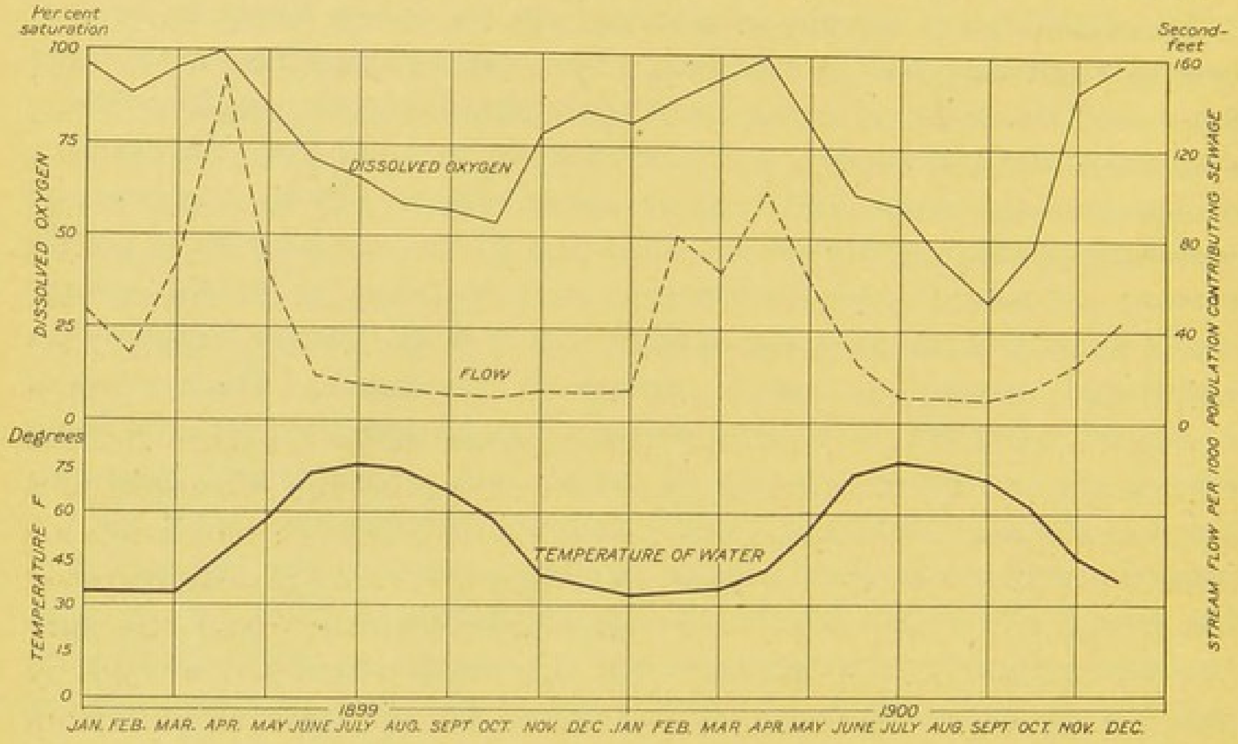

FIG. 3.—Seasonal variations in the condition of Merrimac River at Lawrence, Mass.

is sometimes distinctly offensive during the summer. Theoretically, while any dissolved oxygen remains there should not be putrefaction; practically, any value below 50 per cent of saturation is likely to be accompanied at times by malodorous conditions.

The data in the following table are taken from annual reports of the Massachusetts State board of health (Massachusetts, 1900 and 1901) and from Water-Supply and Irrigation Papers Nos. 35 and 47 of the United States Geological Survey (1900 and 1901):

TABLE V.—*Seasonal conditions in Merrimac River at Lawrence, Mass.*

Month.	1899.			1900.		
	Flow per 1,000 persons discharging sewage (second-feet).	Temperature (° F.).	Dissolved oxygen (per cent of saturation).	Flow per 1,000 persons discharging sewage (second-feet).	Temperature (° F.).	Dissolved oxygen (per cent of saturation).
January	42.6	34	96.3	18.2	33	81.6
February	26.4	34	88.1	89.1	34	87.8
March	64.5	34	95.6	87.7	35	......
April	143.2	......	99.3	100	41	99.1
May	51.6	58	84.4	54.1	54	......
June	16.1	73	71.1	21.4	73	62.1
July	13.4	76	66.6	9.8	77	59.4
August	11.3	74	58.3	10.1	75	43.6
September	10.8	67	57.2	8.2	71	32.5
October	9.7	58	53.7	13.6	62	47.6
November	15.1	40	78.1	31.6	46	91.2
December	15.1	36	84.3	36.6	38	98
Average	34.5	53	77.8	39.9	53	70.3

It is evident that for inland cities, except those situated on the largest lakes and rivers, some other process of sewage disposal must be substituted for the direct discharge into water. In England this is an old story. The first of the royal commissions on sewage disposal investigated the subject in 1857 and reported in 1865 that the only way to prevent the pollution of rivers was to purify town sewage by disposal on land. A second royal commission on rivers pollution, appointed in 1865, made five exhaustive reports between that date and 1874, and a third commission, on the metropolitan district, reported in 1884 that treatment of London sewage was essential to the protection of the Thames. In the United States the Massachusetts legislature in 1872 directed the State board of health to investigate and report on "the disposition of the sewage of towns and cities," eliciting a memorable series of reports from William Ripley Nichols and his associates, and in 1886 the Lawrence experiment station was founded for the study of sewage-disposal problems. To-day 23 cities in the State of Massachusetts alone maintain purification works. According to Fuller (1905), about 28,000,000 persons in the United States are connected with sewerage systems. The sewage from 20,400,000 is discharged into fresh water and from 6,500,000 into the sea, leaving 1,100,000 connected with sewage-purification works.

DISPOSAL OF SEWAGES BY BROAD IRRIGATION OR SEWAGE FARMING.

The most obvious alternative to the discharge of sewage into water is its distribution over the surface of suitable land, allowing the liquid to pass through to join the great reservoirs of ground water below. When the amount of sewage on a given area is not excessive the organic solids do not accumulate, but are gradually decomposed with the formation of soluble products beneficial to the growth of the higher plants. The disposal of waste water in every dooryard early gave an illustration of this process, and the absorption of manure in the fertilization of land indicated the great power of the purifying agents involved.

The practice of sewage disposal by broad irrigation gained a firm empirical basis long before there was any comprehension of the true principles involved. At Bunzlau, Prussia, for example, in the sixteenth century, the water from a famous spring was delivered to the inhabitants and a primitive sewer installed. The sewage from the outfall was distributed for irrigation on privately owned farms as early as 1559 with marked success (Du Marès, 1883). At the Craigentinny meadows part of the sewage of Edinburgh has been treated by irrigation for over two hundred years. The development of this method in England was largely due to the health of towns commission of 1844 and the sewage of towns commission of 1857. The latter commission in 1858 gave a full description of the system at Milan, where the liquid refuse of the city was conducted by a canal called the "Vettabbia" to an irrigation area of about 4,000 acres. The same commission concluded in 1865 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."

With the desire to dispose of polluting material grew up a still greater interest in sewage farming as a profitable method of turning organic wastes into valuable crops, Liebig and his followers having laid great stress on the danger of an exhaustion in the nitrogen supply. The two conceptions are well combined in the definition of irrigation by the British metropolitan sewage commission of 1884 as "the distribution of sewage over a large surface of ordinary agricultural land, having in view a maximum growth of vegetation (consistent with due purification) for the amount of sewage applied."

Progress along these lines was rapid in England during the sixties, and many of the present sewage farms were then laid out, as Croydon (1861) and Aldershot (1864). On the continent of Europe the first irrigation plant to be successfully operated on a large scale was at Danzig. In 1869 a contract was signed with an English engineer, Alexander Aird, by which the sewage of the city and 1,300 acres of land were ceded to him for a term of thirty-two years, the entire maintenance of the sewerage system being in his charge. The operation of this plant had a special interest on account of the severe winter weather to which it was subjected. At about the same time the application of sewage to land was begun at Paris by Mille and Durand-Claye, after much preliminary investigation by Schloesing, Muntz, and others, of the chemical and biological principles involved. At present a total area of 13,338 acres at Gennevilliers, Acheres, and two other adjacent places is irrigated with Paris sewage. The flow amounts to 185 million gallons a day, and the standard rate of filtration is 0.012 million (12,000) gallons per acre per day.[a] The sewage, after passage through screen chambers and detritus tanks, is distributed on farms which are mostly owned by private individuals, although the city operates a small area. Part of the land is used for pasturage and part for raising peas, artichokes, tomatoes, and other table vegetables. The sewage farms of Berlin do not date quite so far back. Operations were first begun at Osdorf in 1876, after a long investigation under the leadership of Rudolf Virchow. An area at Falkenberg was added in 1879, and two areas at Grossbeeren and Malchow were added in 1882. The farms are to-day the largest in the world, the sewage of a population of 1,750,000 being treated on 22,881 acres of land at a rate of 0.003 million gallons per acre per day. The crops are chiefly timothy and Italian rye grass. The farms are operated mainly by convict labor under German military discipline (Roechling, 1892).

The English sewage farms are so designed that the sewage is allowed to run continuously over the surface of the soil in as thin a film as possible without being specially encouraged to pass downward. As a rule, the sewage is brought to the highest level on the farm and thence distributed by open carriers following the contours; these in turn discharge through lateral carriers or ditches. On many farms special areas of porous soil are leveled so that they may be completely flooded, serving for intermittent filtration, which is discussed on pages 35–42.

To obtain an available area of proper soil is the chief problem in sewage farming. A light soil on a sandy or gravelly subsoil proves most satisfactory, while peat, chalk, and clay are bad. All three are too impervious, and the last two are likely to discharge unpurified sewage through cracks and fissures. With unsuitable soils rates of filtration must be low. Rideal (1901) estimates that the sewage from 100 persons can be treated on an acre of loamy gravel and that the number may rise to 500 under rarely favorable circumstances, while with stiff clay it falls to 25. The rates commonly in use in England vary from 0.002 million gallons per acre per day at Leamington and

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[a] Throughout this report rates of filtration are expressed in millions of United States gallons per acre per day, and where possible in "net rates," i. e., total quantity passed in a given period divided by the number of days in that period.

Wrexham to 0.015 at Cheltenham and Birmingham (Watson, 1903). German figures range from 0.002 at Brunswick to 0.007 at Danzig, and probably average about 0.004 (Bredtschneider and Thumm, 1904).

When an irrigation farm is overdosed it becomes "sewage sick," to use an expressive English term. The surface clogs, pools are formed, putrefaction begins; only a complete rest restores the health of the area. Under such conditions the temptation to discharge unpurified sewage into the nearest stream is very strong. At times of rain, when sewage flow is highest, the crops are least in need of water and may be seriously damaged by it. The aims of sewage purification are too apt under such conditions to be sacrificed to those of agriculture. Thus, at the famous Craigentinny meadows, where profitable crops are obtained from once barren areas of blown sands, we are told that "the great bulk of the foul water merely runs over the surface of the ground and deposits a portion of its suspended matter" (Barwise, 1904). Many of the English farms, on the other hand, have been operated for thirty years with no nuisance and without the accumulation of offensive sludge.

The statistics for eight of the principal English farms have been compiled from the fourth report of the royal sewage commission (R. S. C., 1904 a, b) to form Table VI, and they give a fair idea of general practice. The low rates on clayey soil at Leicester, Rugby, and South Norwood will be noticed, as well as the fact that careful screening and settling has in most cases been found a necessary preliminary. The analyses, which from their source may be considered representative, indicate that English irrigation effluents are by no means of exceptional quality, although the Nottingham and Cambridge results are excellent. The Aldershot plant appears to be doing fairly well, considering the very strong sewage with which it deals, but at Altrincham and other places the purification is much less satisfactory. By incubator tests the Nottingham and Cambridge effluents stood very high, and of the samples from Leicester and Aldershot 90 per cent gave no secondary putrefaction. Norwood, Croydon, and Rugby, on the other hand, gave putrescible effluents about one-fourth of the time. On the whole, it seems fair to conclude from a general survey of English conditions that when a sufficient area of porous soil with a low water table is available a well-managed irrigation area may prove a satisfactory method of sewage disposal from the sanitary standpoint.

TABLE VI.—*Statistics of sewage farms in England (R. S. C., 1904 a, b).*

Farm.	Date of construction.	Average daily flow (million gallons).	Area of filter beds (acres).	Rate (million gallons per acre per day).	Character of soil and subsoil.	Character of sewage.	Method of treatment.	Analyses (parts per million).							Remarks.
								Material.	Total suspended solids.	Nitrogen as—				Oxygen consumed in 4 hours at 80° F.	
										Total organic.	Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.		
Aldershot camp..	1864	1	120.5	0.008	Sand............	Purely domestic.	Screening, settling tanks, and land filtration.	Sewage...	306	50.6	78.7	16.2	......	207.9	Average of 3 sets of 24-hour samples, January, 1902.
								Effluent..	.....	9.4	18.5	2.6	32.1	27.2	Average of 17 samples, 1900–1901.
Altrincham (Cheshire).	1870	.8	35	.023	Peaty soil lying upon sand and gravel.	Domestic.....	Settling tank and land filtration.	Sewage...	720	12.4	22.9	6.2	......	52.2	Average of 9 samples, 1900–1901.
								Effluent..	.....	2.6	12.3	1.3	......	17.5	Average of 16 samples, 1900–1901.
Beddington (Croydon).	1861	4	420	.01	Gravelly loam overlying gravel and sand.	Almost purely domestic.	Screening, surface irrigation, and filtration.	Sewage...	345	20.7	45	9.1	......	124.8	Average of 7 sets of 24-hour samples, January, 1902.
								Effluent..	.....	2.61	14.8	1.4	3.7	14.1	Average of 18 samples, 1900–1901.
Cambridge.......	1895	2.25	74	.3	Sandy loam overlying gravel and sand.	Mainly domestic; some brewery refuse.	Screening, settling tank, and land filtration.	Sewage...	265	18.8	38.2	9.1	......	10.8	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	2.1	6.5	.9	12.6	8.1	Average of 18 samples, 1900–1901.
Leicester.........	1891	7.25	1,350	.005	Stiff clayey soil overlying dense clay.	Three-fourths domestic; one-fourth trade refuse.	Screening, settling tanks, surface irrigation and filtration combined.	Sewage...	341	23.4	81.2	11.9	......	223.5	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	4.5	16.5	2	5.1	25	Average of 13 samples, 1900–1901.
Nottingham, ...	1880	7	651	.011	Light sandy loam and gravel overlying gravel and sand.	Four-sevenths domestic; three-sevenths trade refuse.	Screening (partial) and land filtration.	Sewage...	519	31.5	39.8	14.5	......	232.1	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	.8	1.3	.3	20.6	1.9	Average of 13 samples, 1900–1901.
Rugby...........	1867	.3	35	.009	Heavy loam overlying stiff clay.	Mainly domestic.	Screening, settling tanks, surface irrigation and filtration combined.	Sewage...	473	32.9	61.1	17.3	......	184.4	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	1.7	16.2	1.8	5.2	14.1	Average of 19 analyses, 1900–1901.
South Norwood.	1864	.6	152	.004	Clay soil resting on London clay.	Purely domestic.	Screening, settling tanks, and surface irrigation (with a little filtration).	Sewage..	219	14.9	35.4	6.7	......	77.1	Average of 7 sets of 24-hour samples, January, 1902.
								Effluent..	.....	10.4	8.7	1	3.9	14.4	Average of 11 analyses, 1900–1901.

The economic advantage of sewage farming is somewhat more doubtful. English chemists estimate the manurial value of sewage at from 1 to 4 cents a ton (Rafter and Baker, 1894). This value can no doubt in part be recovered, since the crops grown on sewage fields are often astonishingly heavy. Whether it really pays to recover it depends on local economic conditions. In many English towns the operation of farms has proved unprofitable, and there is some tendency toward their abandonment. Lieut. Col. A. S. Jones and others are, however, ardent advocates of the process; and in certain cases the farm, besides paying all running expenses, yields in some years as much as $12 an acre toward rent (Baker, 1904). McGowan, Houston, and Kershaw, in their valuable report to the royal sewage commission, conclude:

> Although we are of opinion that sewage farms in general can never be expected to show a profit if interest on capital expenditure is included, the fact that in favorable seasons some of them more than cover the working expenses is a point in favor of cropping in connection with the land treatment of sewage. [R. S. C., 1904 c.]

With regard to the question of the sanitary quality of the produce grown on a sewage field, the experience of Berlin and Paris indicates that there need be no serious danger of the spread of disease from irrigated crops. The writers believe, however, that fruits and vegetables to be eaten raw should never be so treated; and McGowan, Houston, and Kershaw (R. S. C., 1904 c) would limit sewage farms to stock raising, saying:

> We are, on the whole, not in favor of sewage farms being utilized for the raising of crops for human consumption.

In the western part of the United States the conditions for sewage farming are specially favorable. In the arid regions some form of irrigation is essential and the manurial value of sewage is reenforced by its water value. The first plant in this country was laid out at Cheyenne, Wyo., in 1883, and to-day there are a score or more of sewage farms in operation, of which those at Los Angeles and Salt Lake City are the largest. The experience of Los Angeles is of considerable interest as indicating the value of sewage in such a region. Prior to 1889 the sewage from the city, amounting to 7 million gallons, was carried to the so-called Vernon district, where it was taken by the South Side Irrigation Company and distributed to adjacent farms. So useful did the sewage prove that the value of the land rose from $2.50 an acre to from $15 to $25. A boom followed, house lots were developed, and the population so increased that the sewage, which had built up the district, became a nuisance and had to be taken elsewhere.

In the East the problem of sewage irrigation takes on a different aspect. The high cost and poor quality of land and the heavy rains of spring and autumn combine to make the success of such a venture more than problematical. It is true that the waste of valuable manurial elements is unfortunate, and authorities like Rafter (1897) have been strongly moved by such considerations. The saving of organic nitrogen, however, appears to-day in a less important light than formerly, since we know that its dissipation may be made good from the ocean of the atmosphere by the activities of the nitrogen-fixing bacteria. At any rate the question is one which must be judged on a basis of dollars and cents. There are valuable elements in sewage, as there is gold in sea water; but if it costs more to save them than they are worth after they are saved we must let them go. On the Pacific coast sewage farming is profitable. In the East, under present conditions, it is unlikely to prove so.

TREATMENT OF SEWAGES BY CHEMICAL PRECIPITATION.

Parallel with the development of broad irrigation there grew up a method, or a group of methods, for the utilization of the useful elements in sewage on a different principle. The idea that sewage sludge may be valuable is so discredited to-day that it is difficult to believe that the first attempts at chemical treatment were made with a view to the recovery of its constituents in a "portable and consequently marketable form." Such, however, was the object with which numerous processes were devised in the early sixties. Between 1856 and 1876 no less than 417 patents were issued in England for processes connected with the chemical precipitation of sewage.

The various methods of treatment consist, as a rule, of two stages—the addition of some substance which will produce a flocculent precipitate, and the sedimentation of the mixture to separate the heavy sludge from the supernatant liquid. The precipitants used are various, but the active elements in most cases are salts of lime, aluminum, or iron. The rivers pollution commission in its report of 1870 discussed the action of lime, lime and chloride of iron, sulphate of aluminum, Sillar's "ABC" mixture (alum, blood, and clay with other substances), and Holden's compound (iron sulphate, lime, and coal dust). Hazen (1890) in 1889 carried out for the Massachusetts State board of health an elaborate series of experiments, from which it appeared that either ferric salts or a mixture of ferrous sulphate with lime proved most satisfactory. In the first case ferric hydroxide was precipitated, and in the second case ferrous hydroxide, calcium carbonate, and various insoluble organic lime salts. Ferrous sulphate alone gave less satisfactory results, as did also sulphate of aluminum.

Exhaustive studies of various precipitants were made by Dibdin in connection with the treatment of the sewage of London, results and cost of different processes being worked out in great detail. All suspended matter could be removed, and with regard to the dissolved organic matter the efficiency ranged from a removal of 10 per cent with 52 parts per million of lime to a removal of 31 per cent with 784 parts of lime, 168 parts of ferrous sulphate, and 560 parts of sulphate of aluminum, and a removal of 52 per cent with 9,800 parts of lime, 1,400 parts of ferrous sulphate, and 700 parts of sulphate of aluminum. The annual cost for a daily flow of 157 million gallons was estimated at $60,000 for the first result quoted, $400,000 for the second, and nearly $50,000,000 for the third. In general it was found that lime was the best basis, and for use in combination with it iron salts were preferable to those of aluminum. The combination finally determined on was 56 parts of calcium oxide (4 grains per gallon) with 14 parts of ferrous sulphate (1 grain per gallon). After the addition of precipitants the sewage is allowed to settle in tanks where it either remains quiescent for a time or flows through slowly and continuously. The second or continuous method is most satisfactory, and a capacity of from one-half to twice the daily flow is sufficient for sedimentation. For a complete separation on a small area a tank of special form is sometimes used, whose bottom is an inverted cone in which the sewage passes upward, its flow supplementing the action of gravity. At a certain level in the tank the precipitated material collects, so as to form a sort of filtering layer through which the ascending sewage must pass. A tank of this form (Röckner-Rothe type) was installed at the World's Columbian Exposition in Chicago in 1893 (Hazen, 1894); it was practically identical with the Dortmund tank extensively used in German plants for the treatment of industrial wastes.

The results to be expected from the chemical treatment of sewage may be learned from the experience of London. The sewage of the city was originally discharged from the various sewers directly into the Thames, producing a nuisance which culminated in the historic stink of 1858. To cope with these conditions a system of intercepting sewers was completed in 1865 which discharged the sewage from the district north of the river at Barking Creek and that from the south side at Crossness, about 12 miles below London Bridge. This arrangement proved satisfactory for a time, until the volume of sewage had too greatly increased. By 1875, however, it became necessary to discharge part of the flow on the flood tide; the liquid carried up the river and the solids deposited on the shores became once more a serious nuisance. In 1882 the metropolitan sewage commission was appointed and advised the removal of solid matter from the sewage by deposition or precipitation. In accordance with its recommendations precipitation works were constructed at both outfalls, the sewage being treated, as noted above, with 56 parts per million of calcium oxide and 14 parts per million of ferrous sulphate. At the present time the same system is still in force. The sewage from the city of 4,500,000 inhabitants amounts to 280 million gallons per day, and 7,200 long tons of sludge are daily carried 50 miles out to sea by a fleet of six dumping boats. The total cost of treatment is nearly $900,000 a year (Baker, 1904). The results of the chemical treatment for London are indicated in Table VII and show a removal of somewhat over three-fourths of the suspended matter, but only slight improvement in the soluble constituents. The effluent is by no means purified. It is merely so improved by the removal of most of its solids that its discharge into the Thames is for the time being permissible.

TABLE VII.—*Results of chemical precipitation at London, 1894 (Dibdin, 1903).*

[Parts per million.]

Source.	Material.	Suspended solids.	Dissolved material.			
			Total.	Oxygen consumed in 4 hours at 80° F.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.
Northern outfall	Sewage	417	862	44.5	35.6	4.1
	Effluent	99	910	46.2	36.9	4.2
Southern outfall	Sewage	441	1,300	53.1	34.8	4.9
	Effluent	87	1,420	44.5	28.9	3.9

At Manchester conditions appeared somewhat more favorable for precipitation on account of the presence of certain chemicals in the factory wastes, and only 31 parts of calcium oxide and 17 parts of ferrous sulphate were added. The results with respect to the total organic constituents are indicated in Table VIII. The figures are five-year averages of the results of analyses made twice a day on hourly samples. The purification of the effluent proved inadequate to meet local conditions, and the system has been abandoned in favor of newer biological processes.

TABLE VIII.—*Results of chemical precipitation at Manchester, England, 1900–1904 (Manchester, 1900–1904).*

[Parts per million.]

Material.	Oxygen consumed in 4 hours.	Oxygen consumed in 3 minutes.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.
Sewage	116	56.7	23.6	5.9
Tank effluent	76.4	37.2	24.2	3.9

At Birmingham a number of chemical processes were tested in 1871 and found unsatisfactory. Watson, the present engineer of the drainage board, comments:

> I venture to say that a similar conclusion would have been arrived at if the committee, instead of trying only seven chemical processes, had tried all the 454 processes which were patented previous to 1886. [Watson, 1903.]

At Salford a thorough test of 13 different precipitants yielded no satisfactory effluents.

The disposal of the sludge is a serious problem in chemical precipitation. Its quantity is considerable, amounting to 26 tons per million gallons of sewage at Salford, 21 tons per million gallons at Manchester, and 60 tons per million gallons at Chorley. Of this crude sludge 90 to 95 per cent is water. Wallace found the composition of the air-dried residue from eight different English plants to average 12 per cent of water, 26 per cent of organic matter, 1 per cent each of nitrogen and phosphoric acid, and 35 per cent of sand (Robinson, 1896). Far from being marketable, as the projectors of the process dreamed, the disposal of this sludge generally involves considerable expense. In 1894 a canvass by the local government board showed that of 234 places using chemical processes only 30 were able to obtain any revenue from sludge. In some German plants the sludge is evaporated and burned for generating gas. The usual course, however, is to compact it in filter presses and dispose of the press cake by burning it or burying it in the ground.

On the whole, chemical precipitation has become somewhat discredited of recent years. The cost of chemicals is considerable, the disposal of the sludge is vexatious, and the effluent produced is imperfectly purified and always subject to secondary putrefaction. Except under special conditions this treatment can be considered only a preliminary process, to be followed by some final biological treatment which shall effect real purification. Even in this rôle the process is generally less applicable than the septic tank, since, as compared with the latter, it produces results only slightly better with a considerable additional cost for chemicals and with an increase in the quantity of sludge.

In special cases, however, chemical treatment still has its application. While most English cities are abandoning chemical precipitation for some newer process, Glasgow is installing new tanks which will eventually handle 140 million gallons of sewage daily, using lime and sulphate of alumina as precipitants. The experience of Worcester, Mass., is of considerable interest in this connection, since there, too, chemical precipitation is apparently likely to be maintained. In 1867 the city of Worcester was permitted to use as a common sewer Mill Brook, which discharges into Blackstone River. In 1880 vigorous complaints began from Millbury and other towns below that the stream was so foul as to be a nuisance and a danger to the health of the community. Phineas Ball, Colonel Waring, and others reported various plans for relief, and in 1882 the State board of health recommended the installation of intermittent filters. In 1886 the legislature ordered that the city should remove from its sewage before discharge into Blackstone River "the offensive and polluting properties and substances therein, so that after its discharge into said river it shall not create a nuisance which might endanger the public health." A chemical precipitation plant was duly installed in 1890, but the condition of the river remained bad. In 1895 Millbury brought suit against Worcester on the ground that the act of 1886 had not been complied with. After full expert discussion it appeared that the condition of the river was in part due to the past pollution which had for years accumulated in its bed as sewage mud, and in part to the imperfectly purified chemical effluent still being discharged. The courts declared that the city had acted in good faith in attempting to carry out the act of 1886, but ordered that it should take further steps to comply with its provisions. Since that date sand areas for intermittent filtration have been progressively added for the final purification of the chemical effluent. It is possible in this case that chemical treatment is the best available preliminary process, since the city sewage contains free sulphuric acid and sulphate of iron from the wire works which aid the chemical process and perhaps interfere with bacterial action.

In 1904, 4,622 million gallons of sewage were received at the Worcester works, of which 4,227 million gallons were treated chemically. Six hundred million gallons of the chemical effluent and 395 million gallons of raw sewage were treated on sand filters. Lime is the only precipitant used, in the amount of 120 parts per million, sufficient iron being already present in the sewage to complete the reaction. For every million gallons of sewage treated 5,756 gallons of wet sludge are obtained, containing 6.93 per cent of solids. After pressing, this is reduced to 5.7 tons of pressed sludge containing 28.9 per cent of solids. The cost of pressing and sludge disposal amounts to over $5 per million gallons. The analyses of sewage and effluent from 1894 to 1904 show that the yearly removal of the total albuminoid ammonia has varied from 46 to 63, averaging 52 per cent; of total oxygen consumed from 37 to 59, averaging 51 per cent; of suspended albuminoid ammonia from 83 to 98, averaging 93 per cent; and of suspended oxygen consumed from 77 to 89, averaging 82 per cent (Worcester, 1905). The results for 1904 are shown in Table IX.

TABLE IX.—*Results of chemical precipitation at Worcester, Mass., 1904 (Worcester, 1905).*

[Parts per million.]

Material.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia. Total.	Nitrogen as— Albuminoid ammonia. Soluble.	Oxygen consumed in 2 minutes' boiling. Total.	Oxygen consumed in 2 minutes' boiling. Soluble.
Raw sewage	15.9	6.8	2.5	96.9	59.7
Chemical effluent	14.4	3.4	3.1	54.2	43.1

Another large American precipitation plant is that at Providence, R. I., where since the sewage effluent is discharged into a tidal estuary the removal of suspended solids alone is all that is necessary. Precipitation was recommended by S. M. Gray after an exhaustive investigation in 1884, but the plant was not finally installed until 1902. Comparative statistics for the operation of the Worcester and Providence purification works in 1903, copied from Fuller, are given in Table X.

TABLE X.—*Statistics of chemical precipitation at Worcester, Mass., and Providence, R. I., 1903 (Fuller, 1905 a).*

		Worcester.	Providence.[a]
Population connected to sewers, estimated		122,000	170,000
Average daily sewage flow, total	million gallons	15.55	20.38
Average daily sewage flow, treated	do	14.39	20
Total annual sewage flow treated	do	5,250	7,300
Applied lime	pounds per million gallons	871	606
	grains per gallon	6.1	4.2
Applied copperas	pounds per million gallons	0	65
	grains per gallon	0	.46
Gross capacity of basins	million gallons	5.5	11.1
Percentage of removal:			
Total organic matter by albuminoid ammonia		51.69	[a] 49.80
Suspended organic matter by albuminoid ammonia		91.58	[a] 82.54
Wet sludge:			
Average pressed daily	gallons	67,200	95,600
Percentage of total sewage flow		.4671	.4776
Average percentage of dry solid contents		7.44	5.37
Average amount of lime added per 1,000 gallons	pounds	33.5	23.6
Pressed sludge cake	tons daily	69	76
	percentage of dry solids	30.3	28.25
Dry solids in sludge:			
Tons daily		20.80	21.40
Tons per million gallons		1.45	1.07
Tons per 1,000 population per annum		62	46
Cost of sludge pressing and disposal:			
Per ton of dry solids		$3.39	$2.27
Per million gallons sewage flow		$4.91	$2.44
Cost of chemical precipitation (labor and supplies) per million gallons		$4.01	$3.31
Total cost of operation:			
Per million gallons		$8.92	$5.75
Per capita connected to sewers per annum		$0.384	$0.248
Cost per ton:			
Lime		$6.00	$6.90
Copperas		....	$7.80
Minimum wage per hour for laborers		$0.23½	$0.15

[a] Providence sewage well screened before treatment.

Before leaving the subject of chemical treatment it will be well to refer briefly to certain special processes which have been suggested and adopted in exceptional cases without finding general application. For example, with the Liernur system of sewerage in use in certain Dutch and Belgian cities, which lie at too low a level for gravity systems, the excreta diluted with a small volume of water are drawn off by suction through a system of tight sewers, and sewage of this type has been handled by direct evaporation, the residue being used as fertilizer. Its application is naturally limited (U. S. Dept. State, 1895). The Degener process applied in some German cities involves mixture of the sewage with crushed lignite, precipitation with ferric sulphate, pressing of the sludge, and treatment of the effluent with bleaching powder. The process is costly, but at Potsdam and Tegel is said to produce a very perfect effluent (Grünbaum, 1902). The bleaching powder in this process is supposed to disinfect the final effluent; and the same end is aimed at in a number of chemical processes based on the use of such substances as ozone and the oxychlorides. The Webster process allowed sewage to flow between iron electrodes so that the chlorides present were electrolyzed, liberating free chlorine and oxygen and forming iron salts. In the Hermite process a stronger action was obtained by electrolyzing sea water and adding it to the sewage (Rideal,1901). Considerable interest has been manifested in these and similar methods during the last year. Disinfection processes, however, ignore the fundamental problem of sewage disposal, which is the production of an oxidized, not of a sterile, effluent. Until a really purified and stable effluent has been produced disinfection is a step in the wrong direction.

An interesting method has been suggested by Adeney and installed by Kaye Parry at Dundrum, Chapel-Izod, and other Irish towns. It aims at the addition of chemicals in such a way as to favor rather than to check biological action. The sewage is first precipitated by oxanite, which is a crude sulphate of manganese mixed with the higher oxides of that element, and then nitrate of soda is added to the supernatant liquid. The manganese supplies the sludge with oxygen, so that a rapid aerobic fermentation occurs and the nitrate performs the same function for the effluent.

PURIFICATION OF SEWAGES BY INTERMITTENT FILTRATION THROUGH SAND.

The only general method for the purification of sewage is its oxidation by micro-organisms. We have seen how this process has been empirically utilized in dilution and in broad irrigation. Its scientific principles were grasped by a few investigators at an early date. About 1865 Alexander Mueller described the purification of sewage as a process of digestion and mineralization carried out by minute animal and vegetable organisms (Rideal, 1901). In 1878 he took out a patent for a "process for the disinfection, purification, and utilization of sewage by the scientific cultivation of yeastlike organisms" (Bruch, 1899). In 1877 the fact that the purification of sewage is due to bacteria was demonstrated by Schloesing and Muntz in a series of experiments in which it was shown that nitrification did not occur in soils sterilized by heat or chloroform (Schloesing and Muntz, 1877). Warington reported further suggestive results along this line in 1892.

These suggestions appear to have made little impression in Great Britain and the United States. Meanwhile, however, the practical side of the subject was undergoing an important development in England. In 1870 Sir Edward Frankland carried out a series of significant experiments, the results of which were published in the first report of the rivers pollution commission. Sewage was filtered both upward and downward through various soils at different rates, and it was shown that a good effluent could be obtained by downward filtration through coarse gravel at a rate of 0.08 million gallons per acre per day, while upward filtration produced only a foul and turbid effluent. Doubling the rate interfered with the purification, and it was seen that a resting or aerating period between the applications of sewage was a necessity. The principle of the process as a chemical oxidation of organic matter to water, carbon dioxide, and nitrates was clearly recognized, as well as the practical necessity for intermittency in operation. The cycles in the life of a sewage filter were compared to the inspirations and expirations of the lungs (rivers pollution commission, 1870).

These researches indicated that with suitable soil the process of broad irrigation might be made more intensive, the growing of crops being subordinated to the treatment of sewage at a more rapid rate. This principle was quickly applied on a practical scale by J. Bailey-Denton, who constructed an intermittent filter at Merthyr Tydvil, Wales, in 1871. Beds 20 acres in area were furrowed, cropped, and operated at a rate of 0.06 million gallons per acre per day. This rate was later reduced to 0.016 by the addition of more irrigation land, but the original plant worked admirably and was of importance as a practical demonstration of Frankland's experiments on a large scale (Bailey-Denton, 1882). Neither Frankland nor Bailey-Denton, however, understood the biological nature of the process. The latter said of his filters in 1882:

> The assimilative powers of growing plants are brought to bear on the fertilizing elements of the sewage at the same time that the percolation of the sewage through the soil brings it in contact with the atmospheric air pervading the soil and renders it harmless by oxidation, as explained by the rivers pollution commissioners.

Altogether, it is clear that in the early eighties the *theory* of sewage oxidation was understood by French and German investigators. On the other hand, the *practice* of intermittent filtration had been empirically worked out in England by Frankland and Bailey-Denton. The laboratory investigations, however, were academic and the practical data incomplete. To combine a sound conception of the biological principles involved with a study of the engineering data of operation on a practical scale was left for American investigators. English sanitarians have not been slow to recognize that "it was primarily due to the Massachusetts State board of health, who began their investigations in November, 1887, and have continued them ever since, that the bacterial treatment of sewage has been forced on public attention" (Watson, 1903). For the mass of data accumulated and the thoroughness with which these data were analyzed, as well as for the almost revolutionary effect which they worked in sewage practice, the Massachusetts experiments well deserve the term of "classic," by which they are so commonly designated.

In 1886 the legislature of Massachusetts charged the State board of health with the advice of cities and towns, corporations, and individuals as to water supply and sewage disposal and ordered it to collect information and conduct experiments on the purification of sewage. Hiram F. Mills, a distinguished hydraulic engineer and a member of the board, organized the investigation, with the assistance of T. M. Drown and W. T. Sedgwick, both of the Massachusetts Institute of Technology, as chemist and biologist, respectively. An experiment station was fitted up in 1887 on the bank of Merrimac River at Lawrence, under the immediate charge of Allen Hazen. Here ten circular cypress tanks 17 feet in diameter and 6 feet deep were filled with various filtering materials—sand, gravel, peat, river silt, loam, garden soil, and clay—and dosed with sewage pumped from the city sewer. The results exceeded the hopes of the investigators. By passage through a fairly porous soil on the intermittent plan, one dose being applied every twenty-four hours, sewage could be converted into a clear and completely nitrified effluent. Peat and garden soil proved too impervious and, although operated at very slow rates, clogged. In this condition the air supply was cut off and nitrification failed. All the other filters showed good purification at rates of from 0.02 to 0.1, the quality of the effluents being equal in many cases to that of well waters in use in the city of Lawrence.

The true nature of sewage purification as a bacterial oxidation was clearly brought out in these experiments. Intermittency of application supplies the needed oxygen, and any fairly porous material will serve as a resting place for the active bacteria.

> The experiments with gravelstones give us the best illustration of the essential character of intermittent filtration of sewage. In these, without straining the sewage sufficiently to remove even the coarser suspended particles, the slow movement of the liquid in thin films over the surface of the stones, with air in contact, caused to be removed for some months 97 per cent of the organic nitrogenous matter, a large part of which was in solution, as well as 99 per cent of the bacteria, which were of course in suspension, and enabled these organic matters to be oxidized or burned, so that there remained in the effluent but 3 per cent of the decomposable organic matter of the sewage, the remainder being converted into harmless mineral matter.
>
> The mechanical separation of any part of the sewage by straining through sand is but an incident, which, under some conditions, favorably modifies the result; but the essential conditions are very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact with the films of liquid.
>
> With these conditions it is essential that certain bacteria should be present to aid in the process of nitrification. These, we have found, come in the sewage at all times of the year, and the conditions just mentioned appear to be most favorable for their efficient action and at the same time most destructive to them and to all kinds of bacteria that are in sewage. [Mills, 1890.]

The organisms active in the nitrifying process, isolated independently by Winogradsky in France and by Richards and Jordan (1890) at Lawrence, have been studied by a number of bacteriologists, of whom Schultz-Schultzenstein (1903) and Boullanger and Massol (1903) are perhaps the latest. The necessity for an alkaline base for nitrification, known to agriculturists since the time of Varro, has been confirmed by these observers, who find that free acids, organic or inorganic (0.5 per cent), and nitrates or nitrites in 1 to 3 per cent solution, quickly check the work of the organisms. A marked excess of free ammonia or of any alkali has the same effect. Thus Warington found that a 12 per cent solution of urine having a maximum alkalinity of 446 parts of ammonia as carbonate would stop nitrification. At Burton sewage containing 100 parts of free lime would not nitrify till it was neutralized (Barwise, 1904). Rideal also notes a harmful effect due to carbon dioxide, and Letts believes that sodium chloride from sea water hinders the formation of nitrates at Belfast (R. S. C., 1902 a). The optimum temperature for the reaction lies between 28° and 37° C. It is stopped in the neighborhood of 50° C.

Later work at Lawrence, where numerous small experimental filters have been operated since 1890, has brought out further details of the process of intermittent filtration. In the 1891 report, prepared by Allen Hazen, the chemist in charge of the station, it was shown that while most of the organic matter of the sewage is actually destroyed and while there is no important storage in the depths of the filter, its surface accumulates a certain amount of stable organic matter which must be removed at intervals. It was made apparent that in severe winter weather the quality of the effluent, while considerably deteriorated, was still reasonably satisfactory. The maximum rate at which sewage could be conveniently applied varied from 0.03 with sand of an effective size of 0.03 mm. to 0.06 with sands of 0.06 to 0.35 mm., 0.1 with sands of 0.17 and 0.48 mm., and 0.2 with gravel of 5 mm.

One of the strong points about the Lawrence experiments has been their continuity for a sufficient period to show the long life of intermittent filters, four of the original outdoor filters having been operated for seventeen years. A comparison of the effluents during the first seven and the last nine years of operation has been compiled from the reports of the State board and is shown in Table XI. Although, with a considerably increased concentration of sewage the effluents have deteriorated, yet the percentage purification has only slightly decreased, and the effluents are still of good quality.

Table XI.—*Results of intermittent filtration at Lawrence, Mass., in successive periods (Massachusetts, 1895–1903).*

	Quantity of sewage applied (gallons per acre per day).	Temperature (°F.)	Analyses (parts per million).					
			Nitrogen as—				Oxygen consumed in 2 minutes' boiling.	Chlorine.
			Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.		
1888–1894								
Filter No. 1	76,000	53	2.3	0.4	16.8	0.18	4.7	68.5
Filter No. 2	34,000	52	1.7	.1	15.9	.15	1.7	65.4
Filter No. 4	27,000	52	1.7	.2	10.4	.02	3.7	59.9
Filter No. 6	47,000	53	1.9	.3	16.4	.34	3.2	68.1
Filter No. 9A	74,000	53	4.9	.3	18.3	.08	3.2	80.2
Sewage	....	....	18.8	5.5	....	....	36.2	68.4
1895–1903.								
Filter No. 1	51,000	55	8.6	.6	25.8	.23	6.6	94
Filter No. 2	30,000	54	5.8	.3	28	.10	3.3	91.4
Filter No. 4	16,000	54	2.4	.2	26.9	.03	1.8	86.1
Filter No. 6	51,000	54	7.6	.6	26	.31	5.8	90.8
Filter No. 9A	52,000	54	8.8	.5	26.7	.09	5.6	89.6
Sewage	....	....	32.6	5.9	....	....	41.3	91.8

The early Massachusetts experiments led at once to practical developments. In the 1887 and 1888 reports of the board of health preliminary results were announced, and in 1889 the board reported that a plan suggested for the disposal of the sewage of the Mystic Valley on the Saugus marshes was impracticable on account of the peaty nature of the soil. Also in 1889, in accordance with the favorable results obtained at Lawrence by filtration through coarse sand, the first large intermittent filtration area in the State was laid out in the town of Framingham. Gardner and Marlboro followed in 1891, and at the same time the first filter in Connecticut was built at Meriden.

In 1903 (Massachusetts, 1904) the State board of health of Massachusetts discussed the results of the operation of 23 plants in the Commonwealth. All made use of intermittent filtration, and the report concludes that—

> The ready availability of sand and gravel areas naturally adapted for the purification of sewage, the simplicity of the process, and the small cost of maintenance have made this method of purification the most advantageous for adoption in practically all the cases in which sewage-purification works have been found necessary, and the resulting effluents turned into the stream have been satisfactory in all cases where the works are of sufficient capacity and have received proper care.

The principal analytical data from the report are shown in Table XII, which gives a fair idea of the operation of the intermittent process. It will be noted that the rates vary in general from 0.05 to 0.1 and that the effluents are in most cases of satisfactory quality. They are superior in almost every instance to those obtained at the English sewage farms, as shown in Table VIII.

TABLE XII.—*Statistics of intermittent filtration in Massachusetts (Massachusetts, 1904; Worcester, 1905).*

Place.	Date of construction.	Average daily flow (million gallons).	Area of filter beds (acres).	Rate (million gallons per acre per day).	Population contributing sewage.	Preliminary treatment.	Material.	Average of monthly analyses, 1903[a] (parts per million).				
								Nitrogen as—				Oxygen consumed in 2 minutes' boiling.
								Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.	
Andover	1898	0.125	3.65	0.0342	3,600	Screening; sedimentation	Sewage	39.7	5.6			49
							Effluent	9.1	.5	8.3	0.2	7.4
Brockton	1894	.878	21.48	.0409	25,000	Partial sedimentation	Sewage	43.8	12.9			219
							Effluent	1.9	.1	30.8	.1	3.3
Clinton	1899	.785	23.5	.0334	10,000	do	Sewage	33.2	7.9			113.7
							Effluent	.8	.6	4.4	.2	11.2
Concord	1898	.312	3.3	.0945	1,200	Screening	Sewage	5.7	1.4			13.6
							Effluent	.01	.09	8.5	0	1.1
Framingham	1889	.652	19.9	.0328	7,500	do	Sewage	26.1	6.5			47.3
							Effluent	1.8	.2	9.9	.2	2.6
Gardner (Gardner system).	1891	.302	2.5	.1208	3,500	Sedimentation	Sewage	20.2	4.9			49.2
							Effluent	14.8	.7	.4	0	10.7
Hopedale	1892	.150	2.3	.0652	2,000	Septic tank	Sewage	18.3	2.8			29.8
							Effluent	8.6	.7	15.9	.3	7.2
Leicester	1894	.030	.36	.0833	500	Sedimentation	Sewage	22	4.1			50.8
							Effluent	5.8	.7	9.1	.4	9.6
Marlboro	1890	1.100	11.2	.0982	10,000	do	Sewage	25.9	4.4			44.4
							Effluent	10.2	.5	3.5	.3	7.3
Natick	1895	.566	11.1	.0510	4,000	Screening	Sewage	12.2	2.6			32.7
							Effluent	5.1	.3	2.2	.2	4.4
Pittsfield	1890	1.456	21.67	.0672	15,000	do	Sewage	12	8.2			79.2
							Effluent	2.2	.3	6.7	.2	3.8
Southbridge	1899	.350	7.25	.0483	2,200	do	Sewage	16	3.5			40.1
							Effluent	3.2	.3	2	.1	3.6
Spencer	1897	.375	9.3	.0403	3,000	do	Sewage	1.5	4.5			46.5
							Effluent	1.2	.2	3.7	.2	3.3
Stockbridge	1899	.075	3.6	.0208	800	do	Sewage	9.8	1.6			15.2
							Effluent	0.9	.2	1.4	0	3.3
Westboro	1891	.282	4	.0705	3,000	Screening; partial sedimentation	Sewage	13.8	4.4			35.5
							Effluent	5.3	.7	3.6	.5	7.3
Worcester	1898	1.080	8.77	.123	122,000	Sedimentation	Sewage	18	8.1	.6	.1	138.7
							Effluent	10.9	.9	2	.3	18.1

[a] Worcester analyses of daily samples analyzed weekly from December 1, 1903, to December 1, 1904.

With regard to the comparative results of different Massachusetts plants the following points may be noted: The poor effluents at Westboro and Gardner are due partly to careless operation, the sewage being allowed to run on continuously for days. At Clinton the applied sewage is very strong. At Leicester, Andover, and Hopedale the board attributes results below the average to the fact that the sewage is stale or septic when applied. At Worcester the sewage is strong, and it is probable that its acid-iron waste interferes somewhat with the process of nitrification. It has been thought best, at any rate, not to attempt to treat crude sewage, as was done in the experiments included in Table XII. The comparative results of filtration with and without chemical precipitation, as shown in Table XIII, indicate the great advantage of special treatment.

TABLE XIII.—*Results of intermittent filtration of crude sewage and chemical effluent at Worcester, Mass.* (*Worcester, 1905*).

[Parts per million.]

Material.	Nitrogen as—					Oxygen consumed.	
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.	Total.	Soluble.
		Total.	Dissolved.				
Raw sewage	18	8.1	3.8	0.6	0.1	138.7	79.5
Sand effluent	10.9	.9	.9	2	.3	18.1	18.1
Chemical effluent	20.1	3.6	3.2	1.1	.4	56.5	44.4
Sand effluent	.8	.7	.7	4.1	.2	9.5	9.5

In construction the Massachusetts filters are simple, being built in general of natural glacial drift. The subsoil is removed, being used to form embankments between the beds, and the sand is not disturbed except for the laying of underdrains. Beds, as a rule, are 1 acre in area, the sewage being distributed through branched wooden carriers of sizes so varied as to secure approximately uniform distribution. This point is of much importance, since the passage of large volumes of sewage through a portion of a bed necessarily leads to poor results. At many plants, as at Framingham, Natick, and Brockton, crops have been grown on the beds. At Brockton this practice has recently been abandoned, since it was found to cause an accumulation of fine organic matter detrimental to the surface.

The effect of winter weather on the process has not been found to be serious. The actual freezing of the surface is prevented by furrowing the beds, so that a layer of ice forms on the top of the ridges, leaving an open space between them. Here the sewage flows, its warmth being sufficient to keep the surface open under the covering of ice. The process of nitrification is, however, considerably interfered with by the direct action of cold, as is shown on page 131 of this paper. This fact, combined with the impossibility of scraping off surface accumulations during severe weather, leads to a general clogging of the filters during the winter months. With ample capacity this period may easily be tided over. Goodnough said in 1904 (Winslow, 1905 b):

> Of the 15 sewage-disposal plants of considerable size where works were originally provided for the treatment of all of the sewage, all of the sewage is treated at all times at 6 places, or more than one-third of those having purification works, and very little sewage is discharged untreated at 6 of the remaining places, leaving only 3 places out of the 15 at which, at the present time, any considerable quantity of sewage is allowed to escape without treatment.

The accumulation of a certain amount of material on the surface of the beds is a necessary feature of the process of intermittent filtration as practiced in Massachusetts. This material, appearing in the form of a dry cake of a stable and inoffensive character, scarcely deserves the name of sludge, by which it is frequently designated. However, it necessitates a considerable expense in operation. The beds must be frequently raked and harrowed and occasionally plowed and scraped. At Pawtucket it has been found in ten years that for every million gallons of sewage 8.39 cubic yards of material (including sand) were removed from the surface (Pawtucket, 1904). At the Brockton plant, which is admirably designed and operated, full data are published on this point. In 1904 a daily flow of 900,000 gallons from a population of 40,000 was treated on 21½ acres of sand. A storage well at the pumping station holds the night flow of sewage, so that the pumps are run only in the daytime. The sediment which collects at the bottom of this reservoir is stirred up at the end of a run and discharged on four special "sludge beds." The cost of labor on the surface of all the beds during 1904 was $2,932, and the total cost of maintaining the area $4,412 (including gate tending, care of roadways, etc.), amounting to over $15 per million gallons (Brockton, 1905). The expense of maintenance at 16 Massachusetts plants varied in 1903 from $0.61 per million gallons at Natick to $21.92 at Stockbridge (Massachusetts, 1904). The Natick beds received practically no care except in connection with cropping, but operated satisfactorily. The next lowest figures were $2.45 at Pittsfield and $2.60 at Marlboro (large plants) and $2.87 at Concord (weak sewage). The costs at Clinton, Southbridge, Spencer, Westboro, and Worcester were between $3.91 and $7.80; at Gardner, over $9 at each of its two areas; at Brockton and Leicester, $11; and at Andover, $13.98.

TREATMENT OF SEWAGES IN THE SEPTIC TANK.

While the process of intermittent filtration was being scientifically developed in Massachusetts, English sanitarians were beginning to treat sewage on a totally different principle—that of anaerobic putrefaction. At an early period it had been noticed that in cesspools some action took place which led to the dissolution of solid matter. In Paris, where until 1880 various receptacles were largely used by individual householders for the reception of excreta, there might be found "the fosses fixées, from which the matter was raised by metallic vessels or vacuum pumps; the fosses sèches, used in the barracks; the tinettes filtres or filtrantes, which permitted the liquids to escape and reduced the refuse to one-fifth part, and the vidange automatique, invented by Mouras to do away with the necessity for even periodic removal of the solids" (Metcalf, 1901). The latter was "a closed vault with a water seal, which rapidly transforms all the excrementitious matter which it receives into a homogeneous fluid, only slightly turbid, and holding all the solid matters in suspension in the form of scarcely visible filaments." The action was attributed to anaerobic bacteria. This tank was introduced by Mouras about 1860, was fully described by Abbé Moigno in the Cosmos les Mondes in 1881, and was patented in 1882. In 1883 E. S. Philbrick, an American sanitary engineer, described a tank "in which the solid particles of the sewage may become macerated and finely divided by fermentation." In 1891 Scott-Moncrieff constructed at Ashtead, England, what he called a cultivation tank, in which sewage was allowed to pass upward through a tank containing stone prior to passage through "nitrifying channels" of coke. The attempt to produce a purified effluent failed, but it was shown that the first or anaerobic tank exerted a remarkable dissolving action on the solid constituents. In 1893 a plant on the same plan was designed for the borough of Towchester. A year later, in 1894, C. N. Talbot built a sewage tank at Urbana, Ill., in which the liquefying anaerobic action was observed; and a larger plant, with this definite end in view, was designed for Champaign, Ill., in 1895 and built in 1897.

The anaerobic process of sewage purification owes its practical development chiefly to Donald Cameron, of Exeter, England, who holds much the same relation to this process that the Massachusetts State board of health holds toward intermittent filtration. In 1895 he installed a water-tight covered basin for the treatment of the sewage of a portion of the city by anaerobic putrefaction and gave it the picturesque name of the septic tank. The sewage flowed slowly through the tank, taking about twenty-four hours in passage, the inlet and outlet being about midway between the top and bottom. He found that the liquid turned dark colored, while in the solids collected at the bottom an active fermentation was set up. Bubbles continually rose to the surface, carrying with them solid particles, which gathered at the surface to form a scum, sometimes so firm and compact that a man could stand upon it. This scum appeared and disappeared without any recognized reason. Meanwhile the effluent flowing off was freed from gross floating matter, and its total solids and organic constituents were decreased to one-half and two-thirds their initial value, respectively. The material removed did not, however, merely accumulate in the tank, which was operated for three years without cleaning. At the end of the first year 25 tons of solids had been removed from the sewage, of which it was calculated that 5 tons remained in the tank, and this in the form of a rather stable peaty deposit, only one-third organic in composition (Rideal, 1901).

The action in the septic tank is probably not the work of strict anaerobes, which appear to be rare in sewage, but of organisms able to grow either with or without the presence of oxygen. Under the latter condition the nature of their action is characteristic. They first decompose the solid materials by a lysis, which may or may not be hydrolysis (decomposition with the addition of water to the molecule). Next they decompose the dissolved molecule, producing gases on the one hand and more stable peaty compounds on the other. Nitrogenous compounds are partially reduced to gaseous nitrogen or free ammonia, and, together with cellulose, to carbon dioxide and marsh gas. The reaction is an exothermic one, evolving about 8 per cent as much heat energy as is left in the final products (Rideal, 1901). The amount of gas produced in the septic tank was found by Fowler at Manchester (1901) to be 7.5 gallons per 100 gallons of sewage, and Clark (1900) at Lawrence obtained concordant results. Kinnicutt and Eddy (1901), on the other hand, found less than half this amount (2.3 gallons) produced by the septic treatment of the acid-iron sewage of Worcester. The composition of the gas appears to vary widely at different places, but as a rule about three-fourths is methane and one-fifth free nitrogen. The amount of gas produced and, in general, the activity of septic action vary greatly with the temperature. Fig. 4, plotted from the data given by Kinnicutt and Eddy, shows this in a striking manner.

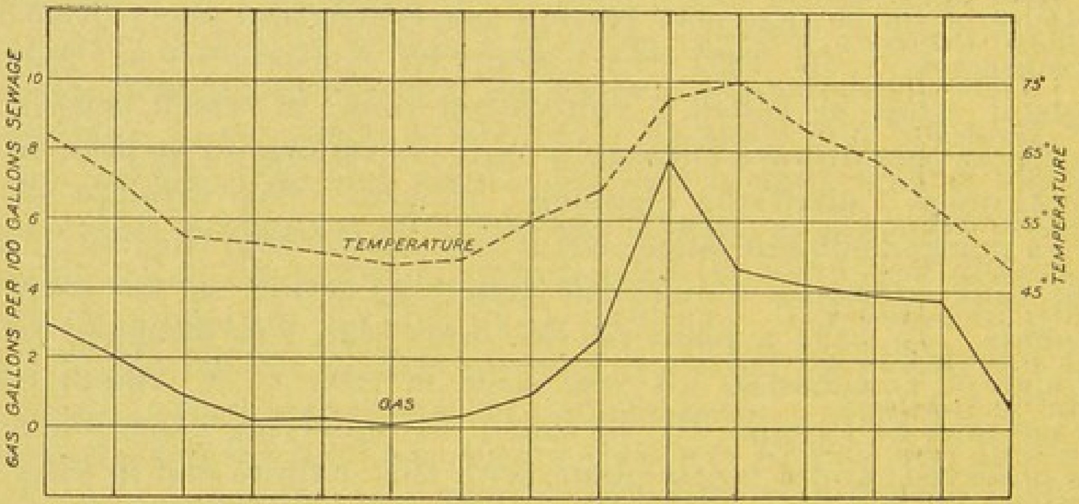

FIG. 4.—Seasonal variation in gas production in the septic tank.

The first septic tanks, like that at Exeter, were covered tightly. It soon appeared, however, that this type of construction is not at all necessary to the maintenance of anaerobic conditions. If sewage be merely allowed to run slowly through an open tank the general reactions appear to go on just the same. At Manchester the results from closed and open tanks under like conditions showed no marked difference, and in similar experiments at Leeds the open tank gave slightly better results, as shown in Table XIV. For promoting anaerobic conditions tight covers are therefore needless. Covering has been advocated in order that the gases produced may be utilized for burning and that the temperature of the sewage may be maintained. The burning of the gases is picturesque but not practically important, and the temperature of open tanks is never seriously lowered. At Leeds sewage in closed tanks lost 0.8°, in open tanks 1.6° F. For the prevention of odors and the fly nuisance and for protection against wind and rain a light frame roof may often be convenient.

Table XIV.—*Results from closed and open septic tanks at Leeds, England (Harrison, 1900).*

[Parts per million.]

	Solids.		Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	
Open tank:					
Crude sewage	1,710	633	23.6	11.3	124
Effluent	1,110	172	20.6	4.9	54.3
Closed tank:					
Crude sewage	1,720	666	25.5	12.4	131
Effluent	1,130	197	20	5	69.3

Scott-Moncrieff, in his Ashtead experiments, used, as already indicated, what was really a septic tank filled with stone. This principle has been applied in many other cases to the construction of anaerobic filters, lateral filters, etc., of various types. The so-called "ladder filters" tested at Leeds, formed by a series of trays of stone, from one to the other of which the sewage flowed continuously, operated on this principle--and very badly. At Salford, roughing filters containing one-fourth inch to 2-inch gravel were used for continuous filtration at a rate of 20 million gallons per acre per day. It was intended to wash these filters by upward flow with artificial aeration, but they have clogged seriously (Baker, 1904). At Lawrence a thorough study has been made of various strainers which operate with more or less continuous flow, of which further particulars are given in the second part of this report. All such devices, as well as the anaerobic filters installed at certain sewage plants in the Middle West, act like septic tanks, with the additional straining action due to the included material. Against this increased straining action must be set the tendency to clog and the difficulty of cleaning.

The most important point in the construction of a septic tank is its size in relation to the flow of sewage which is to pass through it. The tank is really a sedimentation basin in which the supernatant liquid and the settled sludge both undergo fermentation. The construction of special "hydrolytic" tanks, like that at Hampton (Baker, 1904), is gratuitous, since the bottom of the tank necessarily exhibits the hydrolytic phenomena to a high degree. The first requisite is that the period should be long enough to allow the maximum quantity of solids to settle out. From laboratory experiments on sedimentation it appears that this maximum is about 80 per cent and that it will be nearly reached by six hours' storage (Steurnagel, 1904). In practice it has often been found that a longer period is of advantage, perhaps for the liquefaction of suspended solids of too fine a character to settle out. The Leeds results in Table XV indicate an appreciably greater removal in twenty-four hours than in twelve hours, while further prolonging the period to forty-eight or seventy-two hours is of no advantage. The rules of the local government board require a septic-tank capacity of one and one-half times the dry-weather flow, and actual English practice generally contemplates a twenty-four hour period. At Birmingham the septic tanks proper accommodate only an eight-hour flow, but ten hours of additional storage are allowed in detritus tanks and a long conduit. Alvord (1902) and other American engineers provide shorter periods, often only four to eight hours, and some tanks operated on this principle, like that at Lake Forest, seem to work well. On the other hand, short periods of septic treatment at Wauwatosa and East Cleveland yield less satisfactory results (Winslow, 1905 b).

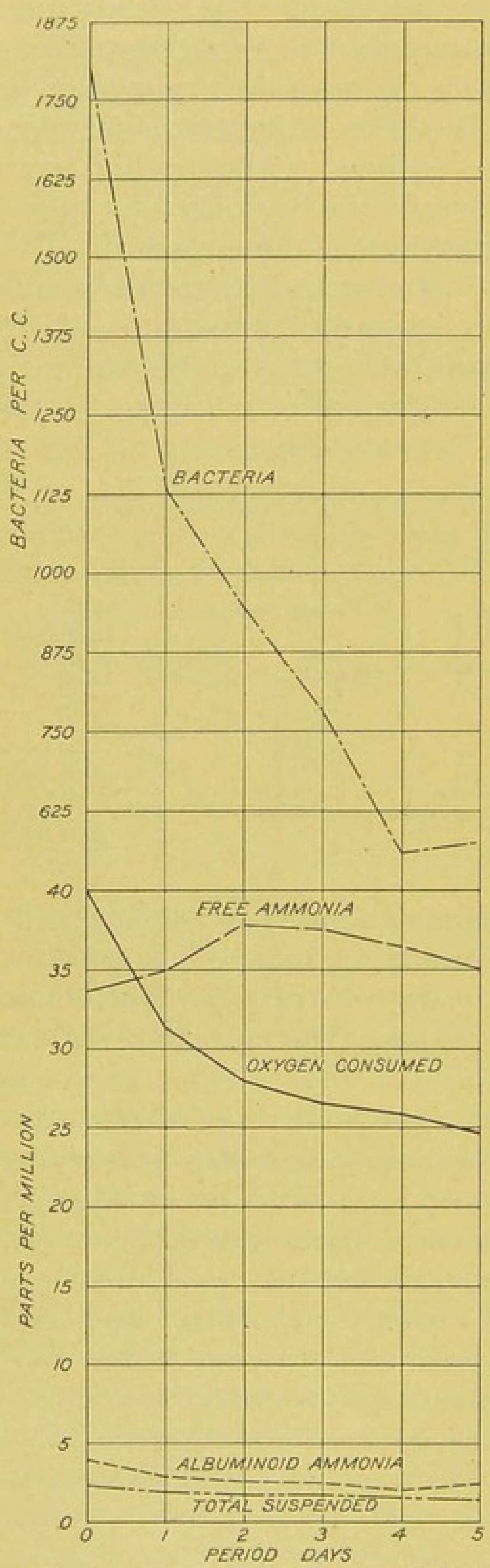

FIG. 5.—Progressive effect of septic action at Lawrence, Mass.

TABLE XV.—*Average of analyses illustrating the effect of different rates of flow through open septic tanks (Leeds, 1905).*

	12 hours' flow.		24 hours' flow.		48 hours' flow.		72 hours' flow.	
	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).
Total solids	1,250	....	1,110	....	1,120	....	1,050	....
Suspended solids	272	52	162	71	155	73	141	76
Nitrogen as—								
Free ammonia	18.2	22	17.5	24	18.8	19	20.8	37
Albuminoid ammonia	6.3	50	5.2	58	4.5	64	4	52
Oxygen consumed in 4 hours at 80° F	74.2	45	68.8	49	61.2	55	51.1	55

An interesting experiment was carried out at Lawrence on a small experimental tank with five successive compartments, each equivalent to one day's flow. The results are shown in Table XVI and are plotted in fig. 5. They indicate that although a steady change in the various constituents takes place the chief purification is accomplished in the first twenty-four hours.

TABLE XVI.—*Results of treatment of sewage in septic tank with five successive compartments, each holding one day's flow, April to December, 1903 (Massachusetts, 1904).*

	Analyses (parts per million).					Bacteria per cubic centimeter.
	Nitrogen as—				Oxygen consumed in 2 minutes' boiling.	
	Free ammonia.	Albuminoid ammonia.		Organic by Kjeldahl method.		
		Total.	In solution.			
Sewage	33.8	4.1	2.3	11.6	40.1	1,800,000
Effluent from first compartment (D-1)	36.1	3	2	....	31.4	1,100,000
Effluent from second compartment (D-2)	37.9	2.7	1.9	6.4	28	950,800
Effluent from third compartment (D-3)	37.5	2.6	1.8	....	26.6	800,000
Effluent from fourth compartment (D-4)	36.4	2.2	1.6	....	25.9	600,000
Effluent from fifth compartment (D-5)	35.1	2.4	1.5	5.3	24.7	600,000

The septic period should not be too prolonged, since, as will be seen later, the anaerobic fermentation, if carried too far, may produce an effluent difficult to nitrify. Furthermore, it is probable that even the anaerobic action itself may be checked by the concentration of waste products in too long a period. The marked decrease in bacteria in Table XVI indicates some such toxic action. An earlier Lawrence experiment is also suggestive. A small septic tank was dosed, not with sewage, but with the more concentrated sludge from settled sewage. For six months the storage period was from five to fifteen days and sludge accumulated, filling up 60 per cent of the tank. The rate was then increased, so that the storage period was reduced to forty-nine hours, when the accumulated sludge decreased to 8 per cent and did not further increase for a year (Massachusetts, 1901). At Leeds it was found that a seventy-two-hour septic period interfered with the solution of sludge (Leeds, 1905). Clark and Gage

(1905) have found that certain types of bacteria specially active in sewage purification increase during the first twenty-four hours of septic treatment and then fall to numbers smaller than are present in raw sewage. It seems possible that too long a period of action may actually favor the accumulation of sludge while producing an effluent hard to nitrify. Alvord (1902) for these reasons suggests the use of an "elastic tank" with separate compartments, which can be included in or thrown out of the system to adjust it to varying conditions of flow and temperature.

The results of septic treatment in three English cities and at Lawrence, Mass., are shown in Table XVII, and in Table XVIII is cited an interesting example of septic action on an intensive scale.

TABLE XVII.—*Effect of septic treatment.*

Place.	Material.	Solids.		Nitrogen as—		Oxygen consumed.		Remarks.
		Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Total.	Dissolved.	
Exeter	Sewage	778	350	44.4	....	29	....	April to June, 1897.
	Tank effluent	593	154	32.5	....	20.1	....	
Leeds	Sewage	1,690	622	24.7	11.7	127	....	February, 1899, to January 15, 1900.
	Tank effluent	1,090	183	21	5.2	58.5	....	
Birmingham	Sewage	1,967	676	31.9	13.7	153	76.1	Septic tank No. 1, 1901, open tank.
	Tank effluent	1,399	245	43.3	18.7	108	68.5	
Lawrence	Sewage	769	232	38.1	7	49.5	....	Tank A, January, 1898, to January, 1903.
	Tank effluent	597	107	37.7	3.3	27.3	....	

NOTE.—Oxygen consumed in four hours at 80° F. in the English results; in two minutes' boiling at Lawrence. Solids in Lawrence figures for year 1902 only.

Table XVIII shows the results obtained with an experimental tank at Brockton, Mass., in the treatment of very strong sewage pumped from the bottom of the receiving well during the last portion of the brief daily period of pumpage. The period of septic action was twenty-four hours. The results indicate a very high rate of purification. Bolling figures that of the suspended solids entering the tank 45 per cent remained as sludge, 6 per cent escaped in the effluent, 16 per cent went into solution, and 33 per cent disappeared as gas (Barbour, 1904).

TABLE XVIII.—*Results of treatment of sludge at Brockton, Mass., August and September, 1900 (Barbour, 1904).*

[Parts per million.]

Material.	Volatile residue.		Fixed residue.		Nitrogen as—			Oxygen consumed.	
					Free ammonia.	Albuminoid ammonia.			
	Dissolved.	In suspension.	Dissolved.	In suspension.		Total.	Soluble.	Total.	Soluble.
Sludge	229	1,810	271	555	34.5	42	3.9	396	74.5
Effluent	285	116	299	31	44.1	7.5	4.6	122	65.4

In comparing the work of the large English tanks, shown in Table XVII, it will be noticed that the effect on free ammonia varies, this constituent sometimes decreasing appreciably, as at Exeter, but generally remaining fairly constant. Sometimes, as at Worcester, it exhibits a marked increase. The reactions in the septic tank naturally vary materially with the original composition and age of the sewage. In a very fresh sewage there is always a considerable formation of free ammonia by the decomposition of more complex organic bodies. If this process has been completed when the sewage is subjected to septic treatment a decrease in free ammonia may be expected in the tank. Albuminoid ammonia and oxygen consumed in each case fall to one-half or two-thirds of their initial value. The evidence accumulated by the royal sewage commission indicated that an increase of free ammonia is the general rule in English septic tanks, while the albuminoid ammonia is reduced 38 to 54 per cent at Exeter, 50 per cent at Leicester, and 36 per cent at Birmingham. The oxygen consumed was reduced 25 to 33 per cent at Exeter, 50 per cent at Accrington, 50 per cent at Leeds, 36 to 60 per cent at Leicester, and 29 per cent at Birmingham (Martin, 1905). A curious phenomenon in certain septic tanks is the presence of oxygen or highly oxygenated compounds in the effluent in spite of the active reduction which takes place in the tank. Thus Barwise (1904) notes the occasional presence of nitrates and nitrites (up to 1 part per million) in the septic effluent at Exeter, and at Burnley after twelve hours' treatment in the septic tank oxygen was present to the extent of 1 to 3 per cent of saturation and nitrates up to 10 parts per million.

The most important practical result of septic treatment is the removal of suspended solids. Tanks at Exeter, Leeds, and Birmingham, as noted in Table XVII, show a reduction of 56, 71, and 64 per cent, respectively. At Leicester the removal has ranged from 60 to 70 per cent. At Lawrence 181 parts per million of suspended solids were reduced to 73 parts, a removal of 61 per cent (Massachusetts, 1904). Experiments on London sewage at the Crossness outfall showed that six hours' sedimentation in what was really a septic tank gave a reduction from 281 to 125 parts of suspended solids (November, 1900, to March, 1901) and in another series (March to October, 1901) from 253 to 143 parts, a removal of 56 and 43 per cent, respectively. These London results illustrate the gradual increase in suspended solids discharged in the effluent, which is sometimes noticed during the first year of a tank's operation. At Leeds 127 parts appeared in the septic effluent from March to June, 1899, 156 parts from July to October, and 213 parts from November, 1899, to February, 1900 (Leeds, 1900). At Huddersfield the septic effluent contained 66 parts in August, 1900, 82 parts in September, 113 parts in

October, 122 parts in November, and 117 parts in December (R. S. C., 1902 b).

The action of the septic tank on dissolved solids is a variable one, as shown in Table XIX, taken from Kinnicutt, with the addition of figures from a recent Lawrence report.

TABLE XIX.—*Removal of solids by the septic tank* (*Kinnicutt, 1902; Clark, 1904*).

Place.	Solids removed (per cent of total).	
	Dissolved.	Suspended.
Exeter	− 2.57	56.01
Lawrence	2.12	61.60
Leeds	12.05	70.37
Manchester	15.45	57.06
Worcester	20.67	25.57

It will be noticed that a slight removal of dissolved solids occurs, except at Exeter, reaching a considerable amount at Worcester. The phenomena in the case of Worcester are peculiar on account of the acids and iron salts in the sewage. In the first place all the reactions are hindered by the antiseptic action of these substances. The reduction of albuminoid ammonia is small, only 20 to 25 per cent, the gas production is only half that at Lawrence and Manchester, and the liquefaction of sludge is imperfect. In the second place the proportionate decrease of suspended solids is small and of dissolved solids great on account of the reduction and precipitation of iron compounds.

Granting that the septic tank effects a removal of 60 to 70 per cent of suspended solids under favorable conditions, the fate of the matter retained must next be determined—how much is stored as sludge and how much is reduced to liquid or gaseous form. Evidence before the royal sewage commission indicates a destruction of the stored solids, amounting to 26 per cent at Manchester, 25 per cent at Birmingham (too low a figure, since a great deal of reducible sludge is removed from sedimentation chambers cleaned out weekly), 20 to 60 per cent at Leeds, 30 per cent at Sheffield, 35 per cent at Accrington, 40 per cent at Huddersfield, 50 per cent at Glasgow, and 80 per cent at Exeter (Martin, 1905). At Saratoga the septic tank destroys 40 per cent of its sludge (Barbour, 1904). This value will naturally vary widely according to the ratio of organic to inorganic solids in the sewage, the inorganic solids being much less likely to disappear. In the London experiments the destruction of total sludge was 41 per cent and of organic sludge 71 per cent (Dibdin, 1903). At Hampton 58 per cent of the organic sludge was destroyed (Baker, 1904).

Practical experience with septic tanks yields widely varying results with regard to the destruction of stored solids, as indicated by the necessity for emptying the tanks and removing sludge. At Exeter

Cameron's original tank was operated for eight years without cleaning, but from the present installation, with a fourteen-hour period, sludge is pumped out once a month. At Barrhead a tank has been in use for six years (twenty-four-hour period) without cleaning and with little deposit. At Acton (sixteen hours) a tank has been operated for fifteen months with no deposit. At Yeovil (twenty-four hours), Burnley (twelve hours), Sutton (five hours), and Accrington (twenty-eight hours) it has been found necessary to remove sludge about once a year. At Oldham the tank is cleaned every two or three months (Baker, 1904). American plants exhibit similar variations. The Lawrence tank has not been cleaned for six years, and in 1903 was less than half full of accumulated sludge. At Marion a twenty-hour tank worked for two and one-half years without emptying. At Mansfield, with a twenty-four-hour period, admirable results have been obtained, only an insignificant amount of sludge having accumulated after three years of use. At Plainfield solids accumulate in the form of scum rather than sludge and are removed several times a year. Sludge and scum are probably largely interchangeable, a slight difference in specific gravity determining the destination of the solids (Barbour, 1904). At Lake Forest (four hours), the tank has been operated for three years without cleaning, while at Wauwatosa (ten hours) the tank is emptied twice a year (Winslow, 1905 b). Of conditions in Ohio, Pratt (1904) said in 1903:

> There are now in use 10 septic tanks, while plans for 14 more have been made. The present tanks have been in operation from one to five years. As sludge destroyers they have been fairly successful, but in a few cases offensive odors are created, and in some the effluent from the tank is probably not in the best possible state for subsequent oxidation in the filters. As far as can be learned the tanks have continued in use from one to two years without decreasing in capacity more than 25 per cent. The scum formed at the surface and bottom accumulation appears to remain fairly constant after reaching a certain volume; but a change in the composition of the sewage or in other conditions may cause a rapid increase in the deposits.

On the whole, it seems necessary to conclude with Baker (1904) that "in the majority of septic tanks thus far built for municipalities the sludge must be removed at intervals of a year or less." In certain special cases, as at Exeter and Mansfield, unknown conditions intervene to cause a more complete destruction of the stored solids.

The chief purpose for which the septic tank has been introduced is the diminution of suspended matter and the consequent lightening of the sludge burden. It is claimed by some experts that in addition to this action the anaerobic putrefaction brings the soluble constituents into a form in which they are more easily acted on by the nitrifying organisms. Martin, Cameron, and Fowler all expressed this opinion before the royal sewage commission (Martin, 1905). The writers are not aware of any data which support this contention. Harding and Frankland (Martin, 1905) are skeptical as to such an advantage and Dibdin (1904) wholly disbelieves in it. On the other hand, it is probable, as was shown before the royal sewage commission, that when not accurately regulated, "the anaerobic process may be carried too far, so as to interfere with the subsequent aerobic action" (Dibdin, 1903). Martin and Rideal minimize such interference, while Scott-Moncrieff, Woodhead, and Fowler consider it of great importance (Martin, 1905). It appears certain that with strong sewage the putrefactive process may be carried so far that its products will check the aerobic organisms. In experiments at Caterham an effluent was obtained containing 1,260 parts per million of dissolved solids, 288 parts of nitrogen as free ammonia, and 53 parts of organic nitrogen, which would not undergo nitrification until diluted (Rideal, 1901). Experience at Andover leads to the same conclusion. Here the sewage is strong and already twenty-four hours old when it reaches the disposal area. Most of it is discharged on sand beds without further treatment. While the beds were successfully handling raw sewage at a rate of 0.03 million gallons per acre per day, a small filter gave poor results with septic effluent at a rate of 0.04 and very bad results when the rate was increased to 0.1 (Clark, 1900).

From a general review of the results cited above it is not easy to determine just how much is to be gained by the introduction of the septic tank in a sewage-disposal system. With a small plant receiving very fresh sewage from a small town or an institution, it is of great advantage in breaking up masses of fecal matter. In such plants and in those which handle considerable quantities of manufactural waste the equalization of flow and composition may be of much importance. The latter factor, for example, carried weight at Manchester. These, however, are special cases. The chief point is that by proper septic treatment 60 to 70 per cent of the solids in sewage may be removed. When such a removal is necessary before final aerobic treatment, the septic tank will generally be found the best means for effecting it. Compared with chemical precipitation it has the advantage that its sludge is less in amount, besides the fact that the cost of chemicals is saved. Experiments at Oldham (R. S. C., 1902 b) pointed clearly to the superiority of the treatment without chemicals, and at Birmingham the substitution of septic tanks for precipitation resulted in a saving of $20,000 per annum and a decrease of 25 per cent in sludge (Watson, 1903). Whether any preliminary removal of solids is always desirable before final aerobic treatment is believed to be by no means certain. English authorities strongly tend to the opinion that such treatment is necessary. Rideal (1901) holds that an anaerobic stage is necessary in the process of sewage purification, although he admits that it may be accomplished in long sewers without special treatment. Ward and Woodhead maintain that the destruction of cellulose in particular can be accomplished only under anaerobic conditions (R. S. C., 1902 a). Scott-Moncrieff, Whittaker, Stoddard, and Fowler (Martin, 1905) all hold the process to be necessary. The practical data on which these conclusions are chiefly founded are discussed on pages 63–64. These data are in general the results of experiments at Leeds, Manchester, and other cities which showed that aerobic filters of large material, worked as contact beds, tended to clog badly when treated with crude sewage, while they worked well if the sewage was previously septicized. Experiments on coarse filters through which sewage is allowed to trickle continuously have suggested, on the other hand, that crude sewage may sometimes be successfully treated at rapid rates and settled later after it has been nitrified. There are numerous examples in nature of the destruction of organic matter by purely aerobic processes. Even cellulose is most actively attacked just at the surface of the ground, as evidenced by the decay of fence posts. Dibdin (1904), almost alone among the English sanitarians, has recently taken a strong position against the theory that the decomposition of cellulose must necessarily be anaerobic. The writers are of the opinion that the anaerobic process has not been shown to be a universally necessary step in the process of purification. In many plants it will no doubt prove useful. In other cases, however, a short preliminary sedimentation without septic action or subsequent sedimentation of a trickling effluent obtained by the treatment of crude sewage may be more economical.

In the eastern part of the United States, where ample areas of sand of the right quality are available for intermittent filtration, the use of the septic tank is rarely held to be necessary. In most cases the solids are discharged directly on the surface, where they are partly oxidized and partly accumulate as sludge. In the Middle West, on the other hand, where sand areas are limited and rates must be high, the use of the septic tank is very general. Barbour, Alvord, and Shields are all strong advocates of the practice, and the plants they have installed work very satisfactorily at higher rates than those in use with raw sewage in Massachusetts. At Saratoga (Barbour, 1905) the rate is 0.1, at Lake Forest it is over 0.4, and at the Wauwatosa county institutions 0.4.

PURIFICATION OF SEWAGES BY THE CONTACT PROCESS IN BEDS OF COARSE MATERIAL.

It has been shown that the scientific development of the process of purifying sewage by the action of oxidizing bacteria really dates from the experiments conducted at Lawrence, Mass., under the direction of Hiram F. Mills. The direct application of the method of intermittent filtration is, however, rather narrowly limited by local conditions. In many regions the cost of constructing sand filters of sufficient area to treat sewage at a rate of 0.1 million gallons per acre per day would be entirely prohibitive. For England, in particular, it was necessary to modify the process so as to obtain higher rates of filtration, even at the cost of a lower purification. This was first accomplished in a practically effective manner in a series of experiments carried out at Barking for the London county council, the attainment of a high rate being made possible by the use of materials coarser than sand. Almost insensibly this changed the whole conception of sewage purification. With coarse material there was little true "filtration," and it became evident that the bed was really not a filter, but an oxidizing machine. Frictional resistance could no longer be depended on to delay the flow through the bed sufficiently to allow purification to occur. It was necessary, therefore, to regulate the rate by constructing water-tight filters, in which the sewage could be retained in contact with the filling material and its accumulated growth of micro-organisms. Hence this type of purifying plant was called the "contact bed." It operated with success, attracted wide attention, and inspired the design of numerous so-called "biological filters" on similar principles.

W. J. Dibdin, chemist to the London county council, was one of the first English sanitarians to grasp the essential principles of sewage purification. In studies of the self-purification of the Thames, H. C. Sorby had pointed out as early as 1883 the part played by living organisms, although he had in view chiefly the consumption of solids by the larger microscopic forms. In 1884 Dupré went a step further in affirming the relation of organic life to the oxidations which take place in a purifying stream. Didbin, who had been associated with both these observers, read a paper before the Institution of Civil Engineers in 1887, in which he worked out the whole theory as follows:

> In all probability the true way of purifying sewage, where suitable land is unavailable, will be first to separate the sludge, and then to turn into the effluent a charge of the proper organism, whatever that may be, specially cultivated for the purpose, and retain it for a sufficient period, during which time it should be fully aerated and finally discharged into the stream in a really purified condition. This, indeed, is only what is aimed at and imperfectly accomplished on a sewage farm. [Dibdin, 1903.]

The treatment of London sewage by chemical precipitation alone was recognized by the metropolitan sewage commission in 1884 as only a temporary expedient, a final treatment on land being contemplated. As soon, therefore, as the Massachusetts results were published Dibdin saw their importance and began a series of investigations on the treatment of sewage on the Lawrence principle, but at more rapid rates. His first series of investigations was carried on between May and August, 1892, to determine the best material to employ. Four wooden tanks were installed at the northern (Barking) outfall. Each was 5 feet deep and had an area of one two-hundredth of an acre, and they were filled, respectively, with burnt clay, pea ballast (Lowestoft shingle), coke breeze, and a combination of gravel and sand over a layer of proprietary material. All received effluent from the chemical precipitation tanks at an average rate of 0.4 million gallons per acre per day. Sewage was allowed to run through continuously for eight hours, the rate being controlled by partially closing the outlet valves, and the beds were allowed to stand empty for aeration during the remainder of the twenty-four hours. The coke breeze, as indicated in Table XX, proved most satisfactory, the coarser burnt clay yielding a much poorer effluent, and the sand clogging seriously and giving a clear but imperfectly purified filtrate.

Table XX.—*Results of filtration through various coarse materials, London experiments, first series, May to August, 1892 (Clowes and Houston, 1904).*

[Parts per million.]

	Oxygen consumed in 4 hours at 80° F., filtered.	Albuminoid nitrogen.
Chemical effluent	20.1	2.7
Effluent from filter No. 1 (burnt clay)	11.6	1.3
Effluent from filter No. 2 (pea ballast)	9	1.3
Effluent from filter No. 3 (coke breeze)	7.2	1.1
Effluent from filter No. 4 (sand, etc.)	7	.8

Coke breeze was fixed on as the best material for further experiments, and a second series was begun to study the details of practical operation on a larger scale. A filter bed 1 acre in area, consisting of 3 feet of pan breeze covered with 3 inches of gravel, was constructed at Barking and put into operation in September, 1893. At first the bed was dosed too heavily and soon became clogged and foul. The need for rest and aeration, especially when a new filter is first operated, was thus clearly shown. After three months' rest the bed could handle two fillings a day, the sewage being allowed to stand in it for a period of from one to two hours. The cycle finally established allowed one and one-half hours for filling the bed, two hours for standing full, two and one-half hours for emptying, and six hours for aeration. When gradually worked up to its full capacity sewage could be treated at a rate of 1.2 million gallons per acre per day; the purification effected by the filter suffered no reduction with age; and the analytical results were excellent, as indicated in Table XXI.

TABLE XXI.—*Results of contact treatment at London, acre filter (Clowes and Houston, 1904)*

[Parts per million.]

Period.	Oxygen consumed in 4 hours at 80° F.		Nitrogen as—			
			Free ammonia.		Nitrates.	
	Chemical effluent.	Filter effluent.	Chemical effluent.	Filter effluent.	Chemical effluent.	Filter effluent.
September–December, 1893	59	17	4.8	1.4	1.6	1.9
April–June, 1894	59	12	4.9	1.1	1.8	3.4
July–November, 1894	52	10	4.7	1.3	.3	2
January–March, 1895	61	14	4.8	1.4	5.4	9.7
April–September, 1895	46	9	4	1.3	2	7.6
May–June, 1897	31	6	3	.9	.6	4.1
1900–1901	55	9	....	....	.4	10

The early London experiments of Dibdin have been greatly extended since 1898 by Clowes and Houston. Various details of construction and operation were worked out at both the Barking and Crossness outfalls, and the recommendation was finally made that the present plan of chemical treatment be abandoned and that the London sewage be, first, settled to remove gross mineral matter; second, septicized for six hours; and, third, treated in single contact beds of coke, 12 feet deep, at a rate of 5.2, attained by four fillings per day (Clowes and Houston, 1904).

In 1894, as a result of the first Barking experiments, Dibdin installed seven experimental contact beds at Sutton, in Surrey. Here two important modifications of the contact system were introduced. In the first place, the sewage was subjected to successive treatments, first in coarse and then in finer-grained beds—the "double contact" system. In the second place, after the process had worked well with chemical effluent, as it had done at London, the treatment of crude sewage was attempted. Beginning November, 1896, a double-contact system treating crude sewage was operated for the first time. The depth of the beds was 3 feet 6 inches, and the filling material burnt ballast, larger than three-eighths inch. Two fillings a day were made, giving a rate on each individual bed of 0.9. The analytical results showed a reduction of oxygen consumed from 76 parts per million in the sewage to 26 parts in the effluent of the first bed and 10 parts in the effluent of the second bed (Dibdin, 1903). The system worked for five years with admirable results. At present sewage is carefully screened (2 to 3 tons of solids per million gallons being removed) and then treated in primary coarse beds of burnt ballast and secondary fine beds of coke breeze, at a combined rate (based on the area of both sets of beds) of 0.36. It is calculated that the cost of operation is only about $20 per million gallons, as against $75 for the original treatment with iron sulphate and lime (Rideal, 1901).

The general principles of the contact system being thus established, it becomes necessary to work out details of construction. One of the first of these details concerns the nature of the filling material. In the Sutton tanks it was found that burnt clay gave somewhat better results than the other substances, although it tended to break down badly. Granite and slate proved more permanent (Thudichum, 1903). The important series of experiments carried out at Barking and Crossness in 1898–1901 showed that for treating London sewage coke was preferable to stone, as indicated in Table XXII.

Table XXII.—*Results of contact treatment at London (Barking), 1898–1901 (Clowes and Houston, 1904). Analyses of effluents.*

[Parts per million.]

Period and treatment.	Suspended solids.	Oxygen consumed in 4 hours at 80° F.		Nitrogen as—	
		Total.	Dissolved.	Nitrites.	Nitrates.
September, 1898, to April, 1899:					
Crude sewage		145	54	0.2	1.3
Double contact, ragstone, 6 feet		32	28	1.6	21.7
Double contact, coke, 6 feet		24	20	.7	12.5
July 4-15, 1899; Sept. 21, 1899, to May 19, 1900:					
Crude sewage	661	124	63	.2	1.1
Double contact, coarse coke, 10 feet	73	38	23	1.2	10.2
Double contact, coarse and fine coke, 10 feet	31	23	18	.6	21.8
Nov. 7, 1900, to Aug. 10, 1901:					
Crude sewage	667	129	68	.1	.4
Septic tank A	177	84	54	.0	1.7
Coarse coke bed, 6 feet	100	51	33	.4	7.5
Septic tank B	139	82	53	.0	1.3
Fine coke bed, 6 feet	32	37	76	.6	12.9

Dibdin and Thudichum report a series of studies summarized in Table XXIII which again indicate the superiority of coke.

Table XXIII.—*Comparison of filtering material (mean values) (R. S. C., 1902 a). Analyses of effluents.*

[Parts per million.]

Material.	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Free ammonia.	Albuminoid ammonia.	
Coke	16.6	0.58	0.94
Coal	23.4	1.04	1.52
Glass	23.8	.12	1.55

At Lawrence, also, by far the best results have been given by coke. Rough materials give better qualitative results than smooth materials. Broken-stone filters have not been particularly efficient (Massachusetts, 1903). The general results obtained at Lawrence on single-contact filtration are shown in Table XXIV.

TABLE XXIV.—*Results of single-contact treatment at Lawrence, Mass. (Fuller, 1905).*

No. of filter.	Material.	Depth (inches).	Preliminary treatment.	Rate (million gallons per acre per day).	Analyses (parts per million)							
					Sewage.			Effluent.				
					Nitrogen as—		Oxygen consumed.	Nitrogen as—			Oxygen consumed.	
					Free ammonia.	Albuminoid ammonia.		Free ammonia.	Albuminoid ammonia.	Nitrates.		
103	⅛- to ¼-inch coke.	60	Septic	0.6	38.7	3.3	27.3	7.9	0.9	21.2	7.8	
107	Cinders	24	None	.55	23.8	4.6	34.5	13.4	1.7	5.4	15.7	
135	¼- to 1-inch stone	214	None	1.2	37.8	5.6	49.5	20.3	1.7	3.4	13.3	
154	Coke, breeze	48	Septic	.5	58.7	6.6	45.4	42.3	2.2	3.0	14.9	
167	Stone (walnut)	48	Septic	.3	85.3	8.5	65.9	54.6	3.2	13.4	20.9	
176	¼- to 1-inch coke.	60	None	.7	37.2	6.1	42.8	13.1	1.5	11.3	7.7	

At Birmingham it was found that the purification, measured by reduction in oxygen consumed, was 64 per cent with broken stone, 71 per cent with slag, and 93 per cent with coal (Bredtschneider and Thumm, 1904). There is some evidence (see p. 82) that coal exerts a specially favorable action in trickling filtration (Hill, 1897). At Manchester (1901) materials containing iron were found to yield particularly good results. At Hamburg it appeared that the amount of porosity is immaterial and that the chief desideratum is iron content. Thumm, by the addition of 1 per cent iron to gravel or pumice, increased the purification in two contact beds from 46 and 42 to 66 and 62 per cent, respectively (Thumm, 1902).

A series of experiments on various materials conducted by Zahn at Charlottenburg in 1901 showed that brick gave the best results, followed by slag, coal, coke, and gravel in the order named. The results are brought together in Table XXV. In each case the secondary sand filter was operated as a contact bed, the sewage standing on it under a head during the full period. It acted chiefly as a strainer to remove suspended solids.

TABLE XXV.—*Results of Charlottenburg experiments on contact filtration (Zahn, 1903).*

[Parts per million.]

	Total solids.		Suspended solids.		Nitrogen as—			Oxygen consumed in 10 minutes' boiling.
	Total.	Loss on ignition.	Total.	Loss on ignition.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Raw sewage	1,121	294	413	272	65	19	0	118
I. a. Slag	1,059	163	82	54	22	11	Present	64
I. b. Sand	1,068	149	0	0	17	7	do	50
II. a. Coke	1,028	159	38	22	36	9	do	66
II. b. Sand	1,044	177	0	0	24	7	do	50
III. a. Gravel	1,084	203	101	68	32	12	do	82
III. b. Sand	1,137	235	0	0	20	6	do	52
IV. a. Brick	1,229	173	39	20	21	8	do	58
IV. b. Sand	1,280	204	0	0	18	8	do	43

In general, these results with regard to kind of material are somewhat inconclusive. Coke and coal seem particularly favorable and the presence of iron is apparently important. Cameron and Harding consider smoothness of surface desirable (R. S. C., 1902 a), but this conclusion is scarcely borne out by the successful use of coke.

The nature of the material used will necessarily depend much on local conditions. Its size is more a matter of choice and this factor is of even greater practical importance. Reference to the Hamburg results in Table XXVIII illustrates this point. It will be noticed that one-eighth to five-sixteenths inch material in experiments B and C gave twice as much purification as three-eighths to 1⅛ inch material in experiments L, M, N, and P. The high purification in these beds was, however, accompanied by great loss of capacity. At the royal testing station at Berlin, it was found in experiments with several different sewages that one-third to 1 inch slag for the first contact and one-eighth to one-third inch slag for the second contact gave the best results. The primary beds effected a purification of 20 to 30 per cent. The secondary beds raised this figure to 70 per cent and produced a nonputrefactive effluent (Thumm, 1902). Clowes and Houston (1904), as a result of their London experiments, recommended the use of "walnut-size coke." In evidence before the royal sewage commission, Fowler recommended one-eighth inch material, Cameron one-eighth to one-half inch, Frankland one-eighth to three-fourths inch, and Dibdin one-half to 4 inch for first contact and one-sixteenth to three-eighths inch for second contact (Martin, 1905). Barwise (1904) suggests the use of coarser filling—3 to 5 inch material for primary beds and one-half to 1½ for secondary beds to treat septic effluent. An interesting suggestion has recently been made by Dibdin (1904), who recommends the construction of "multiple-surface bacteria beds" of tiers of slate or brick regularly built up so as to secure a liquid capacity sometimes reaching 80 per cent. A bed built at Devizes on this plan is said to have cost less than one-third as much as an ordinary coke bed. Analyses from such a bed are shown in Table XXVI.

TABLE XXVI.—*Results from multiple-surface bacteria bed, February 9 to March 25, 1904 (Dibdin, 1904).*

Average number of fillings per day		0.83
Nitrogen as albuminoid ammonia:		
In sewage	parts per million	9.9
In effluent	do	4.8
Oxygen consumed in 4 hours at 80° F.:		
In sewage	do	76.6
In effluent	do	58.7

If a bed were filled with perfect spheres of uniform size its open space or water capacity would be 26 per cent of its original cubic capacity. In beds built of the ordinary materials actually used this value varies from 30 to 50 per cent. With progressive use the capacity decreases, and this is one of the most serious problems in the operation of the contact bed.

In an admirable analysis of the causes which affect the loss of capacity in contact beds the Manchester experts (Manchester, 1902) arrange them under the following five heads:

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

The first cause must always operate to a considerable extent and in part accounts for the great initial loss when the bed is first put in operation. If the original liquid capacity is determined, not by filling with water and measuring the effluent, as should be done, but by measuring the amount of water or sewage required to fill it, the initial loss will appear much larger than it really is, by the amount of water required to saturate the surfaces and pores of the dry material. The relative importance of this initial loss and of the true loss due to settling, growth, etc., is indicated in Table XXVII.

TABLE XXVII.—*True and apparent loss of capacity in a contact bed* (*Martin, 1905*).

	Capacity.	
	Gallons.	Per cent of total.
Total cubic contents	23,431	100
First filling, Aug. 15, 1896	13,775	59
Filling Aug. 21, 1896	10,302	44
Filling Nov. 14-15, 1896	7,893	34

The actual decrease in capacity after the first filling is partly due, as noted above, to the breaking down of uniform materials into pieces of more varied size which become more closely packed together. The amount of this loss may be measured by the space left by the settling over the top of the material. At Pawtucket it was estimated that about one-third of the total capacity loss in eighteen months was due to this factor. Such loss may be avoided to a great extent, as has been pointed out above, by the use of compact and permanent filling. This was shown very clearly in the Hamburg experiments. Table XXVIII shows, by a comparison of experiment G with H and I and of experiment N with M and O, that slag, while giving as good analytical results as coke and gravel, showed appreciably less loss of capacity.

TABLE XXVIII.—*Statistics of Hamburg experiments on contact filtration (Dunbar and Thumm, 1902).*

No. of experiment.	Material.		Kind of sewage received.	Number of fillings per day.	Length of run (months).	Oxygen consumed in 10 minutes' boiling.		Capacity (parts per million).		Remarks.
	Kind.	Size (inches).				Sewage.	Effluent.	Original.	Final	
B	Slag	$\frac{1}{8}$ to $\frac{5}{16}$	Raw	1	26	96	27	33	20	
C	do	$\frac{1}{8}$ to $\frac{5}{16}$	do	2	14	91	21	41	15	
L	Coke	$\frac{3}{8}$ to $1\frac{1}{8}$	do	6	15	80	52	38	[a] 30	Washed twice.
D	Slag	$\frac{1}{8}$ to $\frac{5}{16}$	Effluent from L	3	15	80	20	43	17	
E	Gravel	$\frac{1}{8}$ to $\frac{5}{16}$	do	2	11	80	19	27	14	Washed once.
F	Coke	$\frac{1}{8}$ to $\frac{5}{16}$	do	2	15	80	19	36	22	
G	Slag	$\frac{3}{16}$ to $\frac{3}{8}$	Effluent from N	3	11	90	30	39	23	
H	Coke	$\frac{3}{16}$ to $\frac{3}{8}$	do	3	11	90	27	39	22	
I	Gravel	$\frac{3}{16}$ to $\frac{3}{8}$	Effluent from M (4 months) and P (7 months).	3	11	90	28	31	19	
K	Gravel + 1 per cent iron turnings.	$\frac{3}{16}$ to $\frac{3}{8}$	Effluent from M	3	11	90	29	31	19	
M	Coke	$\frac{3}{8}$ to $1\frac{1}{8}$	Raw	3 to 6	12	88	63	44	38	
N	Slag	$\frac{3}{8}$ to $1\frac{1}{8}$	do	3 to 6	12	88	65	48	39	
O	Gravel	$\frac{3}{8}$ to $1\frac{1}{8}$	do	3	12	88	46	35	26	
P	Brick	$\frac{3}{8}$ to $1\frac{1}{8}$	do	3	12	88	46	44	28	

[a] Fell to 18 per cent before last washing.

In England the loss of capacity due to breaking down of material has been found to be serious with clay not thoroughly burnt, and the need for permanent filling has led to an extensive use of various sorts of furnace clinker. Many English beds are, however, still built of friable stuff. Baker (1904) says: "It seems strange to an American to see so much perishable material used for filter beds," and suggests that in the United States gravel or broken stone will probably be preferable to cinders, clinker, or brick.

The capacity loss due to impaired drainage, like that from the breaking down of material, may be controlled to some extent by proper construction of the beds. The other two losses, due to growths and to deposition of solids, are more or less inevitable.

The loss of capacity due to the growth of organisms is more or less directly correlated with an increasing purifying power of the bed. At Manchester it was found that "the chemical efficiency is increased by a loss of capacity. These beds purified four doses after they had become partly clogged as readily as three when clean. The amounts were about the same in the two cases." (Manchester, 1899.) Dunbar gives the figures quoted in Table XXIX to illustrate this point. He considers that the ability of the filter to absorb rapidly free ammonia from the sewage is an index of the amount of growth within the filter.

TABLE XXIX.—*Improvement in ammonia absorption in a contact filter (Dunbar and Thumm, 1902).*

Months at work.	Loss in ammon'a (per cent).	
	Single filling.	Double filling.
1	9.1	14.6
2	34.6	30.9
5	35.2	23
8	47.4	41.3
10	43	41.2
14	40.5	41.6

This sort of loss due to growth is almost independent of the character of the liquid filtered. Dunbar treated coke contact filters with various substances (134 fillings in four months) and found with tap water a reduction in capacity from 48 to 40 per cent; with tap water plus 1 per cent urine, from 47 to 37 per cent; with unfiltered sewage from 48 to 37 per cent; with filtered sewage, from 48 to 40 per cent, and with sewage precipitated with lime, from 44 to 36 per cent (Dunbar and Thumm, 1902).

The loss of capacity due to the deposition of the insoluble mineral matter which enters the beds is also serious and in England has necessitated the complete renewal of many contact filters. It may be avoided to a considerable extent by preliminary straining and sedimentation, and it tends to be concentrated in the upper layers of the filter. With some sewages, however, it seems clear that contact filters will require frequent renewal. The experiments at Leeds furnish a good example of this. Table XXX indicates a reduction to values as low as 9 and 11 per cent. It appeared evident to the experts in this case that in order to treat Leeds sewage in contact beds it was necessary to use an even, hard filling material, to remove suspended mineral matter by careful sedimentation, and to exclude iron compounds from the sewers. Even then they considered the permanency of the beds more than doubtful.

TABLE XXX.—*Loss of capacity in contact beds at Leeds—raw and settled sewage (Leeds, 1905).*

No. of bed.	Material.	Period.	Original capacity (per cent).	Final capacity (per cent).
1	Coke, not less than 3 inches	Oct. 2, 1897, to Oct. 7, 1899	48	15
3	Clinker, ½ to 1 inch	Nov. 19, 1898, to Jan. 10, 1901	51	14
5	Clinker, 1 to 2 inches	Feb. 27, 1899, to Dec. 30 1900	52	11
7	Clinker, ⅝ to 1 inch	Mar. 8, 1899, to Feb. 15, 1901	31	9
8	Clinker, ⅜ to 1 inch	Mar. 30, 1898, to Sept. 1, 1899	31	12

It is possible to restore the original capacity of contact beds to a considerable extent by allowing them to rest empty for several weeks Table XXXI shows how efficient this process was at York and at Leeds in the case of two of the beds above referred to. Rest can of course effect only the disintegration of the organic growth and can not affect the accumulated mineral matter. The restoration of capacity can therefore never be complete.

TABLE XXXI.—*Loss in capacity of contact beds and its recovery by resting.*

NABURN DISPOSAL WORKS, YORK (YORK, 1901).

	U. S. gallons.	Per cent open space.
Bed No. 1.		
Cubic capacity	55, 200	100
Initial liquid capacity	22, 300	40
After 90 days' work	11, 200	20
After 14 days' rest	16, 400	30
After 42 days' work	11, 500	21

KNOSTROP SEWAGE WORKS, LEEDS (LEEDS, 1900).

	U. S. gallons.	Per cent open space.
Bed No. 7, single contact.		
Cubic capacity	222, 000	100
Initial liquid capacity	66, 800	31
After 226 days' work	25, 900	12
After 74 days' rest	64, 200	30
After 184 days' work	30, 700	14
Bed No. 8, single contact.		
Cubic capacity	113, 000	100
Initial liquid capacity	35, 400	31
After 185 days' work	12, 800	11
After 50 days' rest	32, 300	28
After 203 days' work	11, 800	10

The treatment of septic effluent instead of crude sewage greatly prolongs the life of the contact bed. In the Barking experiments (Clowes and Houston, 1904) the capacity of two primary coke beds fell in ten months from 69 and 70 per cent to 20 and 18 per cent, respectively. Secondary beds showed only a reduction from 62 to 51 per cent (coarse) and from 53 to 44 per cent (fine). The stone beds lost about 1 per cent of their original liquid capacity per week. A series of experiments with septic effluent followed, in which after the first loss a capacity of about 30 per cent was constantly maintained. At Leeds it was found that beds taking septic effluent showed much higher capacities than those which received crude sewage. Similar conclusions were drawn by the experts at Manchester, although the experiments made with crude sewage were not exhaustive. The capacity of beds treating septic effluent decreased during the first three months and then remained fairly constant at about 33 per cent (of the original cubic contents), as shown in fig. 6. At Burnley, with septic effluent, the capacity of contact beds fell from 44 to 19 per cent; at Exeter it fell from 39 to 28 per cent, and at Leicester from 49 to 29 per cent. At Sutton a minimum of 21 per cent was reached (R. S. C., 1902 a). At Oldham "no clogging" was reported after two years (Oldham, 1901). In still other places even crude sewage has been treated with success. At West Bromwich the capacity of primary beds fell from 33 to 19 per cent and of secondary beds from 33 to 24 per cent in some-thing over a year. At Newbury the capacity of single-contact beds of clinker fell from 19,000 to 10,000 gallons, and that of gravel beds from 19,000 to 9,000 gallons in a year's operation. At Hampton it is

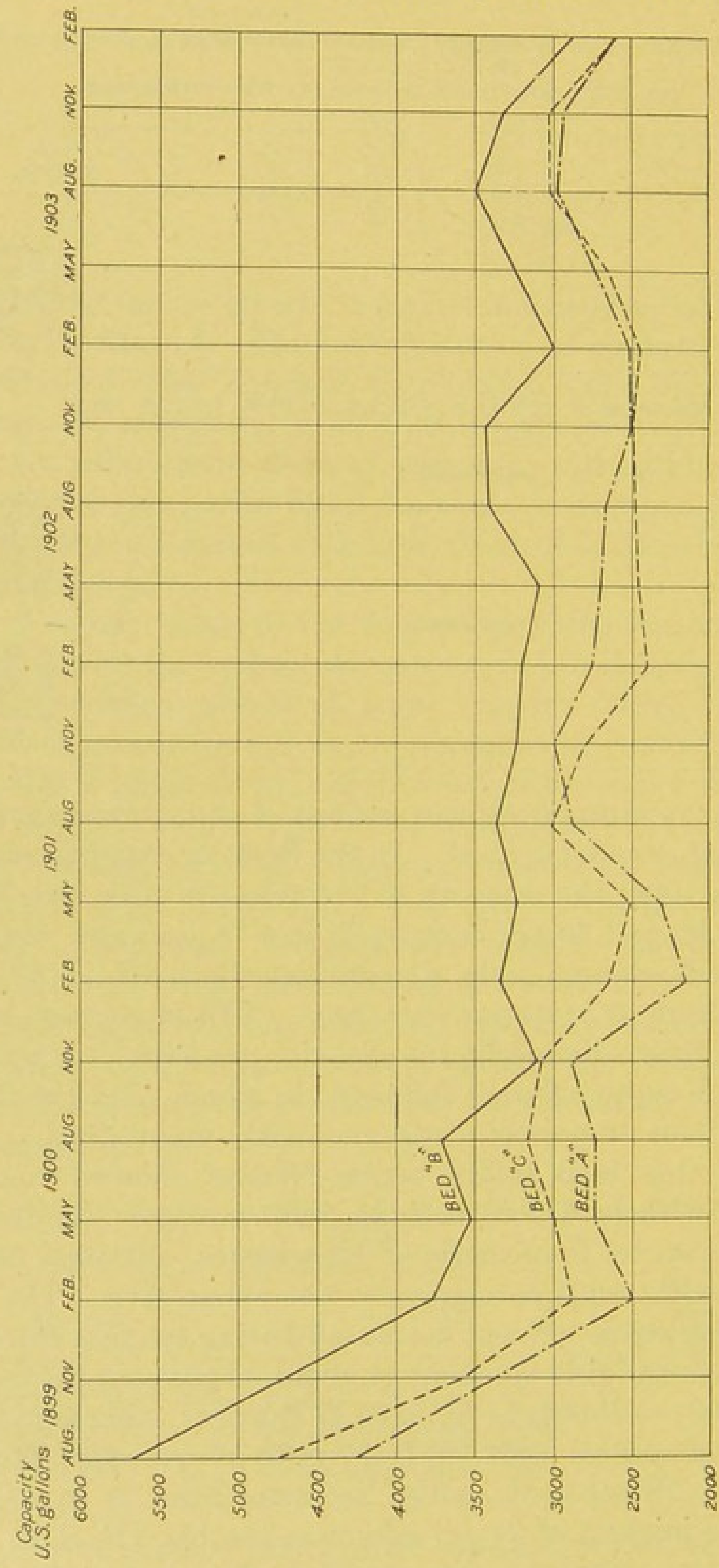

FIG. 6.—Loss in capacity of contact beds at Manchester, England

claimed that coarse beds after more than two years maintain "their original liquid capacity." At Maidstone and Wellington (Somerset) absence of sludge deposits in the beds was reported (R. S. C., 1902 b).

Experiments in Germany have shown less favorable results as to clogging, perhaps from the use of rather fine material and the treatment of very strong sewages. Dunbar's figures, as given in Table XXVIII, indicate final capacities of only 15 to 20 per cent with material ranging down to one-eighth and three-sixteenths inch. Experiments M, N, O, and P, with three-eighths to 1⅛ inch material, show results substantially like those obtained in England. German practice, however, tends to single contact in beds of fine material. Under such conditions it appeared at Hamburg that the loss in capacity went on in a pretty regular ratio to the amount of applied sewage, the beds soon being so clogged that their capacity fell to 15 or 20 per cent. The average reduction with different materials is shown in Table XXXII. Capacities were not satisfactorily restored by periods of rest.

TABLE XXXII.—*Reduction in capacity of Hamburg filters (Dunbar and Thumm, 1902).*

Material.	Loss in capacity (gallons per million gallons filtered).	Material.	Loss in capacity (gallons per million gallons filtered).
Single contact.		*Second contact.*	
Slag, ⅛- to 5/16-inch	1,330 1,680	Slag, ⅛- to 5/16-inch	420
		Gravel, ⅛- to 5/16-inch	700
Coke, ⅜- to 1⅛-inch	340	Coke, ⅛- to 5/16-inch	630
Gravel, ⅜- to 1⅛-inch	280	Slag, ⅜- to 1⅛-inch	340
Slag, ⅜- to 1⅛-inch	170	Coke, ⅜- to 1⅛-inch	360
Brick, ⅜- to 1⅛-inch	440	Gravel, ⅜- to 1⅛-inch	460
		Gravel and iron, ⅜- to 1⅛-inch	650

The German investigators accept this serious clogging with equanimity and suggest the removal and washing of the material when the capacity falls to 20 to 25 per cent. This would be required two or three times a year (Dunbar and Thumm, 1902). The Prussian commission at Berlin came to similar conclusions (Bruch, 1899). Material showed in these experiments a considerably greater capacity after washing than when it was first used. It seems probable that the use of coarser materials, which under proper conditions do not require so frequent removal, is a more economical process. Some of the English filters, for example, have been operated for six years with fair success (Martin, 1905).

Next to the nature and size of filling material the depth of the contact bed is the most important point of general theoretical interest in its construction. Exhaustive experiments were carried out on this point by Clowes and Houston (1904) at London, from which it appeared that beds 3 feet, 5 feet, and 13 feet in depth gave equally good effluents. Studies at Exeter, in which samples were taken from taps placed at different depths in a contact filter, showed the best results at 3 feet below the surface, and at Manchester a 15-inch bed gave specially good results. At Leeds, on the other hand, 6-foot beds proved better than those of half that depth (R. S. C., 1902 a). Thumm (1902) considers 4½ to 6 feet a maximum depth for one-third to 1 inch material and 1½ to 3 feet a maximum for material under one-eighth inch.

With regard to the operation of contact beds, the number of fillings is the first point to be considered. At Hamburg it was found that for single contact two fillings a day gave the best results, while for double contact six fillings of the primary beds and three fillings of the secondary beds were recommended (Dunbar and Thumm, 1902). In the Barking experiments (Clowes and Houston, 1904) it was shown that two fillings a day gave better results than one; apparently a single filling does not maintain the bacteria at their maximum effectiveness. Birmingham experiments have indicated three fillings a day as effective, to be cut down to two if specially high purification is desired (Watson, 1903). At Crossness it was found that London sewage could be purified with as many as four fillings. At Manchester (1901) also four fillings were recommended.

The distribution of fillings at regular intervals over the twenty-four hours does not appear to be a necessity. At Manchester contact beds were operated for two months with four even six-hour cycles and then for three months with four cycles in ten hours, followed by fourteen hours' rest. The results, as shown in Table XXXIII, were better by the second method.

TABLE XXXIII.—*Results of operation of contact beds at Manchester, England (R. S. C., 1902 b).*

Mode of operation.	Analyses of effluent (parts per million).			
	Oxygen consumed in 4 hours at 80° F.	Nitrogen as—		
		Free ammonia.	Albuminoid ammonia.	Nitrates.
4 cycles in 24 hours	29	16.8	1.5	2.6
4 cycles in 10 hours	22.3	14.8	1.1	6.3

The duration of the full period may also vary. Dibdin adopted two hours, and this is perhaps the general English practice. In Germany, too, Schumburg and others advocate this period (Bruch, 1899). Harding at Leeds found that one hour gave inferior results, while four hours was no better than two (R. S. C., 1902 a). Roscoe and Cameron, on the other hand, advocate shortening the period to one hour (R. S. C., 1902 a). Frankland found that a value for oxygen consumed of 555 parts per million for raw sewage was reduced to 93 in five minutes. It was still 93 after thirty minutes and 49 after twelve hours (Barwise, 1904).

The rate of filtration on contact beds, which is usually expressed in relation to the superficial area, is of course a function of the depth and the number of fillings. It would be more reasonable to measure contact rates in such units as acre-yards, which take account of depth. For uniformity with sand and trickling filters, however, the unit of superficial area is used in this paper. With a bed 3 feet deep and an open space of 33 per cent, which is a liberal estimate for a matured filter, two fillings a day would equal a rate of 0.65 million gallons per acre per day and three fillings a rate of about 1. In practice, necessary rests and loss of capacity being taken into account, three fillings of a 3-foot bed will not amount to a rate of more than 0.8. At Barking, in 1898, Clowes and Houston (1904) obtained with one filling rates of 0.6 for coke and 0.5 for ragstone, and in 1899 with two fillings the rates were increased only to 0.7. Watson (1903) considers 0.4 to 0.6 the best rate attainable, even when the sewage has been previously subjected to septic treatment. Table XXXIV, compiled from Watson's Birmingham lecture and from the testimony before the royal sewage commission, indicates the rates which have been recently obtained in actual operation or in experiment on a practical scale.

TABLE XXXIV.—*Contact-filter rates* (*Watson, 1903; Martin, 1905*).

Single contact.			Double contact.		
Place	Depth (feet).	Rate (million gallons per acre per day).	Place.	Depth (feet).	Rate (million gallons per acre per day).
Manchester	3.3	0.6	Burnley	3	0.3
Birmingham	4.5	.6	Leeds	5.5	.6
Croydon	3.7	.8	Blackburn	5.5	.8
Exeter	5	1	Sheffield	3.3	.8
Sutton	3.5	1	Carlisle	4	1.1
London	3	1.2	Sheffield	3.3	1.2
Leeds	4.5	1.4			

When a double-contact system is used the area must naturally be increased, generally by 50 per cent, the secondary beds being operated at double rate. The discussion of analytical results (pp. 70–71) shows that single contact rarely yields a stable effluent, while double contact usually does. The fact that, with a given area, better results can be obtained by double treatment at a certain rate than by single treatment at half that rate is made clear by some Manchester experiments, the results of which are given in Table XXXV.

TABLE XXXV.—*Results of double and single contact treatment at Manchester, England* (*Manchester, 1904 a*).

[Parts per million.]

	Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
	Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.	
Septic effluent	25.8	2.5	....	70
First contact	14.5	1.2	0.5	22
Second contact	4.1	.5	8.5	6.9
Septic effluent	31	3.5	....	80
Single contact (one-half rate)	13.3	1.3	4.3	16

In the Hamburg experiments it was found that with six daily fillings in the primary bed and three in the secondary bed as good results were obtained by double contact as with two fillings in single-contact beds. This is shown in Table XXVIII (p. 61), where experiment C and experiments L and D represent comparable conditions (Dunbar and Thumm, 1902). It may be noted in passing that in England general practice reverses this relation between primary and secondary beds. The Manchester commission suggested that secondary beds

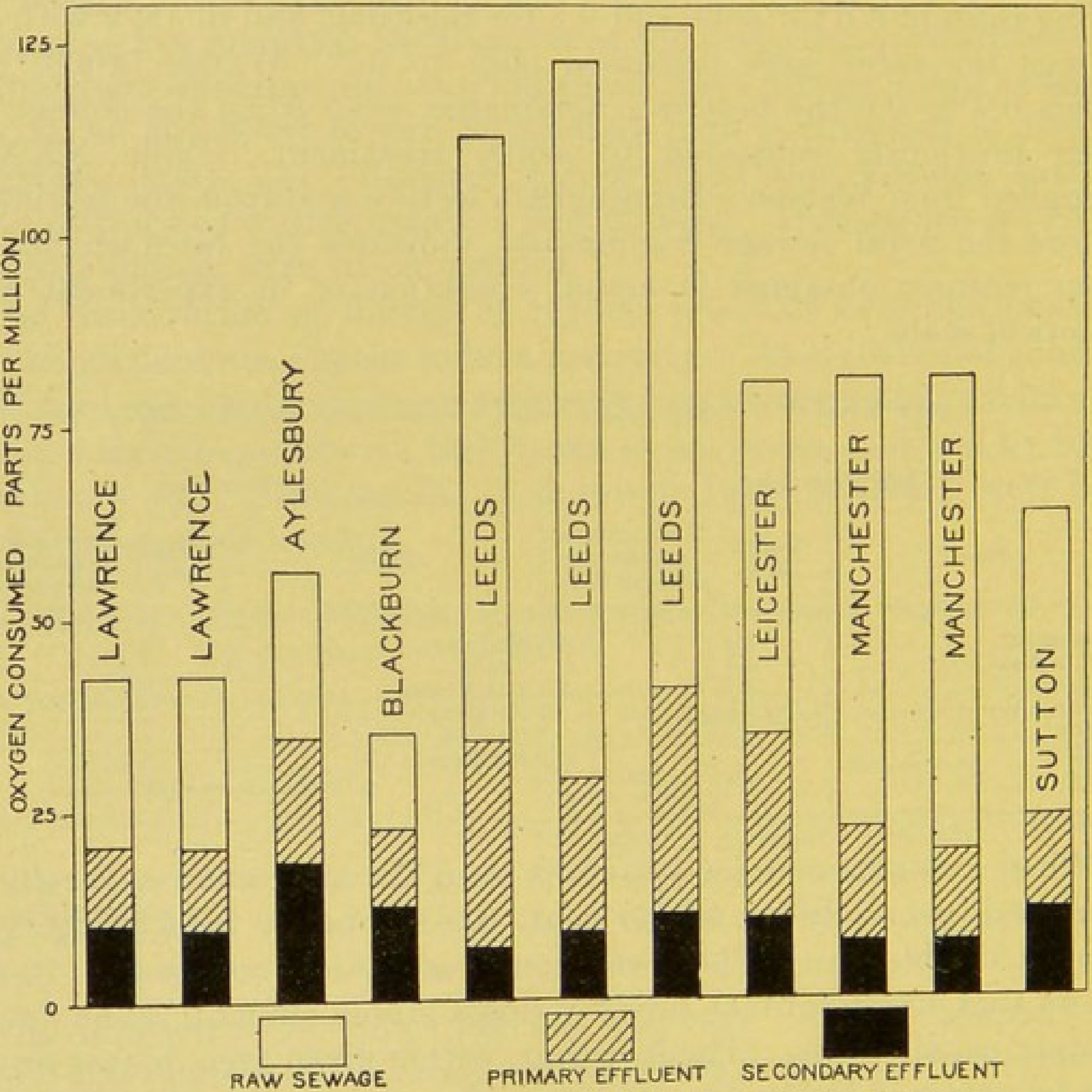

FIG. 7.—Comparison of sewages and effluents from contact beds.

should be operated at twice the rate of the primary beds (Manchester, 1900 a).

The purification effected by single and double contact filtration is fairly represented by the analyses, collected from various sources, given for comparison in Table XXXVI. The removal of oxygen consumed at the two stages in the process is plotted in fig. 7. It will be noted that the first contact removes somewhat more than half of the organic constituents of the sewage, as measured by oxygen consumed and albuminoid ammonia, and two-thirds or more of the suspended solids, while the second contact effects almost as great a purification on the first-contact effluent. Aylesbury and Blackburn showed the worst results among the English plants as far as ratio of purification is concerned. It will be noticed that these are the weakest sewages and in all sewage treatment the last fractions of organic matter are the most difficult to remove. Except at Lawrence the nitrate content of the effluent is rather low, notably at Leeds and Leicester.

TABLE XXXVI.—*Results of single- and double-contact treatment.*

[Parts per million.]

	Solids.						Nitrogen as—												Oxygen consumed in 4 hours at 80° F.[a]		
	Total.			Suspended.			Free ammonia.			Albuminoid ammonia.			Nitrites.			Nitrates.					
	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.
Lawrence: [b]																					
Nos. 137–163	......	......	......	......	......	......	36.3	24.3	12	5.9	2.4	1.4	......	......	......	......	8.3	14.6	42.6	21.2	10.3
Nos. 137–164	......	......	......	......	......	......	36.3	24.2	8.6	5.9	2.4	1.2	......	......	......	......	8.3	21.7	42.6	20.4	9.4
Aylesbury [c]	1,190	1,020	920	367	112	0	56.4	42.7	23.6	6.5	4	1.9	......	0.3	0.9	......	.6	13.3	57.5	35.1	18.4
Blackburn [d]	1,080	602	596	474	60	3	23.3	17.3	11.4	2.8	1.7	1	......	.1	.2	......	.4	1.1	35.8	23	12.6
Leeds: [e]																					
Nos. 1 and 2	1,670	1,080	980	584	165	27	20.2	12.9	3.7	9.5	3.7	.9	......	......	......	......	......	5.6	115	36	7
Nos. 3 and 4	1,690	1,180	1,050	614	180	47	23.8	10.8	6.8	11.3	3.4	1.3	......	......	......	......	......	3.7	126	30	9
Nos. 5 and 6	1,780	1,170	1,020	661	196	47	24.1	14.5	7.8	11.8	4.7	1.7	......	......	......	......	......	1.8	132	42	11
Leicester [f]	1,320	1,070	1,020	296	73.2	23	......	......	......	10.6	4.2	2.5	......	......	......	0.6	.9	4.6	83.9	33.4	10.7
Manchester: [g]																					
Beds A and D	......	......	......	......	......	......	24	9.1	3.7	3.7	1.4	.6	......	.4	.2	......	5.6	10.6	83.9	23.1	7.5
Beds C and D	......	......	......	......	......	......	24	8.5	3.6	3.7	1.3	.6	......	.3	.2	......	6.3	10.8	83	19.6	7.5
Sutton [h]	1,630	895	1,000	824	45	5.6	94.2	32.6	8.3	7.3	2.9	1.4	......	1.5	.7	......	4.1	19.7	56.9	21.9	9.2

[a] At Lawrence, 2 minutes' boiling.

[b] Lawrence: No. 137–163, run for 18 months during 1901–1902; area of beds, 1/20000 acre each; first contact, broken stone ½ to 1 inch, taking raw sewage, rate 0.9; secondary bed, fine coke, rate 0.7 (Fuller, 1905). No. 137–164, run for 6 months during 1901; like No. 137–163, except that coke was "considerably finer" in secondary bed (Fuller, 1905).

[c] Aylesbury: Experiments during first 6 months of 1898; weekly analyses; no further data given (R. S. C., 1902 a).

[d] Blackburn: No further data (R. S. C., 1902 a).

[e] Leeds: Nos. 1 and 2, experiments during October, 1898, to October, 1899; beds about ⅛ acre in area; primary contains 5 feet of coke over 3 inches in diameter, receives raw or settled sewage at rate of 0.8; secondary, 6 feet coke, 3/16 to 1½ inches, rate like primary. Nos. 3 and 4, experiments during November, 1898, to June, 1900: beds each about ⅛ acre in area and 3 feet deep; primary bed filled with clinker ½ to 1 inch, and secondary 1/16 to ½ inch; rate during first 6 months, 1.1 (settled sewage), and during remainder of period 0.3 (raw sewage). Nos. 5 and 6, experiments during March to November, 1899; beds each ⅛ acre in area; primary bed, 3 feet of clinker, 1 to 2 inches; secondary bed, 3 feet of clinker, 1/16 to ½ inch; rate, 0.8, raw sewage on each bed; 4 hours' contact during a portion of the time (Leeds, 1900).

[f] Leicester: Process No. 14; experiments during November, 1898, to July, 1899; primary beds, 1/40 acre in area, filled with clinker 1¼ to 2¼ inches, 4½ feet deep; secondary bed, 1/48 acre in area, filled with 3 feet of clinker, ⅛ to ½ inch; rate, 1.6 on each bed, septic sewage (Leicester, 1900).

[g] Manchester: Experiments during January 4, 1900, to March 27, 1901; A and C were primary beds, the combined effluents of which were run on to D; area of each bed, 1/17 acre on the surface; slope inward, 2:1. A contains 3 feet of clinker ½ to ¾ inch; septic sewage at rate of 0.3. C contains 3 feet of clinker ¼ to ¾ inch; septic sewage at rate of 0.4. D contains 3 feet of clinker ⅛ to ½ inch; rate, 0.7 (Manchester, 1901).

[h] Sutton: Experiments from October, 1897, to August, 1898; coarse bed 3 feet deep, of burnt ballast; 5 beds of burnt clay; rate in each bed, 1 (R. S. C., 1902 a).

To these results may be added one more set of analyses to show what contact beds have actually accomplished in practical operation on a large scale. At Manchester, in 1903, 28 half-acre primary beds had been installed. They were 40 inches deep and filled with one-eighth to 1 inch clinker and were dosed with septic effluent. The results of the first year of operation are shown in Table XXXVII.

TABLE XXXVII.—*Efficiency of primary-contact beds at Manchester, England (Bredtschneider and Thumm, 1904).*

Date.	Rate (million gallons per acre per day).	Analyses (parts per million).					
		Oxygen consumed in 4 hours at 80° F.		Nitrogen as—			
				Free ammonia.		Albuminoid ammonia.	
		Septic effluent.	Contact effluent.	Septic effluent.	Contact effluent.	Septic effluent.	Contact effluent.
1902.							
January to March	0.46	....	....	....	....	....	....
April to June	.54	85	34	30	19	4	2.1
July to September	.56	80	32	29	17	3.2	1.7
October to December	.56	89	32	29	16	4	1.6

The effluent of the first contact process, as is obvious from the analyses in Table XXXVI, almost always retains too much organic matter to be considered satisfactorily purified. Two successive treatments, on the other hand, may produce an effluent which is nonputrescible and of good enough quality to be discharged into a stream. If still better results are desired a third contact may be made. Table XXXVIII shows what may be expected from such a method. The improvement in successive treatments progressively lessens, so that the results obtained are scarcely commensurate with the cost. The head required for successive contacts also introduces a serious factor.

TABLE XXXVIII.—*Results of triple-contact treatment.*

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
	Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Eastry (R. S. C., 1902b).						
Sewage	1,550	1,070	25.5	12.8	4.6	123
Bed 1	1,460	107	22	3	1.9	50.5
Bed 2	1,340	85.5	12.4	2.4	2.1	25.4
Bed 3	1,360	21.4	4.8	1.2	7.4	17.2
Leeds (Leeds, 1900).						
Sewage	1,760	632	27.6	12.4	....	127
Bed 1	1,250	274	18.6	7.1	....	62.4
Bed 2	1,060	113	13.5	5.1	....	39.6
Bed 3	1,030	110	9.7	3.5	2	27.5

It has been shown that the contact bed was developed from the intermittent sand filter with no idea of changing any other condition than the rate of operation. It was assumed that the chemical changes were the same in each case. Many English discussions of the process are based on this assumption, and Clark states that at Lawrence the process of nitrification is considered an essential for good purification (Clark, 1903).

Dunbar and Thumm (1902), in a beautiful series of experiments at Hamburg, have shown, however, that the reactions in the contact filter, as a result of the alternate aerobic and anaerobic conditions, follow a peculiar and characteristic course. First, during the reduction phase the solids in the sewage settle on the surface of the filling material and the soluble constituents are to a large extent absorbed by the bacterial jelly with which the material is clothed. This latter phenomenon takes place in virtue of the general tendency exhibited by colloidal films to remove substances from contiguous solutions (Phelps and Farrell, 1905). Dibdin illustrates the removal of suspended matter by analogy with the adhesion of floating chips to larger bodies, and compares the adsorption of dissolved material to the removal of lead acetate by passage through a carbon filter (Dibdin, 1904). The real purification of the adsorbed material has been shown by Dunbar (1905) to be a bacterial process, although Bredtschneider (1905) attempts to maintain its purely mechanical character. During the oxidation phase of full aeration the bacteria set up the ordinary oxidation processes of the intermittent filter, which may be indicated by the following generalized formula:

Reaction 1. Nitrification:

$$\text{(a) } 2R.N:R' + 3O_2 = R.O.R + 2R':O + N_2O_3;)$$

$$\text{(b) } N_2O_3 + O_2 = N_2O_5)$$

At the end of this period considerable quantities of nitrates are present in the filling material of the contact bed, as shown by Dunbar and Thumm (1902). Experiments by Phelps and Farrell (1905) indicate that the amount of nitrates increases with the length of the period. When the bed is refilled for the next cycle the same action continues for a time. Soon, however, the supply of dissolved oxygen is consumed, active nitrification stops, and anaerobic putrefactions begin, causing hydrolytic splittings of the following type:

Reaction 2. Hydrolysis:

$$(R.N:R' + 2H_2O = R.OH + HO.R'.NH_2)$$

At this stage the contact filter has the liquefying properties of the septic tank. There is a bacterial reduction of the nitrates to nitrites, and a formation of partly reduced nitrogenous bodies, primary amines, etc. This leads to a decomposition of the nitrites present and the liberation of gaseous nitrogen according to the following formula:

Reaction 3. Denitrification:

$$2HO.R'.NH_2 + N_2O_3 = 2R'(OH)_2 + 2N_2 + H_2O$$

During the reducing phase the nitrates formed in the empty period are partly or wholly removed. Much of the organic nitrogen originally present is lost as free nitrogen. Clark (1903) has pointed out that this loss amounts to from 38 to 50 per cent and Phelps and Farrell (1905) found a loss of from 35 to 50 per cent. The nitrates found in the final effluent give no true measure of the purification effected, since under ideal conditions the nitrates formed from half the nitrogen would be exactly used up in decomposing the other half. Dunbar and Thumm (1902) found that the highest purification frequently accompanied the lowest nitrate content in the effluent.

The process in the contact bed is evidently an extremely complex one, involving an alternation of anaerobic and aerobic processes. To those who, like most English authorities, believe that putrefaction is an integral part of all sewage purification, such a method must commend itself. Clark (1900) describes a suggestive experiment in which gravel filters were run at a rate of 0.5 with forced upward aeration. Comparing these filters with others operated on the contact plan, he finds that the latter operate for longer periods and at higher rates without clogging and produce better effluents. Nevertheless, in view of recent English work on open filters through which raw sewage is allowed to trickle continuously, and in the light of some of the writers' own experiments, it can not be conceded that the universal necessity for anaerobic treatment has been clearly proved. Even if the need for some such process be granted, its combination with aerobic action in the same filter must be regarded as of doubtful expediency. As Rideal says, "In methods involving a 'resting-full' and 'resting-empty period' there is alternate inversion of bacterial action between aerobes and anaerobes, with a disturbance of both." And again, "In ordinary bacteria beds these reactions are somewhat fortuitously reversed and confused, according to the periods of filling or rest, the fault being caused by mixing all the different bacteria in one or two large filters" (R. S. C., 1902 a). Chemically the decomposition of organic matter into free nitrogen which takes place in the contact bed seems quite ideal. Bacteriologically the combination of two diverse processes must be regarded as theoretically unsound.

Whatever may be thought of the principle of the process, its practical applicability under certain conditions has been thoroughly demonstrated. The results obtained with the famous 1-acre coke bed at Barking and with the double-contact system at Sutton have been amply confirmed. The Barking bed between 1894 and 1901, inclusive, purified 1,500 million gallons of sewage at an average rate of 0.5 for the whole period. The elaborate experiments at Manchester and Leeds showed that even strong industrial wastes could be treated on this principle. At Exeter, Yeovil, Barrhead, Oldham, and Burnley contact beds are being regularly operated with success.

That the double-contact process may yield effluents as good as those obtained from sewage farms in actual operation is indicated in Table XXXIX, which presents data obtained by two river conservancy boards in the examination of a number of plants. No distinction has been made as to methods of preliminary treatment. All the contact beds and most of the land areas receive septic or chemical effluent. The Mersey and Irwell standard is 1.4 parts per million of albuminoid ammonia and 14 parts of oxygen consumed. The Ribble standard is 1 part of albuminoid ammonia and 20 parts of oxygen consumed.

TABLE XXXIX.—*Comparison of contact treatment with irrigation and sand filtration, Mersey and Irwell and Ribble watersheds (R. S. C., 1902 b).*

District.	Disposal on—	Number of samples.		Per cent of samples below standard.
		Above standard.	Below standard.	
Mersey and Irwell	Contact beds	8	22	73
	Land	55	178	76
Ribble	Contact beds	16	22	58
	Land	88	207	70

German investigations have similarly shown at Hamburg (Dunbar and Thumm, 1902), at Berlin (Bruch, 1899), at Stuttgart (Schury, 1905), and elsewhere that a clear nonputrescible effluent may be obtained by the contact method.

Whether preliminary septic treatment is necessary before contact filtration must be decided by local conditions in the individual case. English opinion strongly inclines to the view that it is generally advisable. The consensus of evidence given before the royal sewage commission indicated that "crude sewage causes so serious a loss of capacity in contact beds as to require preliminary sedimentation and generally septic treatment as well" and that the use of the septic tank "greatly assists the life of the beds by preventing their becoming choked by the accumulation of mineral and indigestible fibrous matters" (Dibdin, 1903). The Leeds experiments certainly showed that the crude sewage of that city could not be treated successfully. At London, Birmingham, and Manchester the conclusion has been reached that septic treatment is desirable. It must be remembered that sludge is produced in the septic tank, the disposal of which must be balanced against the renewal of contact beds. The cleaning of contact beds is of course much more difficult than the emptying of a septic tank. On the other hand, the sludge produced in the beds is probably less in amount and of a less offensive character than that which accumulates in the tank. Furthermore, it has been suggested that septic treatment under certain conditions may interfere with the course of the later biological process. At Hamburg it was found that while contact beds could handle six doses a day of raw sewage only two doses of septic effluent could be applied, a third dose producing a dark and malodorous effluent (Dunbar and Thumm, 1902). Chemical treatment also interfered with the process, as shown in Table XL.

TABLE XL.—*Results of contact treatment of crude sewage and chemical effluent (Dunbar and Thumm, 1902).*

Precipitant.	Oxygen consumed in 10 minutes' boiling (parts per million).	
	Applied liquid.	Contact effluent.
None	102	27
Lime	69	51
Lime and iron	69	53
Iron	72	19

PURIFICATION OF SEWAGES BY A CONTINUOUS TRICKLING PROCESS OVER COARSE MATERIAL.

At about the same time that the system of contact treatment was worked out the foundations were laid for the development of another method of purification by rapid filtration through coarse material under wholly aerobic conditions. In modern filters of this type the supply of oxygen is maintained and the flow slackened sufficiently to permit purification by applying the sewage in a fine, continuous spray, and the beds are termed sprinkling or trickling filters. The early Lawrence experiments on the filtration of sewage "through clean gravelstones larger than robins' eggs" (Mills, 1890) furnished the first suggestion of such a process. In 1892 Hazen started a filter of one-fifth-inch material which received four doses of sewage a day and was artificially aerated. The rate was increased from 0.14 at the start to 0.48. The surface clogged badly, but the effluent was good, showing 30 parts per million of nitrates. In 1892 Lowcock, at Malvern, England, constructed a gravel filter with a sand layer on its surface and filtered chemical effluent at a rate of nearly 0.3 million gallons per acre per day, forcing air under pressure into the middle layer of the bed. A good effluent was obtained and the filter was operated for fifty-one days without rest (Lowcock, 1894). Similar filters were later constructed at Wolverhampton and at Tipton (Rideal, 1901). At both places ordinary trickling filters have since been installed (R. S. C., 1902 a). In the United States Waring was attempting at the same time to use the principle of forced aeration. He obtained a patent on his process as early as 1891 and carried out a series of experiments at Newport in 1894 on "the mechanical straining out of all solid matters carried in suspension in sewage and their subsequent destruction by forced aeration and the purification of the clarified sewage by bacterial oxidation of its dissolved organic matter in an artificially aerated filter." Straining through broken stone removed 40 per cent of the nitrogenous matter in the sewage, and it was concluded that "if the thick sludge is removed and the upper 6 inches of the filtering bed opened up by raking or plowing after the filter is drained an aeration period not exceeding five days is sufficient to quite restore the strainer to its original efficiency." Waring says further that "the sewage, instead of passing through the filter in a solid column, as in the former case, trickles down in a thin film over the surfaces of the particles of coke or other filtering material, while through the voids between the particles and in immediate contact with the trickling films of liquid a current of air is constantly rising, being introduced at the bottom of the tank by a blower." It is stated in the report of these experiments that the aerators removed "over 95 per cent of the organic nitrogen of a strainer effluent applied at a rate of at least 800,000 gallons per acre per day" (Waring, 1895).

Waring's principle of oxidation was undoubtedly correct; but the method of forced aeration is of more doubtful expediency. For the complete oxidation of various organic compounds Dibdin (1903) calculates that an amount of oxygen equal to from two to four times the weight of their total carbon would be required. This means with an average sewage a supply of 5 to 10 liters of air to a liter of sewage. The difficulty of maintaining such a supply of air by forced aeration is manifest, and the plants actually installed on the Waring plan have not generally operated with marked success. The best example of the process is that at East Cleveland. Here the beds speedily clogged when treating raw sewage, although since the installation of a septic tank for preliminary treatment they have worked better. The engineer of the Ohio State board of health says of this plant: "When visited in winter the surfaces of the aerators were frozen and they were out of service, the sewage being passed through septic tanks and primary and secondary filters only. It is said to be practically impossible to clean the surface of the aerators during cold weather, but on account of the rapid rate of filtration these filters rapidly accumulate solid matter on their surfaces and need frequent cleaning" (Pratt, 1905).

A practically successful solution of the problem of aeration has been reached along another line, and depends on the supply of sewage, continuously or at very frequent intervals, in small amounts distributed evenly over the whole area of a filter. Under such conditions the sewage trickles in thin films over the surface of the filling material, while the spaces between are continually filled with air, the oxygen content of which in practice does not become seriously exhausted (R. S. C., 1902 a). The air supply under the best conditions may amount to five times the volume of sewage. The material over which films of sewage continuously trickle supports an active growth of micro-organisms. The condition is analogous to the cultivation of acetic-acid bacteria in the process of vinegar manufacture by the flow of alcoholic liquor over shavings. The complications introduced by "a series of compensating errors of surfeiting and starvation" are exchanged for a simple and constant condition. Under the name of the trickling filter, the percolating filter, the "intermittent continuous" filter, the sprinkling filter, etc., this process has come nearer than any other to realizing the ideal conditions for rapid purification.

The first description of a method for sewage treatment based on the plan of trickling over coarse material with natural aeration was published by Stoddart in 1893. In the next year the same investigator exhibited a model at the Bristol meeting of the British Medical Association in which sewage and other liquids were discharged in drops over a filter of coarse chalk. A solution of ammonium sulphate containing 140 parts per million of nitrogen was almost perfectly nitrified at a rate of 11.6 million gallons per acre per day. Sewage was completely nitrified at a rate of 1.2 and well purified at 5.8 (Dibdin, 1903). Nitrification was found to increase with the depth of the filter. The first working filter actually constructed by Stoddart was installed at Horfield in 1899. Its efficiency under various conditions of flow is indicated in Table XLI.

Table XLI.—*Results of purification by Stoddart trickling filter at Horfield, England (R. S. C., 1902 a).*

Conditions.	Rate (million gallons per acre per day).	Material.	Analyses (parts per million).				
			Nitrogen as—			Oxygen consumed in 4 hours at 80° F.	Suspended solids.
			Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.		
Exceptionally strong sewage.	3.4	Sewage	426	113	0	330	....
		Septic effluent	119	9.1	0	50	....
		Trickling effluent	74.2	3.1	21.4	21	....
Dry-weather flow	8.2	Sewage	80.5	10.7	0	77	300
		Septic effluent	31.8	3.8	0	17.4	45.6
		Trickling effluent	15.2	1.1	25.7	7	0
Wet-weather flow	10.5	do	1.6	.4	18.1	....	0

The same principle was independently worked out by Corbett, the borough engineer of Salford, in a series of experiments begun in 1893 under the inspiration of the work of the Massachusetts State board of health. He first used wooden troughs for distribution and later fixed sprinklers, obtaining excellent results in the latter case. Ducat, another pioneer in the development of the trickling filter, urged the importance of thorough aeration, building filters with open sides to attain that end, and maintained that the aerobic process alone was entirely competent for the treatment of crude sewage. He installed a small filter at Hendon in 1897.

Finally, in connection with the development of this process, should be mentioned Scott-Moncrieff, who carried its principles to a logical extreme in a series of experiments at Ashtead in 1898. He believed that several different types of organisms were concerned in the purifying process and that their separate and successive cultivation under perfect aerobic conditions would give the most favorable results. He therefore constructed a series of nine trays of 1-inch coke, each 2 by 7 feet by 7 inches deep, arranged one over the other, with a space of 2 inches between each pair. The effluent from a "cultivation tank" was discharged on the upper tray by a tipping bucket at a rate of 1.3 million gallons per acre per day (0.14 on the whole area of nine trays), and its passage through the series occupied from eight to ten minutes. The degree of purification attained, as indicated in Table XLII, was extraordinarily high.

TABLE XLII.—*Results of trickling filtration through Scott-Moncrieff's trays (Scott-Moncrieff, 1899).*

[Parts per million.]

Effluents of—	Nitrogen as—				Oxygen consumed in 4 hours at 80° F.
	Free ammonia.	Albuminoid ammonia.	Nitrites.	Nitrates.	
Cultivation tank	103	12.3	0	1.2	98.4
First tray	86.5	10.3	9.9	1	66.9
Second tray	74.2	8.2	9	4.8	57.7
Third tray	41.2	4.9	7.8	18.7	44.9
Fourth tray	33	2.9	6.6	27.6	17.3
Fifth tray	12.4	1.2	4.8	46.8	12.8
Sixth tray	14.4	2.9	5.1	44.2	15
Seventh tray	2.9	2.5	0	66	7.6
Eighth tray	1.7	5.3	0	73.2	4
Ninth tray	2.1	4.9	Slight tr.	90	5.9

A plant of this type has been installed at Caterham Barracks, where it handles daily 16,000 gallons of very strong sewage at a rate of 0.4. Oxygen consumed is reduced from 92 to 27 parts per million, free ammonia from 149 to 50 parts, and organic nitrogen from 27 to 7 parts, with a formation of 90 parts of nitric nitrogen (Rideal, 1901). The German commission on its visit to England in 1902 reported that the effluent from this plant was stable, although it contained 68 parts per million of nitrogen as free ammonia, 5.8 parts of organic nitrogen, and 51 parts of oxygen consumed (Bredtschneider and Thumm, 1904).

It is not clear that there is any such complex division of labor between various classes of nitrifiers as Scott-Moncrieff postulates. Whether any important advantage is to be gained by dividing a trickling filter into layers with air spaces between has never been definitely determined. At Salford Corbett found no gain from dividing his filters into three or four successive heights of 20 inches each (Rideal, 1901).

The general practice is to construct trickling filters in single beds, which are merely heaps of the selected filtering material. It is not necessary that such a filter should be tight as long as its bottom is built with sufficient slope to carry off the effluent. It is desirable that it should be underdrained in some way in order to avoid clogging and to maintain a good air supply, passing upward, chimney fashion, through the filter. In some cases tile drains are so arranged as to form practically a false floor. The walls of the Ducat filter are built of open drain pipe inclined upward and connected with aerating drains at intervals in the body of the bed. The Whittaker-Bryant filters at Accrington and elsewhere are octagonal in shape, with walls of open brick and central open-brickwork aerating wells. Both these types are costly (Kinnicutt, 1902). Filters may be constructed more simply by merely surrounding the filtering material with a fence of upright palings. The Stoddart filter is a heap of coke or cinders of this sort on a sloping floor without any walls. The two quarter-acre trickling beds now in operation at Birmingham are essentially of this type (Watson, 1903). The oldest of these beds was built of slag graded upward from one-half inch to three-fourths inch, heaped up without underdrains, the outside being held together by iron bands. More recent filters are of one-half to 3 inch broken brick underdrained by a false floor of tiles.

The most difficult point in the construction and operation of the trickling filter is the distribution of the sewage over its surface. The ideal condition for aeration would be the discharge of sewage in a fine and even spray over the whole surface of the filter. On the other hand, there is some evidence that a too regular distribution favors alien growths, which clog the surface of the filter. Scott-Moncrieff and Ducat originally used tipping buckets and troughs placed at intervals over the filter, relying on the dash to distribute over intermediate areas. This plan has been tried at Hendon and Leeds. At the other extreme in principle is the Stoddart distributer as used at Horfield. It is practically a series of channels, over the sides of which the sewage overflows continuously, dripping from a series of points on the under side, 360 points being allowed to a square yard. Theoretically this should secure a very even distribution; but such channels are liable to buckle and it is difficult to keep them level. Furthermore, they are liable to clogging from fungous growth (Barwise, 1904). A more practical method than either the tipping bucket or the Stoddart drip distributor is the method of distribution under pressure through perforated pipes. This was developed at Salford after various other attempts with troughs and with a thin layer of sand laid over the surface of the main filter. Disk-like caps were placed over the openings of the pipes in some early experiments in order to secure a good spray for distribution. Then the attempt was made to get a spray by the impact of two converging flows, and finally a special form of opening was designed to give a rotating movement to the stream. This system is in use on the new filters at Birmingham and works well when good pressure is available (Baker, 1904). Barwise (R. S. C., 1902 a) describes the use in Derbyshire of fixed perforated pipes with metal disks placed over the outlets for spraying, dosed intermittently by automatic flush tanks. The same principle is used at Chesterfield. At Accrington intermittently operated fixed sprinkler pipes gave poor results in some preliminary experiments (Bredtschneider and Thumm, 1904).

Many plants in England are equipped with still more complex revolving sprinklers operated either by the pressure of their own jets or by mechanical power. The Candy-Whittaker sprinklers at Accrington are of the former type. With this filter, as well as with that of Ducat at Leeds, it was thought that it would be of advantage to warm the sewage before applying it, and the temperature was raised about 4° by the steam of the pulsometer used for pumping. The heating seems of little advantage, and at Leeds was found actually harmful, since it promoted surface growths which tended to clog the filter. All revolving sprinklers require much attention to keep them in operation and are subject to grave derangement from weather conditions. Daily cleaning with brushes is necessary with many plants to prevent serious clogging of the openings. Even more elaborate than the ordinary revolving sprinklers is the Scott-Moncrieff distributor installed at Birmingham, in which a radial trough revolves about an axis at the center of the bed, its outer end resting on a moving wheel, sewage running in a thin film over a weir which extends for the length of the trough.

With regard to depth and material in trickling filters there may be considerable latitude. In a series of experiments at Salford, analyses from which are quoted in Table XLIII, no better results were obtained with an 8-foot filter than with one only 5 feet deep.

TABLE XLIII.—*Efficiency of trickling filters of different depths at Salford, England (Bredtschneider and Thumm, 1904).*

[Parts per million.]

	Suspended solids.	Oxygen consumed in 4 hours at 80° F.	Nitrogen as—	
			Free ammonia.	Albuminoid ammonia.
Raw sewage	280	58	19.8	5.1
Chemical effluent	40	42	16.5	4.5
Roughing filter	20	40	16.5	4.3
Trickling filter effluent (5-foot)	0	6.5	5.3	2.1
Trickling filter effluent (8-foot)	0	5.5	4.9	1.6

Bell testified in 1902, apparently with regard to the same filters, that the oxygen-consumed value for the 8-foot filter was 12, against

15 for the 5-foot bed. He considered this difference too little to pay for the increased depth (R. S. C., 1902 a). Whittaker, on the other hand, reports much better results with beds 9 feet deep than with a depth of 4 feet 8 inches (R. S. C., 1902 a). Probably 4 feet is the safest minimum, and greater depths are desirable because of the danger in shallow filters that streams of unpurified sewage may pass through channels, due to irregular packing of the material. Ducat recommended a depth of 5 feet when the effluent was to be discharged into brackish water, 8 feet for discharge into rivers, and 10 feet for small streams. The period of flow through trickling beds varies, at Leeds, from two or three minutes with very coarse beds up to thirty minutes with fine material.

It is probable that there is a maximum amount of organic matter present in sewage which can be easily nitrified by the trickling process, and that additional action does not produce results commensurate with the cost of deep single filters or of double and triple beds. Thus at Leeds it was found that the rate of improvement in the effluent of three successive beds rapidly decreased, as shown in Table XLIV.

Table XLIV.—*Efficiency of trickling filters at Leeds, England (Dibdin, 1903).*

[Parts per million.]

	Total solids.	Suspended solids.	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
			Free ammonia.	Albuminoid ammonia.	
Sewage	1,760	631	27.6	12.2	127
Effluent No. 1	1,250	275	18.5	7	62.5
Effluent No. 2	1,060	113	13.3	5	39.6
Effluent No. 3	1,010	110	9.7	3.5	27.6

With regard to the best material for the construction of trickling filters, data have been collected in a number of the English experiments. At Salford slag was found somewhat better than polarite, gravel, coke, or clay (Bredtschneider and Thumm, 1904). At York a well-controlled series of investigations indicated, as shown in Table XLV, that coke and boiler slag (clinker) are slightly better than brick and blast-furnace slag.

Table XLV.—*Efficiency of trickling filters of different material at York, England (Bredtschneider and Thumm, 1904).*

[Parts per million.]

	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Albuminoid ammonia.	Nitrates.	
Raw sewage	13.9	0	82.9
Broken-brick effluent	1.4	18.4	10
Blast-furnace slag effluent	1.2	18.8	9.6
Coke effluent	.9	23	7.1
Boiler-slag (clinker) effluent	1	22	6.9

Coal has been found especially favorable to the process. At Buxton the effluents from destructor breeze and coke showed, respectively, 0.8 and 0.9 parts per million of albuminoid ammonia and 0.8 and 0.7 parts of nitrates, while a coal filter yielded only 0.4 part of albuminoid ammonia and 3.4 parts of nitrates (Barwise, 1904). Striking differences obtained at Tipton are shown in Table XLVI.

TABLE XLVI.—*Efficiency of trickling filters of various types at Tipton, England (Barwise, 1904).*

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
	In solution.	In suspension.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Tank effluent	827	16	10.3	1.9	0	7.7
Coke-breeze effluent	840	9	7.4	1.3	3.8	5.8
Lowcock's filter effluent	807	14	2.2	.4	7.4	2.2
Garfield's coal-filter effluent	914	3	1.6	.3	8.1	2

On the whole, it seems probable that any hard, smooth material will serve well for the trickling filter. Coal is perhaps most promising, but granite, flints, gravel, and hard clinker are all suitable.

The size of material used may also be varied considerably within certain limits. The elaborate experiments carried out by Reid at Hanley, cited in Table XLVII, indicated that fragments from three-sixteenths inch up to 1½ inches yielded almost identical results (Hanley, 1904). Barwisé (1904) suggests one-eighth to one-half inch material. Among the witnesses before the royal sewage commission Garfield recommended one-sixteenth to three-sixteenths inch, Ducat one-eighth to one-half inch, Corbett three-sixteenths to three-fourths inch, Candy three-sixteenths to one-half inch for fine and three-fourths inch to 3 inches for coarse beds, Harding one-fourth inch to 1½ inches for fine and over 3 inches for coarse beds, Whittaker 1 inch to 1½ inches, and Stoddart 2 to 3 inches.

TABLE XLVII.—*Efficiency of trickling filters with material of various sizes at Hanley, England (Hanley, 1904; Wilcox and Reid, 1904).*

	Size of material. (inches).	Analyses (parts per million).					
		Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
		Dissolved.	Suspended.	Free ammonia.	Organic.	Nitrates.	
Sewage		1,250	629	17.3	6.3	0	38.5
Septic tank		1,050	44	15	2.2	0	17.3
Rectangular bed:							
Section 1	$\frac{3}{16}$ to $\frac{1}{8}$	1,120	4	.7	.2	17.5	2.7
Section 2	$\frac{1}{2}$ to $\frac{1}{8}$	1,120	3	.8	.3	17.3	2.8
Circular bed:							
Section 1	$\frac{3}{16}$ to $\frac{1}{8}$	1,120	2	.8	.2	16.6	2.4
Section 2	$\frac{1}{2}$ to $\frac{1}{8}$	1,130	14	.3	.2	15.3	2.6
Section 3	$\frac{1}{2}$ to $\frac{1}{4}$	1,130	7	.3	.2	16.2	2.5
Section 4	$1\frac{1}{2}$ to $\frac{1}{2}$	1,130	17	1	.4	16.2	3.3

The rate at which trickling filters may be operated seems generally to lie between 1 and 3 million gallons per acre per day. Ducat and

Scott-Moncrieff recommend a rate of 1.2; Barwise suggests 1.5; Watson gives the figures quoted in Table XLVIII for current English practice. Still higher figures may be attained at times. At Salford the rate, at first 3, was raised to 6 without injuring the quality of the effluent (Bredtschneider and Thumm, 1904).

Table XLVIII.—*Depth and rates of trickling filters* (*Watson, 1903*).

Place.	Depth (feet).	Rate (million gallons per acre per day).
Leeds	9	1.2
Accrington	8.5	2.3
Birmingham	5	1.2
Hyde	9	2.6
York	6.5	2.6
Rochdale	9	2.3

The analytical results produced by a number of English trickling filters are brought together in Table XLIX. It will be noticed that the process here is a true nitrification, producing considerable amounts of nitrate in the effluent. The purification is good, distinctly higher in general than that obtained by the double-contact process. The results as measured by oxygen consumed are plotted in fig. 8. The trickling effluents are in general better than those yielded by contact beds or sewage farms, if not quite equal to those produced in intermittent filtration.

Table XLIX.—*Efficiency of trickling filtration.*

[Parts per million.]

Place.	Material.	Solids.		Nitrogen as—				Oxygen consumed in 4 hours at 80° F.
		Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites and nitrates.	
Accrington [a]	Sewage				4.6		0	49.9
	Effluent				1.5		23.3	18.1
Hendon [b]	Sewage			71.6	13.2			147
	Effluent			2.5	.8		4.8	7.8
Hyde	Sewage			39.5	16.5			14
	Effluent			5.1	1.6	12	13.7	16.3
Leeds [c]	Sewage	1,120	187	21.2	5.1			57.5
	Effluent	1,000	80	8.1	[d] 1.3	7.8		[d] 9.8
Do. [e]	Sewage	1,110	229	21.7	5.4			59.7
	Effluent	1,010	110	6.2	[d] .9	9.6		[d] 8.4
Do. [f]	Sewage	1,850	768	33.9	12.8			114
	Effluent	1,020	0	11.7	1.4	4.5		[d] 10.1
Do. [g]	Sewage	1,820	850	32.8	12.6			141
	Effluent	986	Trace.	1.9	.5	12.1		[d] 3.4
Do. [h]	Sewage	1,470	486	23.5	9.4			116
	Effluent	979	81	3.2	1.3	6.2		12.1
Wolverhampton [i]	Sewage			47.1	3.3	1.4		43.3
	Effluent			23.8	.6	16.4		3.6
York [j]	Sewage	840		31.8	5.9	0		42
	Effluent	719		2.1	.6	113		6.6

[a] Thermal aerobic filter, September 19 to October 19, 1898, receiving septic effluent (Rideal, 1901).
[b] Ducat filter, October 14, 1898, receiving crude sewage; single analysis (Rideal, 1901).
[c] Whittaker bed No. 1, March 9, 1899, to May 8, 1900, receiving septic effluent (Martin, 1905).
[d] Analysis made of the rough settling of suspended solids.
[e] Whittaker bed No. 2, September 2, 1899, to January 30, 1900, receiving septic effluent (Martin, 1905).
[f] Ducat filter, March 29 to April 30, 1900, receiving crude sewage (Martin, 1905).
[g] Ducat filter, June 13 to July 7, 1900, receiving crude sewage (Martin, 1905).
[h] Leeds filter, December 13, 1900, to January 14, 1901, receiving crude sewage (Martin, 1905).
[i] Coal filter, January 1896, to September, 1898, receiving chemical effluent (R. S. C., 1902a).
[j] Septic effluent.

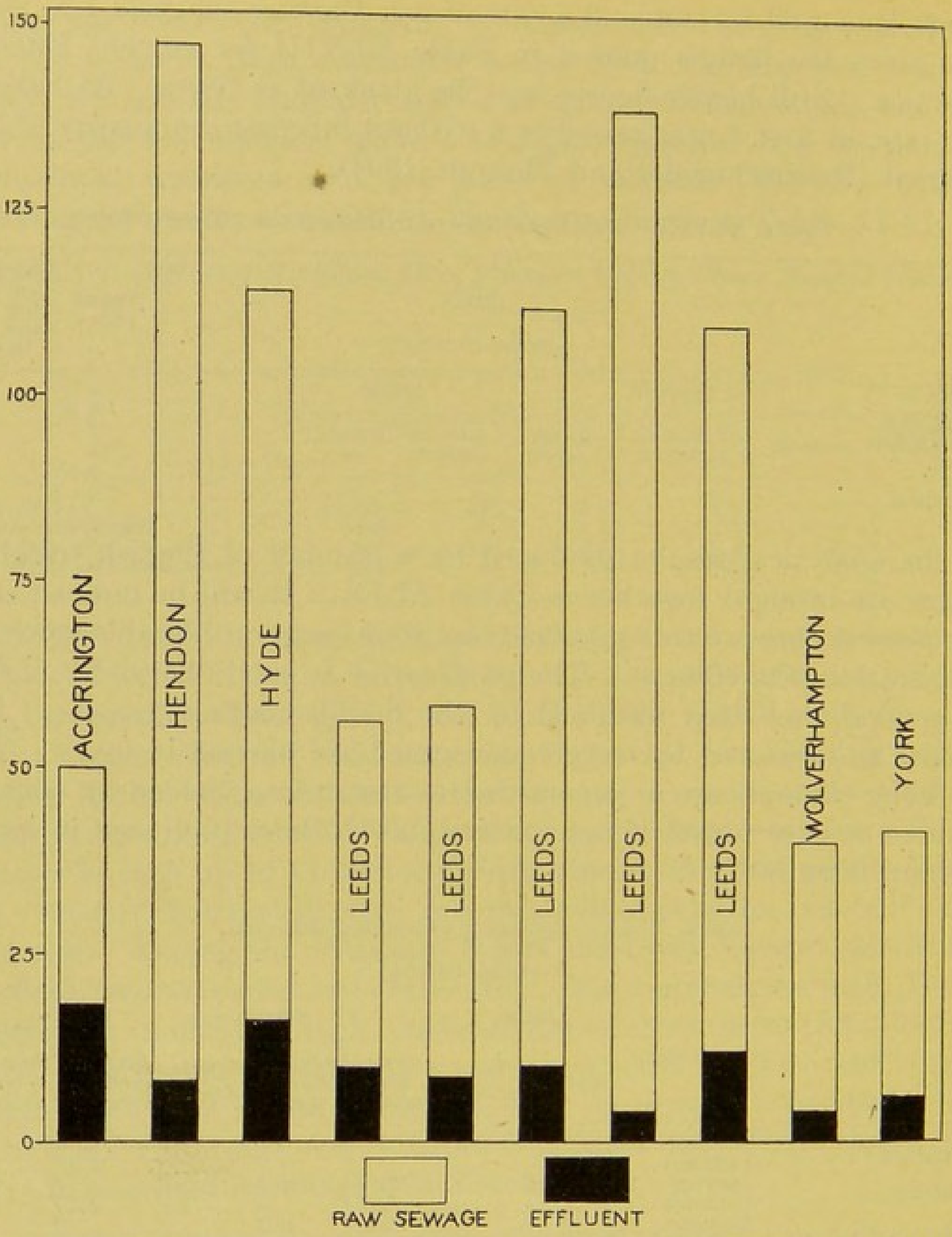

FIG. 8.—Comparison of sewages and effluents from trickling beds, showing oxygen consumed, in parts per million.

Barwise (1904) gives a number of analyses of effluents covering shorter periods, which are summarized in Table L.

TABLE L.—*Analyses of trickling-filter effluents (Barwise, 1904).*

Place.	Rate (million gallons per acre per day).	Analyses (parts per million).		
		Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
		Albuminoid ammonia.	Nitrates.	
Chesterfield	0.5	0.6	19.3	....
Burton	.5	.4	8.7	....
Langwith	1	.2	4	0.3
Chesterfield Borough	1	.5	18	.1
Long Eaton	1	.7	6	.1
Buxton	1	.2	2.5	.1
Dronfield	1	.2	13	.7

The effluent of the trickling filter contains, as a rule, a certain amount of flocculent organic matter which mars its appearance, but this matter has been more or less completely oxidized and is of a stable, humus-like character. The effluents look worse and keep better than would be expected from their analyses. Clark has brought out this difference in a series of experiments summarized in Table LI. In each case the effluent was allowed to stand in a stoppered bottle in the laboratory, samples being withdrawn at intervals. To judge by free ammonia and oxygen consumed, both contact effluents were, at the start, better than those from the trickling filters. It was evident, however, that—

> The large amount of residual organic matter in the effluents of filters Nos. 135 and 136 had been, owing to the aerobic conditions prevailing in these filters, as evidenced by the high nitrates in the effluents, so changed by the bacteria and air that it was in a fairly stable condition. The effluents of these two filters—Nos. 135 and 136—contained dissolved oxygen; at the end of the period of experiment, notwithstanding the large amount of organic matter present, no putrefaction took place, odors did not develop, and the organic matter present remained practically without change. The effluents of filters Nos. 137 and 163 contained less organic matter than the effluents of filters Nos. 135 and 136, but were, nevertheless, in a much lower state of nitrification; dissolved oxygen either was not present or disappeared quickly, and putrefaction occurred. Instead of the amount of nitrogen present as free ammonia remaining constant, as in the effluents of filters Nos. 135 and 136, it increased. The amount of oxygen consumed, instead of decreasing, increased eventually in the effluent of filter No. 137, and the anaerobic actions in the bottles containing this effluent and the formation of gas were quite noticeable, odors developing also. [Clark, 1902.]

The suspended solids may be easily removed from the trickling effluent by a short sedimentation. When so separated they are sometimes in themselves putrescible (R. S. C., 1902 a), but usually show only a small proportion of unstable matter. At Leeds (1900) analyses of the dried sediment from a trickling-filter effluent showed the following composition: Organic matter, 31 per cent; mineral matter insoluble in acids, 19 per cent; other mineral matter, 19 per cent. The clear liquid and the suspension which comes fresh from the trickling filter are stable when the bed is operating properly.

Table LI.—*Comparative stability of stored effluents from contact and trickling filters* (*Clark, 1902*).

TRICKLING FILTER NO. 135.

Time elapsed (days).	Nitrogen as—					Oxygen consumed in 2 minutes' boiling, corrected for nitrites.	Oxygen dissolved (per cent of saturation).
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.		
		Total.	In solution.				
	Parts per million.						
0	20.1	2.3	1	51.8	0.1	24.4	34.3
7	18.2	2.2	.8	44.2	6	19.5	15.3
14	19.4	1.9	.7	49.1	1.1	20.9	9.9
21	19.4	2.1	.8	46.2	1.3	21.5	13.2
28	20.1	2	7	39.4	2	21.3	7.7

TABLE LI.—*Comparative stability of stored effluents from contact and trickling filters (Clark, 1902)*—Continued.

Time elapsed (days).	Nitrogen as—					Oxygen consumed in 2 minutes' boiling, corrected for nitrites.	Oxygen dissolved (per cent of saturation).
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.		
		Total.	In solution.				
	Parts per million.						
TRICKLING FILTER NO. 136.							
0	13.2	2.4	1.1	52.8	0.1	25.6	51.7
7	13.2	2.1	.7	50.8	1.1	19.4	15.5
14	13.2	1.9	.6	49.7	.5	18.3	5
21	13.2	1.8	.6	47.3	.2	17.1	1.6
28	13.5	1.9	.6	44	0	18.4	.3
CONTACT FILTER NO. 137.							
0	21.4	2	1.4	6.2	0.2	17.4	0
7	23.1	1.8	1.1	.1	0	22.8	0
14	23.9	1.6	.8	.1	0	24.8	0
21	26.4	1.4	.8	.1	0	23.2	0
28	26.4	1.3	.9	.1	0	23.2	0
CONTACT FILTER NO. 163.							
0	14.8	1.6	1	14.9	0.1	11.8	46.2
7	14.8	1.3	.6	6.6	0	10.8	0
14	15.1	1.1	.6	5.3	0	10	0
21	16.2	1	.6	1.6	0	9.4	0
28	17.4	.9	.4	2.5	.2	8.6	0

The trickling filter comes into direct competition with the double-contact system of sewage treatment, and it is necessary in every individual case to determine which of the two methods is most suitable. A comparison of the general features of the methods indicates that "on the whole the advantage rests with percolating filters" (Barwise, 1904). It has been pointed out (p. 73) that the trickling filter is simpler in theory, since it depends on the uninterrupted maintenance of a single process of aerobic oxidation. The construction of the body of the bed is cheaper, since the trickling filter need not be made tight and can be built entirely without walls. In operation the advantage probably rests with the contact bed, since the methods of distribution on the trickling filter, as so far developed, are expensive when working well and are liable to get out of order. Since, in principle, the operation of the trickling filter is simplicity itself, it seems that the mechanical difficulties involved should not be insuperable. The operation of trickling filters under severe climatic conditions apparently does not present serious difficulties. At Leeds winter weather produced no derangement of beds or distributors. In America the problem is somewhat more serious. The spray filters at the Columbus experiment station appeared to the casual observer (Winslow, 1905) to be working well in the severe winter of 1904–5; but it is certain that many of the complicated English distributors could never be operated in this climate.

With regard to rate and its converse, required area, the advantage is all on the side of the trickling filter. Double-contact beds 6 feet deep can not be operated at a rate over 0.5 million gallons per acre per day (calculated on the combined area of the two beds). With trickling filters, on the other hand, a rate three or four times as high may easily be attained. It was estimated at Leeds that 17 acres of trickling filters could be substituted for 165 acres of double-contact beds. With regard to the results produced, it must be concluded that the trickling effluent is generally superior to that of the double-contact bed. It is more turbid, but contains less organic matter and shows greater stability. Finally, the trickling filter is apparently not subject to so serious clogging as the contact bed. What little clogging occurs does not interfere with the capacity of the beds. Furthermore, deposits may easily be washed out of the filter, and this washing is to a great extent accomplished automatically at times of storm. It seems even possible that in some cases crude sewage may be handled by the trickling filter. Harding says:

> In the case of Leeds, I must say I do not see that there is any necessity for antecedent septic action, and if it proves practicable, as I think it will, to devise an automatic screening apparatus to take off the grosser solids, I think it would be possible to put crude sewage with finely divided solids direct upon a continuous filter and then have a settling tank at the end of the process, instead of at the beginning, or if the land is available, as it would be probably for the Leeds works, pass it overland for the purpose of mechanically separating—filtering—the suspended solids. [R. S. C., 1902 a.]

As evidence against the trickling process it should be noted that at Belfast Letts obtained very poor results with the trickling filter when filtering septic effluent. He used the Stoddart distributer, and his bed was 3 feet 9 inches deep, filled with 6-inch clinker. The purification was less than that obtained in parallel experiments at lower rates with a single-contact bed (Martin, 1905). The large size of the material used and the poor distribution seem to have vitiated this experiment. At Manchester a Stoddart filter of coarse clinker 2 to 3 inches, dosed with septic effluent, was tested in 1900. The effluents were of fair quality, but so turbid as to require settling (Manchester, 1901). Again, in 1902 a desultory experiment was made by dosing a second-contact bed with a sprinkler and leaving the outlet open. The secondary bed received six fillings a day, each occupying about an hour, so that it worked as a sort of trickling filter for a quarter of the time. A comparison of the effluent obtained in this way with that from the secondary bed operated as a contact bed showed that the latter process gave distinctly better results.

> It should be mentioned that several determinations which have been made show that there is more dissolved oxygen in the filtrate from bed D when this bed is worked continuously than when it is worked as a contact bed; there is, however, invariably more suspended matter in the former case. It is no doubt owing to this suspended matter that the percentage purification results above given are unfavorable to the sprinkler. [Manchester, 1903.]

With the exception of these incomplete and inconclusive studies, the evidence of comparative tests favors the trickling process. At Leeds the matter was studied most exhaustively. The analytical results, as indicated by the figures quoted in Tables XXXVI and XLIX, were slightly better for the trickling process than for the contact beds, with rates threefold higher. While contact beds clogged badly even with septic effluent, the trickling beds, if built of coarse material (over 1½ inches), maintained their efficiency (Leeds, 1900). At York an elaborate series of comparative experiments was carried out in 1899 and indicated a marked superiority for the trickling filter (York, 1901). The principal analytical results are summarized in Table LII.

TABLE LII.—*Results of experiments at Naburn disposal works, York (York, 1901).*

Conditions.	Material.	Rate (million gallons per acre per day).	Analyses (parts per million).				
			Total solids.	Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
				Free ammonia.	Albuminoid ammonia.	Nitrates.	
Closed septic tank and single-contact filters, August, 1899, to September, 1901	Sewage	0.5	872	33.6	5.1	....	31
	Effluent	....	571	19.7	1.8	....	11
Crude-sewage and double-contact beds, August to October, 1899	Sewage	.2	819	38	4.2	....	33
	Effluent	....	711	9.8	1.2	8.3	6.3
Ladder filter, August to November, 1899	Sewage	.4	897	38	4	0	33
	Effluent	....	950	25	2.5	0	18
Open septic tank and continuous filter, July, 1900, to August, 1901	Sewage	2.6	840	31.8	5.9	....	42
	Effluent	....	719	2.1	.6	113	6.6
Open septic tanks and double-contact beds, November, 1900, to August, 1901	Sewage	.2	876	24.7	6.3	....	42
	Effluent	....	645	4.6	.8	27.6	9.1

At Accrington trickling filters have been substituted for contact beds (Baker, 1904); and the same change is contemplated at Heywood (Bredtschneider and Thumm, 1904).

RECENT TENDENCIES IN SEWAGE-DISPOSAL PRACTICE IN ENGLAND, GERMANY, AND THE UNITED STATES.

Advances in the art of sewage disposal by processes of rapid treatment have been made almost wholly in England. It is natural that such should have been the case, since the concentration of population in that country renders some method of treatment necessary and since the lack of sandy soil makes the method of intermittent filtration impracticable. We have seen that the first steps were taken by Dibdin in the London and Sutton experiments of 1892–1896, which proved that the contact bed was capable of successfully treating sewage at high rates. Meanwhile Cameron's septic tank, installed at Exeter in 1896, was demonstrating the anaerobic process of preliminary treatment. At both Sutton and Exeter septic tanks followed by contact beds have since been installed (Baker, 1904). At London the system of chemical precipitation remains essentially as it was in 1892. The experiments carried out by Clowes and Houston in 1898–1901 led, however, to the recommendation that instead of this process there be substituted (*a*) sedimentation of mineral matter, (*b*) septic treatment in tanks of six hours' capacity, and (*c*) treatment in single-contact beds of coke 6 feet deep (Clowes and Houston, 1904).

The next important series of investigations was that carried out at Manchester. This city, the third metropolis of England, has a population of half a million and a daily flow of 42 million gallons of strong industrial sewage. Chemical precipitation was introduced in 1894, but the effluent created a nuisance in the ship canal into which it was discharged. No land was available for treatment, and in 1898 a commission consisting of Baldwin Latham, Percy Frankland, and W. H. Perkins began a series of experiments on the newer rapid methods. The first report, made in 1899 (Manchester, 1900 a), concluded that in spite of the presence of industrial wastes, the "bacterial system is the system best adapted for the purification of the sewage of Manchester." The experts believed that double-contact beds would produce a satisfactory effluent. "It may be taken broadly that in the first contact 50 per cent of the dissolved impurity is removed and that in the second contact 50 per cent of the impurity still remaining in the effluent is disposed of." They held that "in order that a bacterial contact bed may exercise its full powers of purification, it is necessary (*a*) that it should be allowed sufficiently frequent and prolonged periods of rest; (*b*) that the sewage applied to it should, as far as possible, be free from suspended matters; (*c*) that the sewage applied to it should be of as uniform a character as possible." They therefore recommended the installation of open septic tanks and double-contact beds. The secondary beds have not yet been constructed, but 46 acres of primary beds were in operation in 1904 (Baker, 1904).

The next important investigations were carried out at another great manufacturing center, Leeds. Here some experiments were made in 1870 which led to the adoption of chemical precipitation. In 1894 a special commission recommended broad irrigation, but sufficient land was not available. In 1897 investigations were begun by T. Hewson, W. H. Harrison, and T. W. Harding, and reports have been made in 1898, 1900, and 1905. It was found that the double-contact process gave good results with crude sewage and excellent results with septic effluent, but that serious difficulty was experienced in maintaining the capacity of the primary beds. Trickling filters of fine material gave good results, but clogged badly.

On the other hand, continuous filtration over very coarse material of septic effluent and even of crude sewage has given interesting and remarkable results if the solids in suspension which come out in the effluent are settled after filtration. These solids are nonputrescible, can be readily settled, and the drying does not give rise to evil odors. It would seem that the coming through of these solids, which for the most part are not further reducible and largely mineral, insures the permanence of the coarse beds.

It has been found practicable for long periods to work coarse, continuous beds 10 feet deep at the rate of 200 gallons per square yard, or 1 million gallons per acre per day, for septic effluent. At this rate results giving over 90 per cent purification are obtained after settlement of solids coming out in the filtrate; and although at this rate some of the solids are retained in the filter and there accumulate, they can be washed out by the increased flow which naturally arises with storm dilution. This possibility of dealing with storm waters is an important feature of the system.

It would seem practicable to deal with crude sewage (previously strained through several screens); but in this case a depth of 12 feet of material would be required for Leeds sewage, which is not very strong. These latter experiments have not been carried on long enough to draw from them any definite conclusions. [Dibdin, 1903.]

It was finally recommended by the Leeds experts that coarse, trickling filters be installed, either preceded by septic or chemical treatment or followed by subsequent sedimentation. Construction has been delayed on account of legal and political obstacles.

Birmingham, the fourth largest city in England, with a population of 800,000, has faced similar difficulties. The discharge of sewage into the river Tame was begun in 1852. In 1859 experiments were carried out which led, in 1872, to the installation of chemical precipitation tanks and a sewage farm. Recently a most elaborate series of large-scale experiments, unfortunately never reported in print, have been carried out by Watson, the city engineer, and have indicated the application of biological processes. In 1900 a beginning was made by converting the precipitation basins into septic tanks. The sewage is now first settled for about four hours in tanks which are cleaned once a week. Thence it passes through the open septic tanks, which have a capacity of eight hours' dry-weather flow. No sludge had been removed from these tanks after three and one-half years of operation. The septic effluent is then treated on the largest farm in England, 2,830 acres in extent, of which 1,784 acres are in actual use. The results of these various processes in 1902 are shown in Table LIII.

TABLE LIII.—*Results of sewage purification at Birmingham, England* (*Watson, 1903*).

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.	
	Dissolved.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	Dissolved.	Suspended.
Average sewage	1,280	686	39.3	14.2	7	127	60.3
Sedimentation-tank effluent	1,312	346	37.7	10.9	7.3	149	92.5
Septic-tank effluent	1,180	274	48.1	8.3	3.1	121	71.8
Average land effluent	1,010	....	1.7	.1	5.7	19	....

It is planned in the future to settle the septic effluent in Dortmund tanks and to purify it by passage through trickling beds, of which four were in operation in 1904 (Baker, 1904).

Experiments second in importance only to those mentioned have been carried out at other large cities in England. At Leicester in 1898–99 a series of investigations was made by E. G. Mawbey involving 16 combinations of detritus tanks, settling tanks, single, double, and triple contact beds, and land treatment. Most of these experiments were unfortunately of very short duration. At present the Beaumont-Leys sewage farm of 1,700 acres is still in operation, but the installation of settling tanks and single-contact beds is planned for the near future (Leicester, 1900). Huddersfield has a serious problem in the presence of large amounts of industrial waste from the scouring and dyeing of wool; but it was shown in a series of experiments carried out between 1898 and 1900 by J. L. Campbell that chemical treatment, sedimentation, and contact treatment would solve the difficulty satisfactorily (R. S. C., 1902 b). At certain hours of the day a single treatment would be sufficient, while at other times secondary beds should be used. Triple-contact beds treating crude sewage gave good purification, but clogged badly. At Oldham studies carried out by J. B. Wilkinson from 1898 to 1900 led to the adoption of sedimentation and single-contact beds (R. S. C., 1902 b). At York chemical treatment has proved unsatisfactory, and since 1899 investigations have been carried on by A. Creer, which, as shown in Table LII, indicated that septic tanks and trickling filters would best solve the problem. Large-scale experimental filters have been put in operation, but the final construction is not yet under way (Baker, 1904).

The review of existing conditions in 1904 published by M. N. Baker (1904) describes some of the most interesting plants in actual operation. At Manchester, Sutton, Exeter, Yeovil, Barrhead, Oldham, and Burnley he found septic tanks and contact filters. At Birmingham, Salford, Accrington, and York trickling filters were in operation. There is a strong general tendency to the conversion of old chemical-precipitation systems into septic tanks, except at Glasgow, where the former process is to be maintained. Sewage farming is not extending, although it has its strong advocates and many of the farms now in use operate satisfactorily. The popularity of double-contact beds, at a maximum five years ago, seems already on the wane. Trickling filters, either preceded or followed by septic treatment or sedimentation, are growing in favor (Baker, 1904).

The general progress of sewage disposal in England has been seriously checked by the local government board, which enjoys extraordinary authority over any exercise of the borrowing power on the parts of municipal corporations. The sewage of towns commission had reported in 1865 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 rivers pollution commission in its five reports from 1870 to 1874 recommended intermittent filtration as the best method for sewage treatment, with broad irrigation next and chemical precipitation last. The metropolitan sewage commission of 1882 reported in 1884 that chemical precipitation should be adopted by London and that the effluent should finally be treated on land. The local government board, on the strength of these precedents, has maintained a position of extreme conservatism, requiring, 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." The following detailed rules of the board were set forth in a circular issued in 1900: "In any sewage works three times the dry-weather flow must be treated, and an equivalent amount in addition must be provided for by special storm-water filters. Septic tanks or sedimentation basins must have a capacity equal to the dry-weather flow if followed by double-contact beds, and 50 per cent larger if followed by single-contact or trickling filters. Contact beds must not be over 4 feet deep and may receive two fillings a day, or three if automatic devices are provided. Their capacity shall be figured on an open space of 33 per cent with preliminary septic treatment or sedimentation and of 25 per cent with crude sewage. Trickling filters must be at least 6 feet deep and may operate at a rate of 1 million gallons per acre per day with crude sewage, which may be doubled with sedimented sewage or septic effluent. The effluent from either the contact or the trickling process must be subsequently treated on land, 1 acre being allowed for every 1,000 persons contributing sewage. With crude sewage on land 150 persons per acre is the limit."

In view of the experiments at London and Sutton and at Leeds and Manchester, such rules were an almost intolerable burden, and with these facts in view a new royal commission was appointed in 1898, with the Earl of Iddesleigh as chairman, to determine "what method or methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted." This commission made a first interim report of three volumes in 1901, a second on special chemical and bacteriological problems in 1903, and a third in two volumes on the treatment of trade effluents in 1903. Of a fourth report four volumes were issued in 1903 and 1904, three on the pollution of tidal waters, with special reference to contamination of shellfish, and a fourth (in five parts) on the land treatment of sewage. The first interim report of

1901 accomplished the chief work of the commission, since it contained the conclusion 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. [R. S. C., 1901.]

The conclusions of the royal sewage commission throw open the way for progress, and the developments of the next decade may be watched with interest.

On the continent of Europe progress in sewage disposal has been much less rapid than in England. Germany is ahead of other countries in this respect, but even here the problem has not pressed heavily. The population is less dense and the rivers larger than in England. The installation of purification systems was slow, and when they were found necessary land for irrigation was generally available. The knowledge of the process of sewage farming dated from a visit to England made in the early seventies by a Berlin commission headed by Rudolf Virchow, and inspiration along more modern lines has similarly come from England. In 1897 of 43 English cities with over 70,000 population 23 treated their sewage by irrigation or chemical precipitation. In Germany at the same time there were only nine cities with over 70,000 population having disposal systems, of which three were precipitation works and six sewage farms (Kinnicutt, 1898).

The most important experimental work carried out in Germany has been that of the experiment station of the Hygienic Institute of Hamburg. This was founded in 1894 to test various sewage-purification processes and placed under the charge of Doctor Dunbar as director. Experiments on the contact process were begun in 1897, and the studies at this station have done more than any others to elucidate the theory of the contact bed. The general results indicated that good effluents could be obtained from single-contact beds of fine material, but that under such conditions clogging occurred, which must necessitate the removal of the material for cleaning several times a year (Dunbar and Thumm, 1902).

Meanwhile Schweder had installed in 1897 an experimental septic tank and contact bed at Grosslichterfelde to treat part of the sewage of Berlin. A commission appointed by the Prussian ministry of the interior studied this plant in 1897–98 and arrived at the same conclusion which Dunbar had reached in the case of Hamburg (Bruch, 1899).

In 1901 the royal testing station for water supply and sewage disposal was organized at Berlin, and its annual communications since 1902 have furnished a succession of papers of the greatest value. Unfavorable results were first reported from contact beds at Tempelhof and Charlottenburg. In 1901 Zahn (1901) on behalf of the station carried out a series of investigations at Charlottenburg (Westend) which showed that nonputrescible effluents could be obtained with single contact. Experiments by Schury (1905) at Stuttgart led to similar results, septic treatment and single contact giving good results, little improved by secondary treatment. Trickling filters proved slightly better than contact beds.

The general trend of the German experimental work has till recently been in favor of single-contact treatment in beds of fine material, to be dug out and cleaned at intervals. Opinion is not favorable to the septic tank. Considerable interest has been recently manifested in the trickling filter, especially at Berlin. In spite of the great importance of the Hamburg work in relation to theoretical questions, the writers can not feel that the German experiments have furnished a fair test of the modern biological processes. It is true that German sewage is strong and contains large amounts of industrial wastes, yet in addition to these facts it seems even to local observers that the experimental filters have not been operated with the judgment and skill necessary to secure the greatest practical efficiency (Thumm, 1905).

Actual practice in Europe outside of England is still largely confined to chemical treatment and irrigation. In Germany in 1904, according to the official charts exhibited at the St. Louis Exposition, there were 254 cities with over 15,000 inhabitants. Twenty of these had no sewerage system. Of the remainder, 132 discharged their sewage into water, 84 treated it by various chemical processes, and 18 disposed of it on irrigation areas. Bredtschneider and Thumm were sent by the Berlin royal testing station and the city of Charlottenburg to study English conditions in 1903, and their report (Bredtschneider and Thumm, 1904), together with the results of the Hamburg and Berlin experiments, is likely to bear fruit in the near future. In France, too, active interest is manifested in the newer processes. A commission including MM. Calmette, Beckman, and Lannay visited England in 1900 to examine the works there in operation, and later experiments showed that the sewage of Lille could be satisfactorily treated in septic tanks and double-contact beds (Calmette, 1901).

In the United States sewage-disposal practice necessarily varies widely in different localities. New England, covered with a mantle of Glacial drift, finds the Lawrence method of intermittent filtration through sand eminently satisfactory. Following the construction of the beds at Framingham in 1889 and at Gardner and Marlboro in 1891, plants of this type have been rapidly added in Massachusetts till in 1903 there were 23 intermittent-filtration areas in the State

(Massachusetts, 1904). In Connecticut in 1902 there were nine plants in operation, all sand filter beds (Connecticut, 1903).

West of the Appalachian Mountains soil conditions change, and available areas of sand become more and more difficult to obtain. The septic tank is frequently called in to remove solids and make possible the treatment of sewage at more rapid rates. The plants at Saratoga, N. Y. (Barbour, 1905), Lake Forest, Ill. (Alvord, 1902), and Wauwatosa, Wis. (Alvord, 1902), are good examples of this type.

In the Middle West the newer biological processes are rapidly gaining a foothold.

The first septic tanks at Urbana, Ill. (1894), and Champaign, Ill., have been mentioned. Septic tanks have since been installed at Kewanee, Ill. (1898), Fond du Lac, Wis. (1901), Madison, Wis. (1901), Mansfield, Ohio (1902), and a score of other places. The construction of contact beds began about 1900 and some dozen plants are now in operation, the most important being at Mansfield, Ohio (Pratt, 1905). In 1905 there were in Ohio 32 purification plants, of which 19 were sand filters and 7 contact beds; 13 made use of septic tanks at some stage in the process (Pratt, 1905). The only trickling filter of large size is at Madison, Wis.

Most of the plants in the Middle West are small and in many cases their maintenance is grossly neglected (Winslow, 1905). The city of Columbus is the first American municipality to approach the subject with a serious intention of finding the method of treatment best suited to local conditions. Here, under the direction of Hering and Fuller, a testing station was equipped in 1904, and a force of experts, including G. A. Johnson, W. E. Copeland, and A. E. Kimberley, carried out for a year an elaborate series of experiments. The station included a laboratory, one set of open tanks for preliminary treatment, and three sets of filters, with a gallery under a frame covering for each set. The sewage, amounting to about 350,000 gallons per day, was raised by a centrifugal pump to a screen chamber with two movable screens of three-eighths inch diagonal wire mesh. Next it passed to one of the tanks for preliminary treatment. These were seven in number, each 40 feet by 8 feet, 8 feet deep at the upper end and 9 feet deep at the lower end, built of wood lined with galvanized iron. The first two tanks were called grit chambers, the sewage flowing through in about one and one-half hours. The other five tanks were either "plain sedimentation" or septic tanks, in which the sewage remained eight hours or more, the difference being that the former were emptied and cleaned whenever septic action began. In the septic tanks periods of eight, sixteen, and twenty-four hours were compared.

The sewage after treatment by one of these three preliminary processes (grit chamber, plain sedimentation basin, or septic tank) was purified by treatment in one or more of thirty-five experimental filters.

These were cypress tanks 6 feet deep; one was 11 feet in diameter, four 12 feet 10¾ inches in diameter, and the other thirty 7½ feet in diameter. They were all open filters and arranged for the most part in two blocks of two rows each, with a covered dosing and sampling gallery between the rows, in which all the engineering details of operation were regulated with the greatest accuracy. Twenty-one were intermittent sand filters, two primary and four secondary contact beds of broken limestone, two coke strainers, and six trickling filters. With this plant the widest possible series of combinations was tried, including sand filters, trickling filters, and contact beds alone, either of these preceded by plain sedimentation or septic treatment, and sand filters preceded by contact or trickling filters. The results of the experiments have led to the recommendation of septic treatment, followed by trickling beds.

> Plans of the sewage-purification work for a nominal flow of 20 million gallons per day have been presented to the State board of health. The plans propose septic tanks followed by sprinkling filters. The septic tanks will be 12 feet in depth, uncovered, and will have a capacity of about 8 million gallons. The sprinkling filters will be about 10 acres in area, of broken stone, 5 feet in depth, laid on hollow free-draining bottom, with sprinkling nozzles 15 feet, center to center, designed under a 5-foot head to spray the septic sewage over the surface of the broken stone, at a net rate of 2 million gallons per acre per day. The effluent from these filters will be collected in settling basins with a capacity of 4 million gallons. [Griggs, 1905.]

In the extreme West a third set of conditions confronts the sewage expert. The arid climate here makes the sewage of special value for irrigation and the sparseness of population renders sewage farming the most profitable means of treatment. Following the early broad-irrigation areas at Cheyenne, Wyo. (1883), Greeley, Colo. (1890), Hastings, Nebr. (1892), Los Angeles, Cal. (1892), and Trinidad, Colo. (1892), a dozen or more plants have been laid out and are in operation, the largest in 1904 being at Los Angeles, Cal., Salt Lake City, Utah, and Hastings, Nebr.

Chemical-precipitation plants, built before the newer processes were developed, are maintained at Alliance and Canton, Ohio, and at other places to avoid the cost of change. At Providence, R. I., on account of special local conditions, this process seems well adapted for continued use.

In a comprehensive review of conditions in the United States, Fuller (1905 a) states that of 1,524 cities and towns with a population over 3,000, 1,100 have sewerage systems and 90 have purification plants. Among these 90 plants are 14 irrigation areas, 41 intermittent sand filters, 13 chemical-precipitation works, 29 septic tanks, and 10 rapid filters of coarse materials. The fact that of a population of 28,000,000 connected with sewerage systems the sewage of 20,400,000 is discharged into fresh water and of 6,500,000 into the sea furnishes some indication of the problem which must be met in the near future.

EXPERIMENTS ON THE PURIFICATION OF BOSTON SEWAGE, 1903-1905.

THE SEWAGE EXPERIMENT STATION.[a]

The sewage experiment station of the Massachusetts Institute of Technology is situated in the southeastern portion of the city of Boston, near the corner of Albany street and Massachusetts avenue, at the point indicated by the star on the map (fig. 9). Connection is made with the 9-foot sewer of the Boston main drainage system at a point on Massachusetts avenue about 200 feet below the entrance of

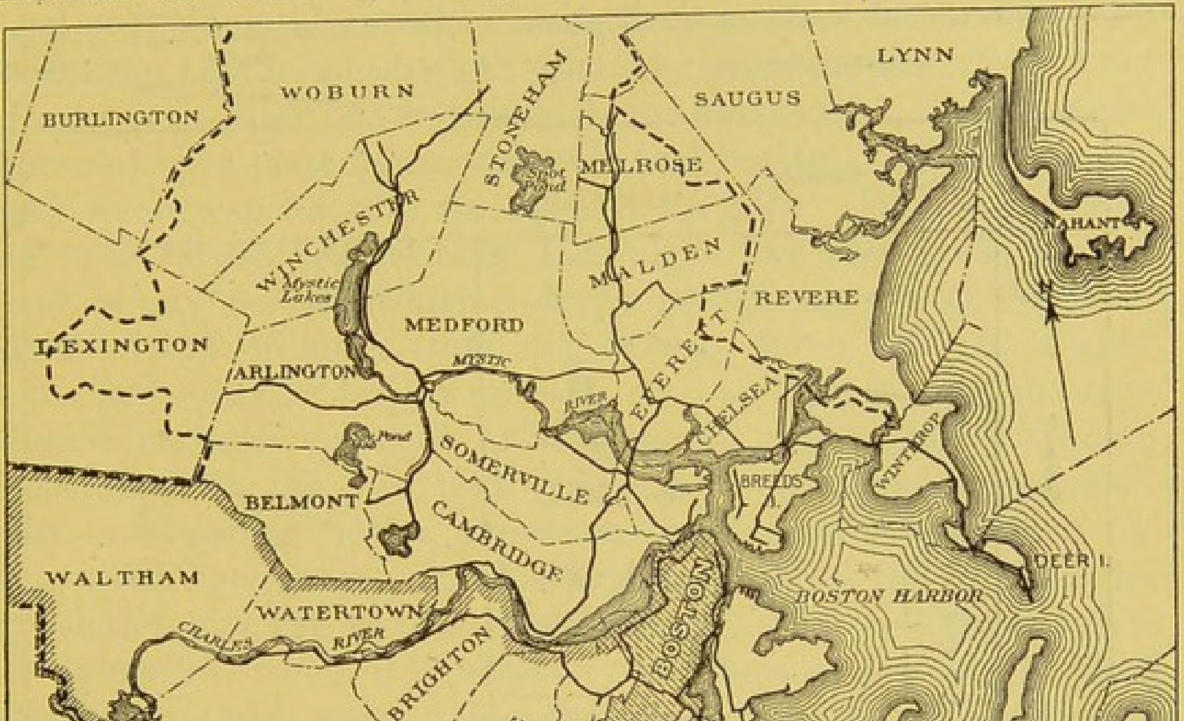

FIG. 9.—Map of Massachusetts metropolitan sewerage district.

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[a] The foundation of this station and the object of the experiments are described in the introduction (pp. 5-9).

the Albany street intercepting sewer. Prior to October 14, 1904, sewage from the whole of Boston south of the Charles, with the exception of the Dorchester and South Boston districts, together with sewage collected by the south metropolitan sewerage system from Waltham, Newton, Watertown, Brighton, and Brookline, flowed past the station intake. This contributory area is shown in fig. 9. In 1903–4 the flow above the station was more than 50 million gallons a day from a district with a contributing population of 350,000, sewered for the most part on the combined system. Since October, 1904, the completion of the new high-level sewer and of the Ward street pumping station has resulted in the diversion of all the sewage from the metropolitan district, outside of Boston proper, to the new sewer, diminishing the average daily flow past the station intake by about one-fourth. The location of the station and of the intake pipe with reference to the sewers is best seen in the accompanying ground plan (fig. 10).

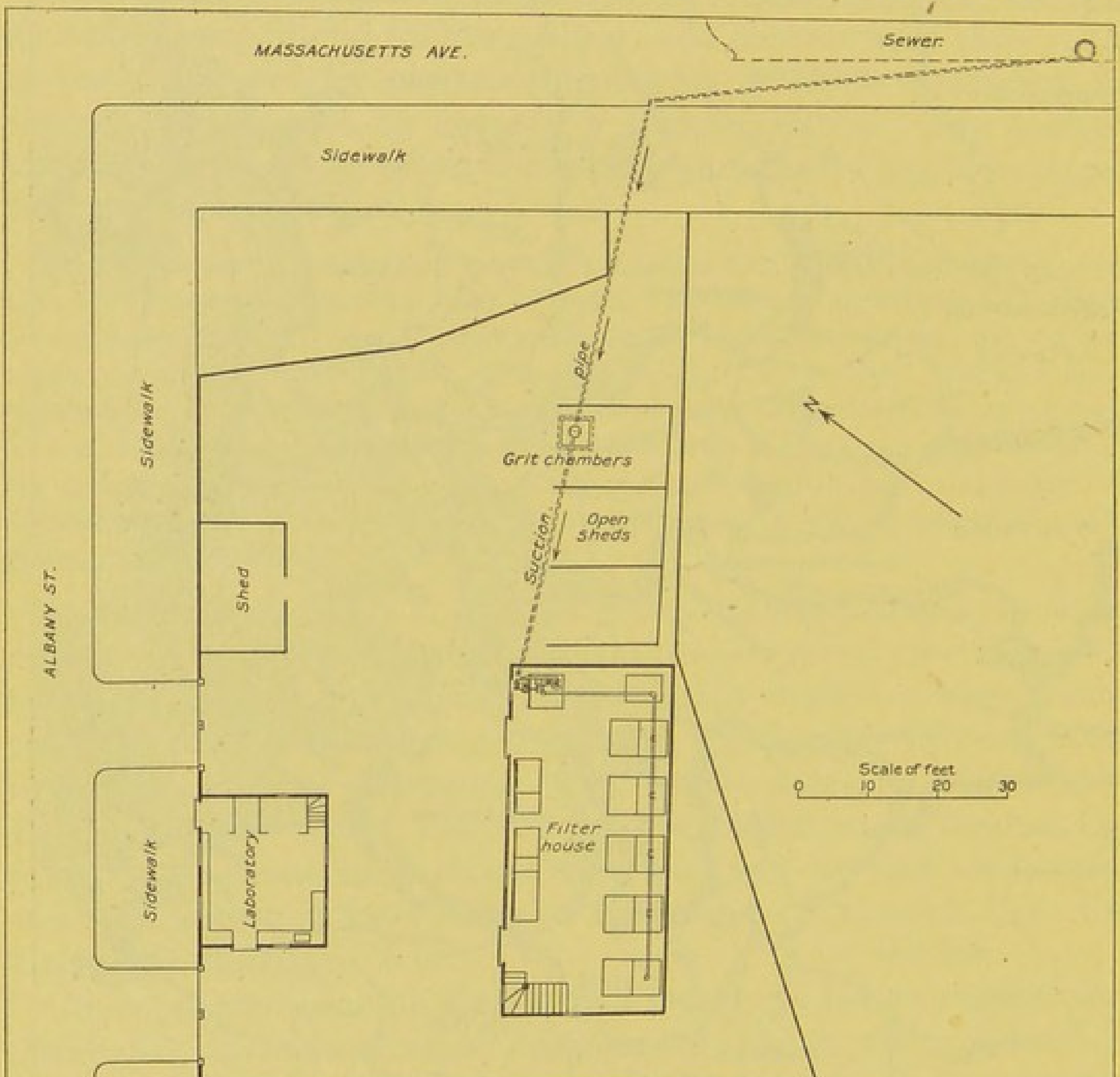

FIG. 10.—Plan of Massachusetts Institute of Technology experiment-station grounds and buildings.

A 2½-inch galvanized-iron suction pipe runs directly to the station pump from a point in one of the sewer manholes about 10 feet below the surface of the street. To the lower end of this pipe is coupled a 20-foot length of rubber suction hose of 3 inches internal diameter. This hose would reach to the bottom of the sewer in the absence of any flow, but is carried by the strong current to a nearly horizontal position at its lower end, so that it is suspended at about mid-depth. The flow is so strong that the sewage is well mixed throughout. At the end of the hose is a strainer made from a 3-foot length of 6-inch wrought-iron pipe in which eight ½-inch longitudinal slots have been cut from a point near one end through the other end. The open end is protected by a plate fastened within and having deep notches cut radially to correspond with the slots in the pipe. Such a device is found to be largely self-cleaning, allowing a free movement toward the end, of any material which is drawn lightly into one of the slots. Strainers of the ordinary type clog badly. Even with the slotted pipe the end must be hauled up each day, or oftener, and the rags and other material collected on it removed. The rubber suction pipe is joined to the iron pipe above it by a "quick-as-a-wink" coupler, a clamping device sometimes used in fire apparatus for making quick connections without screwing. With this coupler the entire suction pipe can be disconnected and hauled up without bending it—a method which it is necessary to adopt in cleaning the end at times of very high water. Just before reaching the pump the suction pipe passes through a grit chamber, where it deposits the heavier particles of sand and cinders. This chamber was put in at the suggestion of Mr. Leonard Metcalf, who furnished its design and other friendly suggestions. It consists of a cast-iron cross of stock water-pipe pattern. The diameter of the large arm, which rests vertically and constitutes the chamber, is 19 inches and its depth 16 inches. The other arm is 2½ inches in diameter and connects with the suction pipe by flanges. Blank flanges form the top and bottom of the chamber and are bolted on and made tight by rubber packing, so that the top of the chamber may be readily removed for cleaning. A vertical grating of half-inch square iron bars, placed so as to give a clear space of half an inch between them, divides the chamber into two parts and serves to retain any rags or other large material which may have escaped the suction strainer. The chamber is placed on the line of the suction pipe 8 feet below the surface of the ground and is covered by a heavy frame structure of pyramidal form, 6 feet square on the bottom. From the grit chamber the suction pipe runs direct to the cellar of the filter house. Details of the grit chamber are shown in fig. 11.

The filter house is a two-story frame structure, the interior arrangement of which is made clear in figs. 12, 13, and 14. Fig. 12 is the ground-floor plan, showing the arrangement of the filter tanks and the pump pit. Fig. 13 is a plan of the second floor, indicating the position of the supply tanks, septic tanks, and sand filters. Fig. 14 is a midsectional elevation bringing out the vertical arrangement of the various parts of the plant.

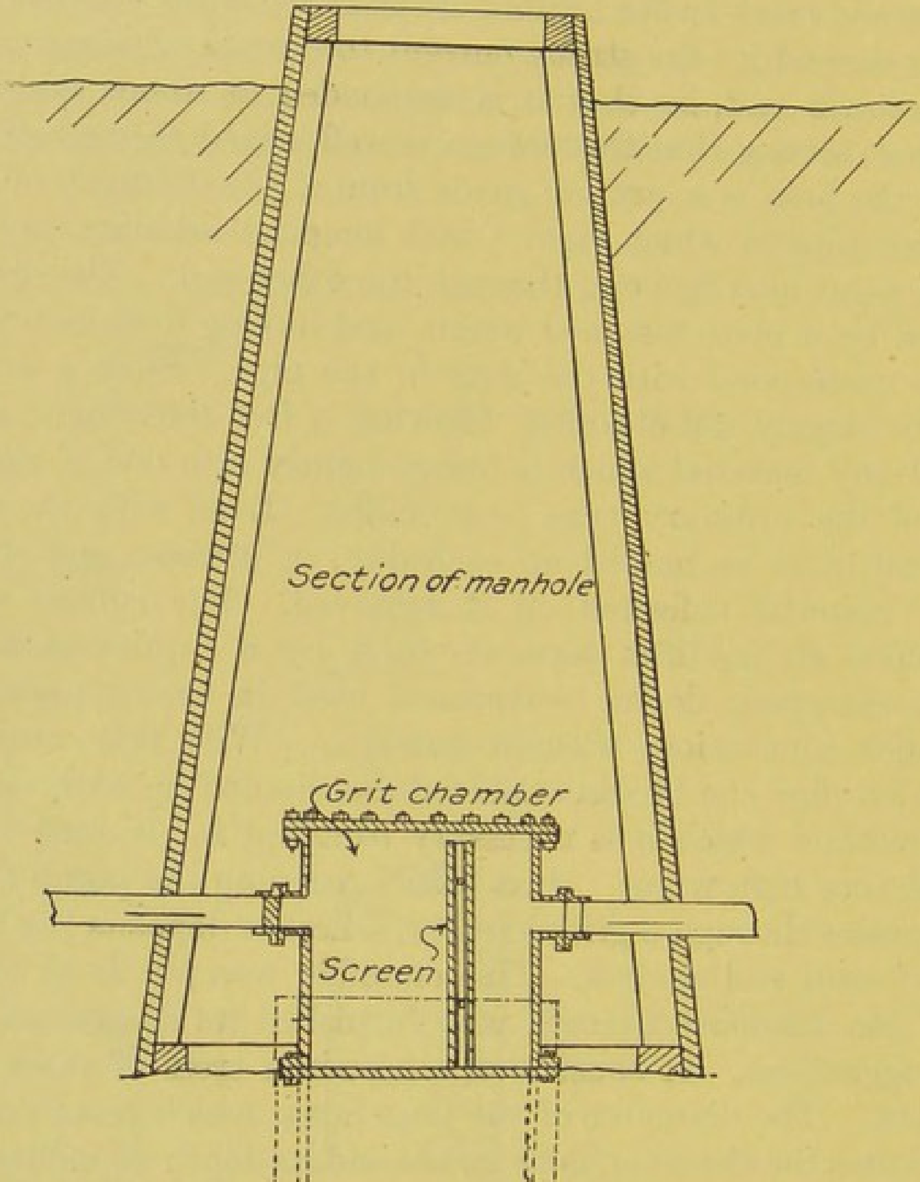

FIG. 11.—Detail of grit chamber.

The position of the pump is shown in fig. 12. It is a 4 by 6 duplex Warren power pump driven by a 2-horsepower induction motor under 110 volts alternating current of 66 frequency. The plunger is of the cup type. It is found that this form protects the composition lining of the cylinder much more perfectly than a packed plunger.

The valves are of the clapper type, with rubber packing, which is frequently renewed. The pump is placed in a pit 7 feet below the

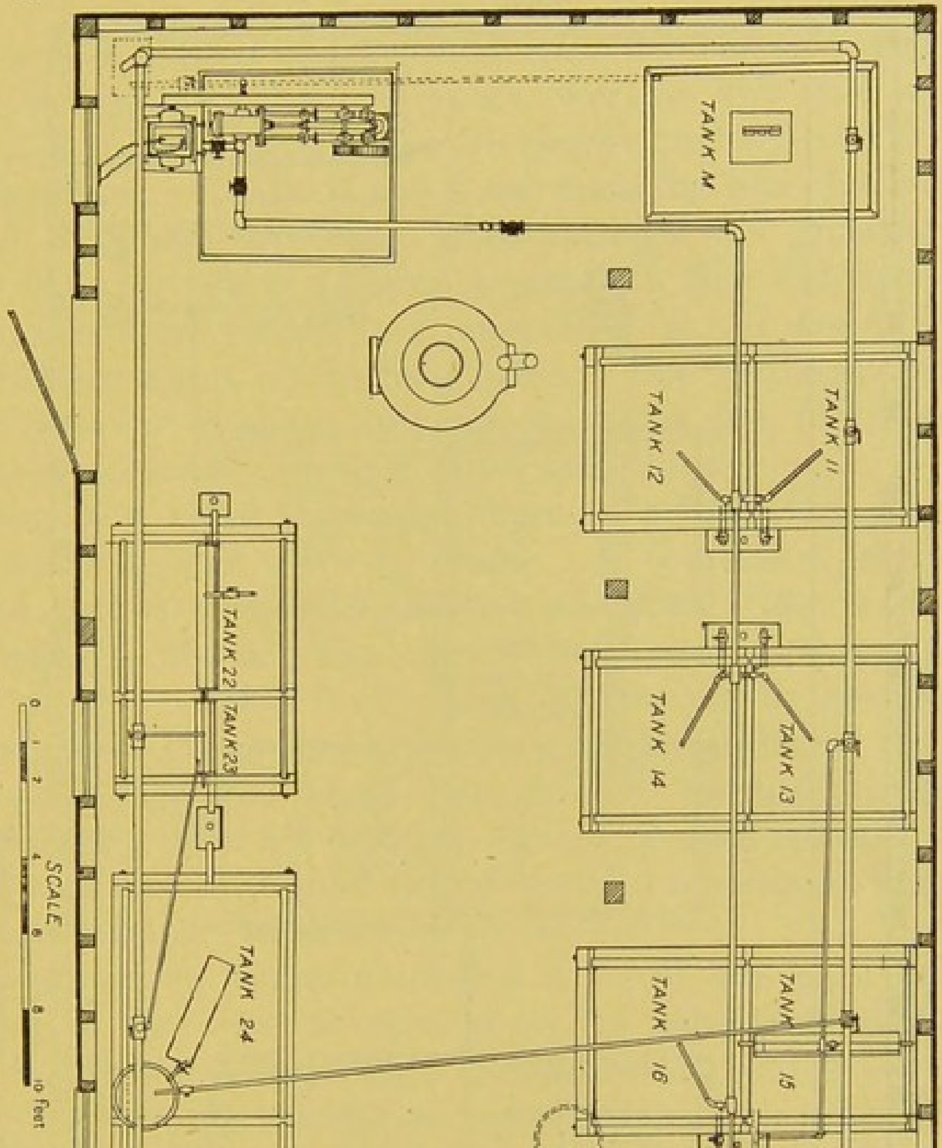

FIG. 12.—Plan of ground floor of filter house.

floor of the filter house. The total suction lift is 16 feet, reckoned from the average dry-weather elevation of the sewage surface to the pump valves. This lift may be increased to 20 feet at times of low flow. The pump is supplied with a vacuum gage, which

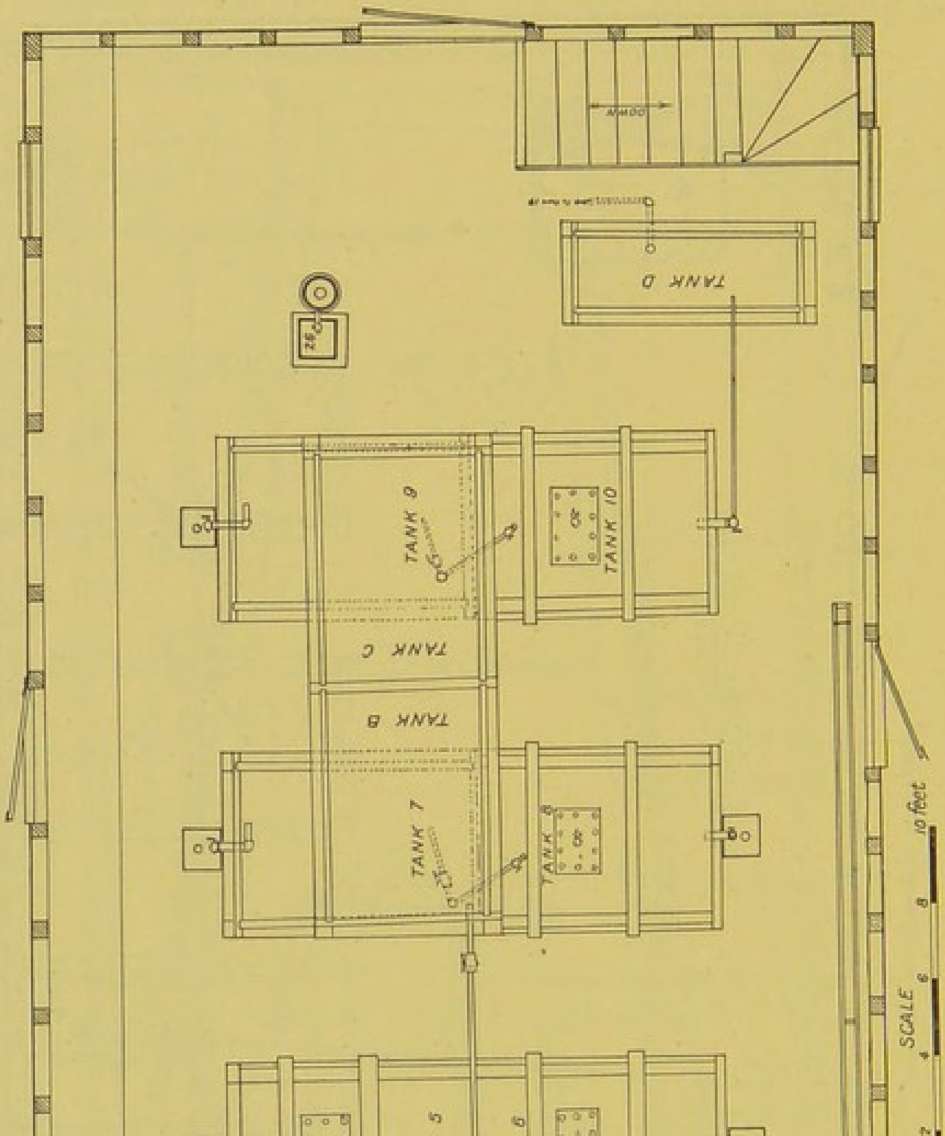

FIG. 13.—Plan of second floor of filter house.

enables the attendant to see at a glance whether or not the valves are performing their duty and whether any stoppage of the strain-

The sewage is delivered through a 2-inch force main to supply tank A, best shown in the sectional elevation (fig. 14). The lift from the pump valves to the tank is 25 feet. The supply tank is 4 by 6 feet in area and 2 feet deep. The sewage enters the tank over the side near one end, passes over the weir shown in the section, and thence through pipes to supply tanks B and C and to the various filters. Tanks B and C are each the size of A and are connected with each other by holes through the dividing partition. They serve primarily to give a constant flow through the septic tanks, which are placed at a lower level on the same floor, and to the trickling filters on the floor below. The two tanks have a combined capacity of about 700 gallons, which is a two hours' supply for the continuously working tanks and filters.

Filters Nos. 1 and 2 are sand filters. Tank No. 1 is a cypress tank 4 by 6 feet in area and 3 feet deep. It contains 2 feet of common Glacial drift sand with an effective size of 0.17 mm. and a uniformity coefficient of 3.5. This layer of sand rests on 6 inches of underdrain material graded from 4-inch cobbles at the bottom to buckwheat gravel just beneath the sand. The outlet of the filter is a 1-inch iron pipe open at all times and not trapped. Filter No. 2 is like filter No. 1 in all respects, except that it contains a layer of sand but 1 foot thick over the underdrain material. The two tanks are built together, as shown in fig. 13.

The six septic tanks, numbered 5 to 10, are also built in pairs and are of the same dimensions as the sand-filter tanks, namely, 4 by 6 feet and 3 feet deep. Tanks Nos. 7 and 9 are uncovered. The other four are covered as tightly as possible with wooden covers. These covers are not absolutely gas tight. Tank No. 6 is filled with crushed stone about 1½ inches in diameter. All the tanks and filters on this floor, except No. 10, drain into small catch basins connected with the main drainpipe underneath the floor. This arrangement is shown in fig. 14. Each drainpipe may be closed off from the main drain by a cock just above the latter and the tank effluent diverted to the filters below. Tank No. 10 drains directly into the small tank D, which is 2 by 6 feet and 2 feet deep. This is used to flood a contact filter below.

Filter tanks Nos. 11 to 16 are all cypress tanks 4 feet square and 6 feet deep, built together in pairs. Tanks Nos. 17 to 20 are of the same area, but only 4 feet deep. The pair Nos. 19 and 20 are at a higher elevation, so that their effluents can flow to the other pair, Nos. 17 and 18, respectively.

Tank No. 15 is a trickling filter, receiving the septic sewage from tank No. 5. Tanks Nos. 11 to 14 and Nos. 16 to 20 are contact filters. Tank No. 11 is filled with coke 2 to 3 inches in size; tanks Nos. 12, 15, 19, and 20 with crushed stone 1 inch to 1½ inches in size, and tanks Nos. 13, 16, 17, and 18 with one-fourth to one-half inch crushed stone. Tanks Nos. 17 and 19 constitute one double-contact system and Nos. 18 and 20 another. Tank No. 14 is the only one which has been altered during the experiments. During the first

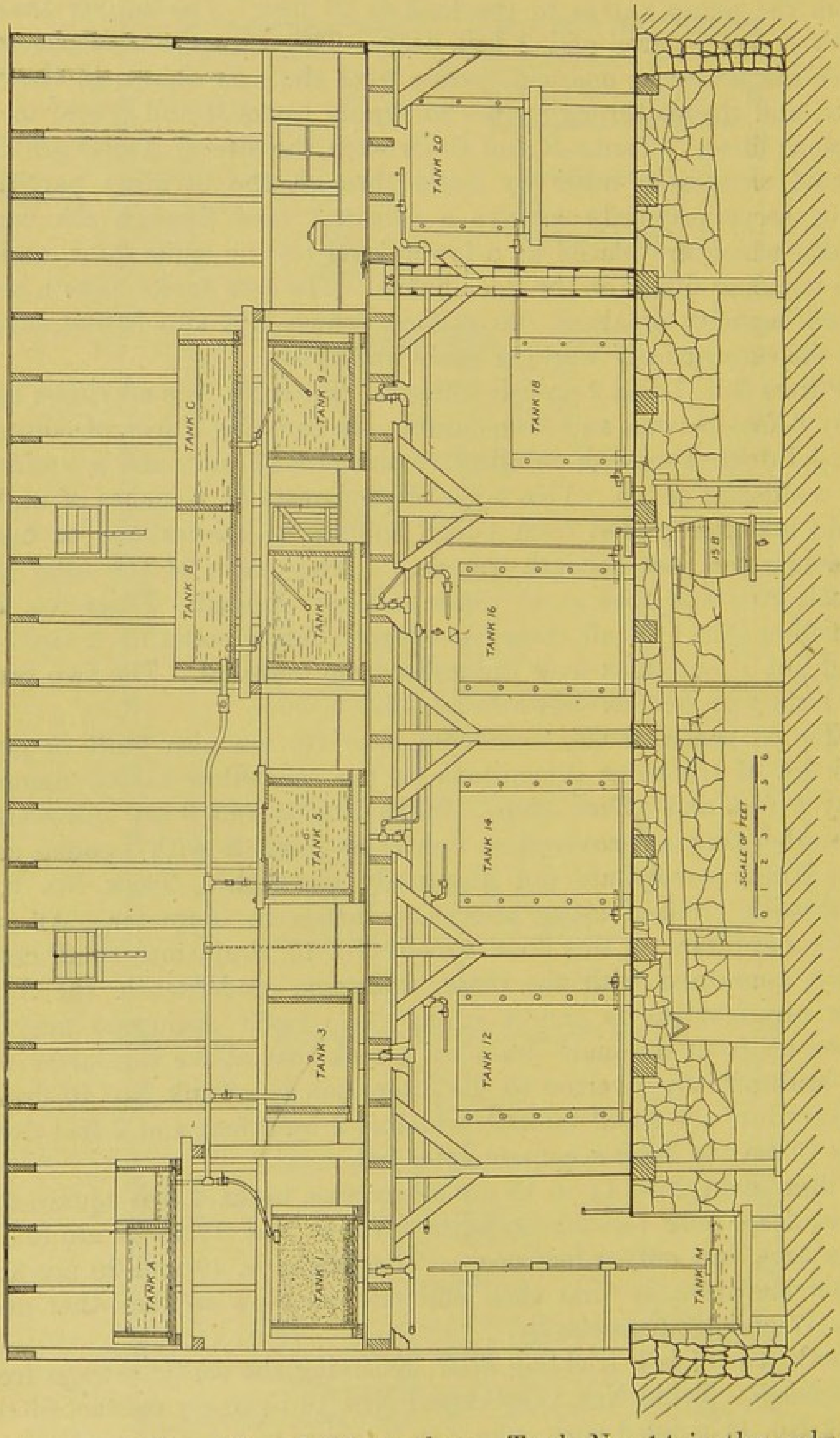

FIG. 14.—Section of filter house.

year it was filled with crushed stone between one-half and 1 inch in diameter. In June, 1904, it was emptied and filled with Raritan facing brick, 1½ by 4 by 12 inches, so laid in even tiers as to give the maximum of open space. Tank No. 22 is 4 by 4 by 6 feet, and No. 23 is 4 by 2 by 6 feet, the two tanks forming a pair. They are filled with 1 inch to 1½ inches crushed stone and are operated as trickling filters. Sand filters Nos. 24 and 25 are exact counterparts of filter No. 1. The filters on the lower floor all drain into catch basins similar to those on the upper floor already described. These empty directly into a main drain underneath the floor. In the case of filters Nos. 15 and 22 the effluent runs into a barrel provided with an overflow. These barrels provide a two hours' storage for the effluents, so that the effect of that period of sedimentation may be studied. The barrel under filter No. 15 is shown in fig. 14. Tank M is used as a measuring tank. It is fitted with a float gage, carefully calibrated, reading by means of a vernier to the nearest gallon. The principal statistics of the tanks and filters are brought together in Table LIV for convenience of reference.

Table LIV.—*Statistics of experimental tanks and filters.*

No.	Dimensions (feet).	Description.	Material.	Size.
1	4 by 6 by 3	Intermittent sand filter	Sand	0.17 millimeter.
2	4 by 6 by 3	do	do	Do.
3	4 by 6 by 3	Sampling tank		
4	4 by 6 by 3	do		
5	4 by 6 by 3	Septic tank		
6	4 by 6 by 3	do	Stone	1 inch to 1½ inches.
7	4 by 6 by 3	do		
8	4 by 6 by 3	do		
9	4 by 6 by 3	do		
10	4 by 6 by 3	do		
11	4 by 4 by 6	Contact filter	Coke	2 to 3 inches.
12	4 by 4 by 6	do	Stone	1 inch to 1½ inches.
13	4 by 4 by 6	do	do	¼ to ½ inch.
14	4 by 4 by 6	do	Stone Brick	½ to 1 inch.
15	4 by 4 by 6	Trickling filter	Stone	1 inch to 1½ inches.
16	4 by 4 by 6	Contact filter	do	¼ to ½ inch.
17	4 by 4 by 4	do	do	Do.
18	4 by 4 by 4	do	do	Do.
19	4 by 4 by 4	do	do	1 inch to 1½ inches.
20	4 by 4 by 4	do	do	Do.
22	4 by 4 by 6	Trickling filter	do	Do.
23	4 by 2 by 6	do	do	Do.
24	4 by 6 by 3	Intermittent sand filter	Sand	0.17 millimeter.
25	4 by 6 by 3	do	do	Do.

According to the plan of the experiments each unit differed from each of several other units by only one variable condition. In this way the results of the whole series may be studied together as one experiment, and it is possible to note the results of changing any one variable condition, the others being constant. Among the variables which have been studied in this way are, first, of course, the various types of purification processes and the coincident necessary variation in the rate of filtration. Then under each principal type of process two or more of the following conditions have been compared, the variables, as stated, being introduced one at a time: Different kinds and sizes of material, different depths of bed, single versus double contact, fresh versus septic sewage of different ages, and open versus closed septic tanks. With the sand filters four combinations have been studied, each differing from each of the others by only one of these variables; with contact filters, six combinations; with trickling filters, three; and with septic tanks, three, which, together with one primary comparison of the main types, makes a total of seventeen combinations of the variables mentioned.

On the sand filters Nos. 1 and 2 the volume of sewage applied has been measured by a float in the supply tank over the filter. The pump was stopped while these filters were receiving their doses. Sand filters Nos. 24 and 25 were dosed from the barrels shown in fig. 12. These barrels contain the exact amount of one dose. Sewage was distributed over the surface of the sand filters by means of small wooden troughs with side openings at intervals. Application of sewage to the contact filters was made by means of a single half-inch pipe discharging horizontally over the filter. The filling was in all cases continuous, about half an hour being allowed for the process. The amount of sewage applied to the contact filter is of course its own liquid capacity multiplied by the number of doses applied daily. To obtain this value and also to study the progressive loss of capacity of contact filters under various conditions very careful measurements of the capacity of all the filters have been made at weekly intervals. For this purpose the measuring tank M was used. Connection with the filter outlet was made by means of a rubber hose, and the total effluent of the filter was run into the measuring tank after the height of sewage within the filter had been noted.

The trickling filters were dosed by means of tipping buckets, long V-shaped troughs divided by a longitudinal partition into two equal parts. As one side fills the weight of sewage overbalances the system and the bucket tips, emptying the full side and bringing up the other side so that it receives the flow and tips in its turn. In this way the sewage is splashed in successive doses over the two halves of the filter alternately.

By connecting an ordinary cyclometer to this tipping bucket it has been possible to record the number of tips and indirectly the total flow. The apparatus was originally rated, and occasionally checked, by allowing the effluent to flow into the measuring tank for a period and comparing the readings of the cyclometer with those of the float gage.

The closed septic tanks were regulated at their outlets, free communication being allowed with the supply tanks overhead. The open tanks were maintained at a constant level by overflow pipes and were regulated at the inflow pipe. All these tanks were under the constant observation of an attendant both day and night, and the rates of flow were determined at frequent intervals by filling a 10-quart pail.

In sampling, a representative sample of the crude sewage was obtained by allowing a portion of the regular pumpage to flow slowly into a tank of 540 gallons capacity, filling the tank in about three hours during each morning. The sewage in the tank was then thoroughly mixed and sampled. Trickling effluents and sand-filter effluents were collected whenever running. Contact-filter effluents were collected at about the middle of the discharge. Analyses of each effluent were made weekly and of the sewage five times a week.

ANALYTICAL METHODS AND INTERPRETATION OF RESULTS.

In the comparison of two sewages from different localities the term "strength" is often used in such a loose way that its significance is more or less obscure. Strictly the strength of a sewage is measured by the amount of certain elementary constituents which it contains, as, for example, the amount of nitrogen present. Only cn such a basis can any fair comparison of sewages be made. The use in this connection of constituents so partial and changeable as the free or albuminoid ammonia or the oxygen consumed is misleading. These constituents are in a state of constant change in any given sewage, and hence can not satisfactorily determine its real strength. This point is well illustrated by the analyses in Table LV, taken from the reports of the Massachusetts State board of health for 1903 (Clark, 1904). The first line represents a nine months' average of weekly analyses of the Lawrence street sewage taken directly from the sewer—a fresh sewage. The second line represents analyses of the same sewage for the same period after it had been pumped through about half a mile of pipe and subjected to sedimentation and septic action.

TABLE LV.—*Comparison of fresh sewage at Lawrence with the same sewage after passing through long pipe, April to December, 1903 (Massachusetts, 1904).*

[Parts per million.]

	Nitrogen as—		
	Free ammonia.	Albuminoid ammonia.	Total organic.
Lawrence street sewage	18.1	5.8	23.4
Station sewage	39	5.2	13.3

The increase in the free ammonia and the decrease in the total organic nitrogen are characteristic of what occurs in stored sewage. Such partial values as are given by determinations of albuminoid ammonia and oxygen consumed do not, therefore, stand in any constant relation to the total figures—for organic nitrogen and carbon, respectively—and hence in different sewages give different proportions of the whole.

Total nitrogen and total carbon values are, then, to be desired in the study of sewage purification. The latter are out of the question, since there is no available method for this determination sufficiently simple for routine use. Total nitrogen values have also been generally ignored until very recently, and these experiments were nearly half completed before their paramount importance became evident. Throughout the present series of studies, therefore, the old determinations of free and albuminoid ammonia and oxygen consumed have been maintained. These must be taken for what they may be worth as roughly representative of the total organic matter.

In this connection it is useful to remember that both the free and the albuminoid ammonia in sewage increase with age, and that the ratio of albuminoid ammonia to organic nitrogen increases at a corresponding rate. In a fresh sewage the albuminoid ammonia is roughly one-third the free and the organic nitrogen generally over three times the albuminoid. As the albuminoid-free ratio decreases the organic-albuminoid ratio decreases at almost the same rate, and Fuller (1903) has found that the former ratio is roughly about one-twelfth the latter; put into algebraic form this becomes—

$$\frac{12 \times \text{albuminoid nitrogen}}{\text{ammoniacal nitrogen}} = \frac{\text{organic nitrogen}}{\text{albuminoid nitrogen}}$$

whence

$$\text{organic nitrogen} = 12 \times \frac{(\text{albuminoid nitrogen})^2}{\text{ammoniacal nitrogen}}$$

This formula is only roughly approximate, but is perhaps the best conversion formula yet devised.

The commonest method of measuring the work of a filter is by the percentage of purification obtained when the amount of some one of its constituents is compared in the crude sewage and the effluent. Dunbar and Thumm (1902) have attempted to justify this practice on theoretical grounds, claiming that percentage of purification, figured on oxygen consumed, runs parallel with keeping properties, irrespective of the original strength of the sewage. It may be assumed that some such general relation exists and that for a given process of purification on a given sewage it might be found with some degree of accuracy, but that the result is of general application to filters of all types and sewages of all kinds seems, in the absence of further evidence, improbable. Even though it may be true that a certain type of filter would produce a stable effluent by oxidizing one-half its organic matter, it does not necessarily follow that another type, working through characteristic and entirely different reactions, would produce the same result by the same percentage of oxidation. The amount of available oxygen in an effluent is also of importance in relation to its stability, and of two effluents showing exactly the same percentage of purification, one might be quite stable by virtue of its high nitrate and oxygen content and the other putrefactive owing to the absence of these substances. Such a difference is observed between effluents from a contact and a trickling filter. A contact filter running in a typical manner has already carried out during its cycle those secondary reactions by which oxygen and nitrates are used up for the oxidation of organic matter. Such an effluent is practically free from reserve oxygen and must for stability be purified to a much greater degree than would be the case with that from a trickling filter in which, by virtue of a reserve of oxygen, the oxidation may proceed after discharge.

The character of an effluent, with respect to its stable or putrescible character, is the thing of paramount importance. The effluent from a good sand filter will show so little organic matter and so high a nitrate value that there can scarcely be a moment's question about its quality after an inspection of the general analytical results. With the newer rapid processes of sewage treatment, however, effluents of such high purity are rarely obtained. In practice it is generally the aim to produce, not the best effluent possible, but merely one which can be discharged, under existing conditions, without creating a nuisance. Such a requirement may be fulfilled by an effluent containing considerable amounts of organic matter if two conditions be present: (1) A sufficient amount of reserve oxygen in the effluent to unite with all readily oxidizable organic matter and thus prevent the development of anaerobic conditions; and (2) a stability of the organic matter by virtue of which it does not readily undergo putrefactive decomposition. A measure of this quality of stability is the essential in judging of an effluent.

Endeavors have been made to develop a relation between the ordinary analytical data and the keeping qualities of an effluent. It must be confessed, however, that the determination of the oxygen consumed and of the various forms of nitrogen, while serving to identify undoubtedly good or bad effluents, fails to discriminate between a partially purified effluent which is perfectly stable and a similar one which is not. It is therefore necessary to fall back on a practical test of keeping quality as furnished by the incubator test. In this test, devised by Scudder (R. S. C., 1902 a) and since modified by others, the sample is bottled up and kept in the incubator at a warm summer temperature from three to five days. If at the end of that time it is still sweet and does not consume much more oxygen from permanganate than it did initially, it is pronounced a stable effluent.

In the tests at this station a modification of Scudder's method has been used. The sample, as in Scudder's work, was stored for five days at 37° and the oxygen consumed from permanganate was determined in the cold. In the Boston sewage and effluents, however, there are considerable amounts of readily oxidizable nonorganic materials, chiefly hydrogen sulphide. In order to exclude these substances the oxygen-consumed value was determined twice, once immediately on the addition of the permanganate and again after three minutes. The difference between the two results represents the true oxygen-consumed value. This method was suggested by Messrs. Johnson and Kimberly, of the Columbus experiment station.

The determination of total and suspended solids, which should form an integral part of every sewage analysis, was made for a considerable period. Unfortunately the enormously high chlorides in the Boston sewage, due to sea water, entirely masked the suspended solids when the determination was made in the ordinary way, and the direct determination of suspended solids by the Gooch crucible method was begun too late to get a large series of results. In the present paper, therefore, it is possible to report only, as an indirect measure of suspended solids, turbidity readings made with the Jackson turbidimeter (Jackson and Whipple, 1901), recalibrated for coarse material as described by Phelps (1905 a).

The determinations actually carried out on each sample in these experiments were as follows: Free and albuminoid ammonia, nitrates and nitrites, oxygen consumed and oxygen dissolved, turbidity, and odor. The albuminoid-ammonia and oxygen-consumed determinations were made on both the filtered and unfiltered samples. In addition to these regular determinations, an average sample was collected during the week, by adding each day to a bottle a definite amount of sewage sterilized with chloroform. On this average sample weekly determinations were made of chlorides, sulphates, iron, and alkalinity.

Analyses were made according to the methods generally employed in this part of the country, as described by Richards and Woodman (1904). Permanent standards have been used for the ammonia readings, as suggested by Jackson (1900). For the nitrite standards the Jackson permanent standards were used during a portion of the time, but it was soon found that a dilute solution of fuchsine, made up to match the desired nitrite reading by eye, gave a perfect standard as far as shade was concerned and was sufficiently permanent for all purposes. This is essentially the method since described by Weston (1905). Nitrates were determined by the Brucine method of Noll (1901), as described by Farnsteiner and his associates (1902).

For the oxygen-consumed determination the Kübel method was used, boiling for two minutes. In future work it is the intention to follow throughout the procedure outlined by the committee on standard methods of the American Public Health Association.

In tabulating the results of these experiments all ammonia, nitrite, and nitrate values are reported in terms of nitrogen, and all chemical results are expressed in parts per million. The dissolved oxygen is reported in this way rather than in the conventional form of per cent of saturation, since, while the latter method of expression may have had some significance in the study of surface waters, it has no value whatever in connection with sewage or filtration work in general. Owing to a change in the temperature of the water during treatment the results expressed in per cent of saturation may show an increase in the amount of oxygen, while in reality there is a marked decrease.

CHARACTER OF THE CRUDE SEWAGE.

During the two years of the operation of the sanitary research laboratory almost daily analyses of the crude sewage have been made. The sewage analyzed, as already explained, is a sample of the flow from 9 to 12 a. m. which has passed through the screen and grit chamber, drawn directly from the supply tank without any further chance for sedimentation or straining. The amount and character of the material previously removed from the grit chamber and supply tank are discussed on pages 115–116. Table LVI (p. 114) gives quarterly averages of the samples, taken, as a rule, on five days of each week. Yearly averages are also shown, the year being taken for convenience from June to June. Detailed studies of hourly and seasonal variations in the composition of the sewage have been previously reported (Winslow and Phelps, 1905).

The organic constituents of Boston sewage appear to be fairly normal in relation to one another. As stated above, regular determinations of the organic nitrogen were not made, but from the results of about fifty such determinations made at various times in the course of experimental work it may be stated that the average organic-nitrogen figure for the whole period would be about 20 parts per million. In this respect the sewage appears to be of about the same strength as the average sewage of Massachusetts cities, being slightly weaker than the sewages of Lawrence and Gardner (new system) and somewhat stronger than those of Framingham, Worcester, and Brockton.

The inorganic analyses of mixed weekly samples covering the calendar year 1904 showed an average of 2,300 parts per million of chlorine, 15 parts of iron, 125 parts of alkalinity, as calcium carbonate, and 220 parts of SO_3 as sulphates. The high chlorine and sulphate values are due to the large amount of sea water present in the sewage of Boston. If the chlorine normal to the sewage itself is assumed to be equal to the total nitrogen, as is commonly the case, a simple calculation shows that the amount of chlorine present represents a volume of sea water equal to 11 per cent of the total volume of the sewage. This, however, is only an average value for the period. During each twelve hours the chlorine reaches a maximum figure of from 3,000 to 4,000

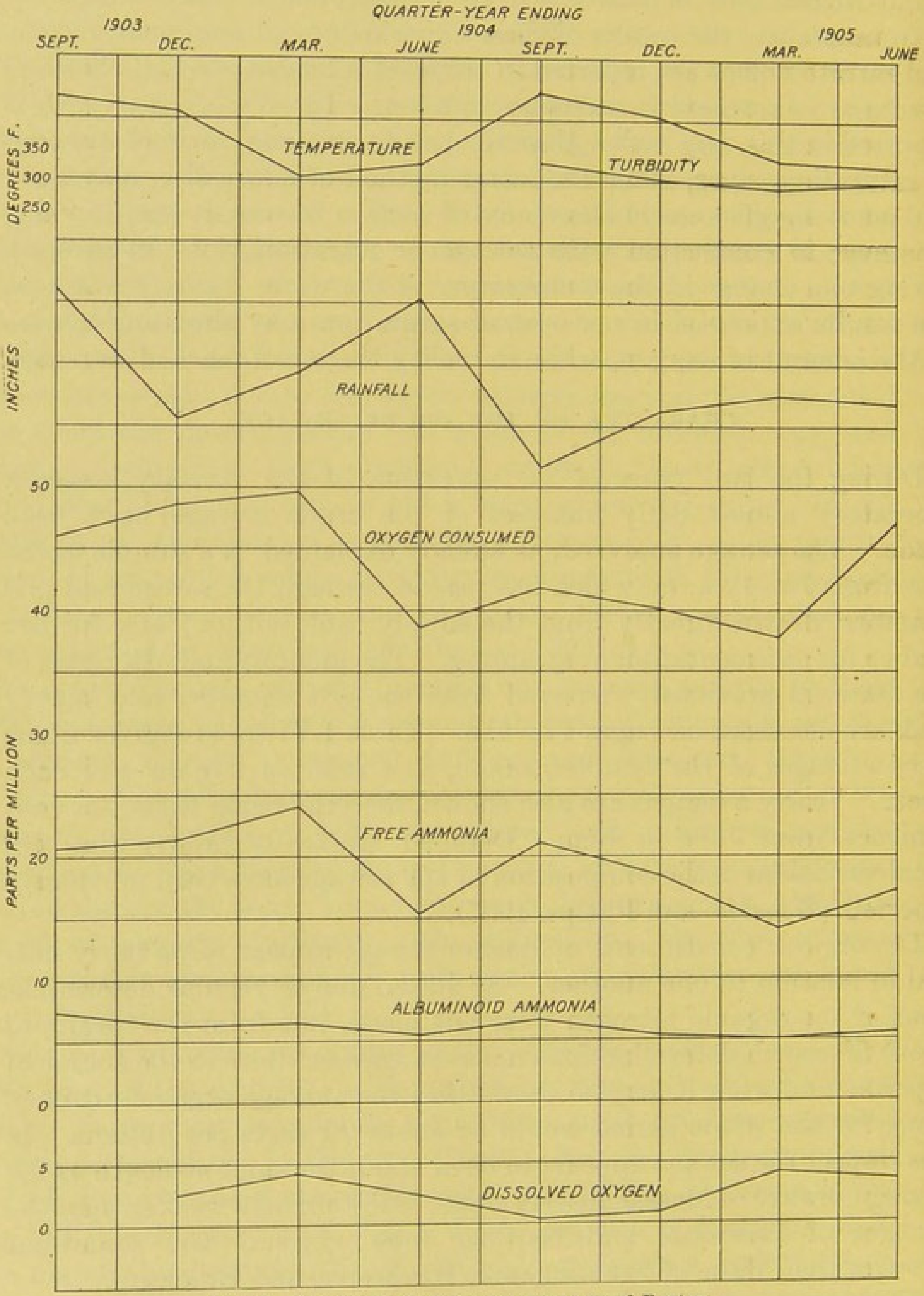

FIG. 15.—Composition of the crude sewage of Boston.

parts per million, representing 19 per cent of sea water, while between these maxima there are minimum points of about 200 parts per million, representing only 1 per cent of sea water. It may be an important question in any project for the purification of Boston's sewage whether the extra cost of pumping and of treating this sea water might not be greater than the cost of keeping it out of the sewers. On the other hand, there is the possibility that this large amount of sea water, saturated as it is with oxygen, may be of actual advantage in any aerobic process of treatment.

With regard to the variations in strength at different periods, the first point of importance to be noticed is the slight falling off in the strength of the sewage during the second year as compared with the first. This effect may probably be attributed to the fact previously mentioned (p. 98) that on October 14, 1904, the sewage of the upper part of the drainage system was diverted to the new high-level sewer. Much of this upper drainage area is sewered on the separate system, and ground water is in the main excluded. Furthermore, even with the combined system, the relative amounts of rain water entering the sewer is much greater in the city of Boston, with its great area of paved streets, than in smaller places with more open spaces and smaller relative amounts of pavement. It might also be possible, with the increasing per capita water consumption noticed in all cities from year to year and amounting in the metropolitan water district to 2 or 3 per cent per annum, that there would be a resulting decrease in the strength of the sewage. On the other hand, the low rainfall during 1905 must have operated in an opposite direction.

The quarterly variations in the strength of the sewage are considerable, and, as is shown on pages 122–123, markedly influence the effluents of the various purifying processes. The controlling cause in these seasonal variations is the rainfall. The first effect of a shower is to increase the oxygen consumed by the introduction of street washings. A long period of rain, however, has the opposite result. The general rule, as has been stated elsewhere (Winslow and Phelps, 1905), is that sewage is weakest in spring and summer. The precipitation was unusually low in the summer of 1904 and the spring of 1905, and therefore the seasonal relations for the second year are somewhat abnormal.

Table LVI.—*Composition of Boston sewage (quarterly averages), 1903–1905.*

Date.	Number of samples.	Temperature (° F.).	Analyses (parts per million).									
			Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
				Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
				To-tal.	In solu-tion.	In sus-pen-sion.				To-tal.	Solu-ble.	
June to August, 1903	27	67	.....	7.4	3.4	4	20.7	0.11	0.1	46	......	......
September to November, 1903	42	62	.....	6.2	3.1	3.1	21.3	.41	0	48.7	......	2.4
December, 1903, to February, 1904.	10	51	.....	6.6	3.6	3	24	.42	0	49.6	......	4.2
March to May, 1904	32	55	.....	5.4	2.7	2.7	15.3	.14	0	38.7	22.5	2.3
June to August, 1904	47	69	330	6.7	3	3.7	21	.16	.2	41.9	23.7	.3
September to November, 1904	33	61	300	5.4	2.6	2.8	18.4	.22	.4	40.2	22.2	.9
December, 1904, to February, 1905.	44	47	300	5	3.1	1.9	14	.10	.2	38.6	25.7	4.2
March to May, 1905	35	45	300	5.6	3.1	2.5	17.2	.08	0	47.4	27.3	3.6
June, 1903, to June, 1904[a]	102	60	.....	6.3	3.1	3.2	19.7	.27	.1	45.2	22.5	2.8
June, 1904, to June, 1905[a]	153	58	305	5.7	3	2.7	17.6	.14	.1	41.5	24.6	2.2
June, 1903, to June, 1905[a]	255	59	305	5.9	3	2.9	18.5	.19	.1	43.1	23.8	2

[a] Yearly and biyearly averages given in this and subsequent tables are obtained by averaging the daily results and are therefore not averages of the quarterly figures given.

REMOVAL OF SUSPENDED MATTER.

In any discussion of the solids in sewage it is necessary to distinguish clearly between three classes of suspended matter. In the first place, there are generally present large floating objects, such as rags, paper, sticks, and other gross débris. Before pumping sewage it is customary to pass it through screens for the separation of such material, which may therefore be denoted as screenings. Another class of matter, present especially in sewage which includes street washings, consists of sand and other heavy mineral particles, sharply distinguished from the ordinary sewage sludge by the rapidity with which they settle out when the sewage is brought either to complete rest or to a low velocity of flow. Chambers or tanks for the removal of such material are commonly called grit chambers or detritus tanks, and the material may be conveniently spoken of as detritus. After the removal of the screenings and the detritus there remains in suspension the sewage sludge proper, composed of finely divided matter largely organic in nature which settles out only at a low velocity, and then but slowly.

As a rule it is found desirable to screen sewage which is to be pumped and to settle sewage which has to pass through an inverted siphon, as is the case with that of the south metropolitan district. Where any purification is to be carried out both these preliminary treatments are generally advisable. The amount of solid material removed is often considerable. At Manchester, England, during 1904, the amount of combined screenings and detritus amounted to about 4,000 tons from a total of 13 billion gallons of sewage, or about 7,000 pounds per million gallons (Manchester, 1904). At Boston during

1903 about 10,000 cubic yards of detritus were removed from the settling chamber at the Dorchester pumping station from a total volume of sewage of 32 billion gallons, an average of about 0.31 cubic yard per million gallons. The composition of this detritus is not known, but a fair estimate would be 60 per cent of water and a solid content of 1½ tons per yard, making 900 pounds per million gallons of sewage (Boston, 1904). The amount of screenings removed during 1897 was recorded and found to be about 1,000 cubic yards, or, roughly, 500 tons, an average of 300 pounds per million gallons of sewage (Boston, 1898).

In the experiments at this station, as noted above, screenings and detritus were taken out by a grit chamber and to a slight extent by supply tank A. During the actual time of pumping the pump discharges on an average about 1,000 gallons per hour, which produces a velocity of 1.1 feet per second in the 2½-inch suction pipe. The velocity is checked in the grit chamber, being reduced to an average of 0.04 foot per second, and the time occupied in passing the grit chamber is about forty-five seconds. Since March, 1904, when the grit chamber was installed, a careful record of the amount of sediment removed has been kept, the whole amount carefully sampled, and an aliquot portion preserved for analysis. A small amount of material removed from supply tank A has also been weighed and sampled and mixed with the grit chamber material in proportionate parts.

The amount of detritus removed by the grit chamber amounted in sixteen months to 4,800 pounds, or 2.4 cubic yards, of wet material from a total volume of sewage equal to a little over 3 million gallons—1,600 pounds, or 0.65 cubic yard per million gallons. All the material thus removed was carefully sampled and its moisture determined. A portion of each dried sample was preserved and mixed with proportionate parts of later samples, and the mixture was finally analyzed. A certain portion of each sample, consisting largely of clean stone, was not included in the analysis. The amount of moisture, the proportions of clean stone and of dry detritus, and the analysis of the latter are shown in Table LVII, first in total amounts and then in parts per million of the total volume of sewage (3 million gallons).

Table LVII.—*Amount and composition of detritus removed from grit chamber from March 26, 1904, to June 1, 1905.*

	Wet detritus.	Water.	Clean stone, etc.	Fine, dry detritus.			
				Total.	Loss on ignition.	Organic nitrogen.	Organic carbon by permanganate.
Total pounds	4,800	1,300	570	2,900	319	6.6	5.1
Pounds per million gallons of sewage	1,600	430	190	970	106	2.2	1.7
Parts per million parts of sewage	190	52	23	117	13	.26	.2

As the analysis indicates, this material is not sludge in any sense of the word. It is for the most part clean sand mixed with a considerable amount of coal cinders and small bits of wood, cloth, and pebbles. During the whole period it has been spread upon the grounds of the station immediately surrounding the laboratory and has given no offense.

The figures show only the total and average amounts of detritus collected for the whole period. No accurate data are at hand to show the effect of the seasons on the amount of detritus deposited It may be judged by the frequency with which it was necessary to clean out the chamber that the maximum deposits occurred during the early spring thaws. The Boston city records, already referred to, show that at Moon Island there is a maximum of deposit in March and a second maximum during the summer months. Local conditions of rainfall evidently largely determine the amount of detritus sent into the sewer, but monthly variations from the mean yearly deposit are not as a rule greater than 25 per cent of that value. In the spring of 1904 a large amount of snow was thawed by the warm rains and during ten days 1,600 pounds of detritus were taken from the detritus chamber and from storage tank A, into which some excess of detritus had been carried over; this was about one-third of the total amount removed during the fifteen months of the experiment. The amount of sewage pumped during that time was 100,000 gallons, giving an average of 16,000 pounds of detritus per million gallons of sewage. This may be fairly taken as the maximum for a like period of time, although for shorter periods the rate of deposit might be greater.

The line of demarcation between the so-called detritus and the remaining suspended solids, or sewage sludge proper, is rather sharply marked by the rapidity with which the particles settle. One class of material will settle out in a very few minutes when the velocity is still considerable and the other will settle only when the liquid is practically at rest and in the course of hours rather than minutes. According to figures given by Robinson (1896), a velocity of 0.5 foot per second will not move fine clay and 0.7 foot will just move coarse sand. Hence it may be stated that detritus may be removed from sewage at any velocity less than the former figure. On the other hand, sedimentation of the true suspended sludge necessitates a slackening of velocity to 0.1 foot per second or less. In the London settling basins velocities of 0.07 foot are maintained; at Manchester, 0.05; at Saltley and Sutton, 0.03; and at Frankfurt a. M., 0.01 to 0.02. Steurnagel (1904) found that velocities less than 0.07 foot permitted as complete sedimentation as was possible with absolute rest, but that 0.13 foot was too great. Again, the time required for sedimentation is considerably different in these two classes of material. Detritus, being largely sand, will settle out in a very few minutes; but the remaining solids require a much longer time for sedimentation. In some experiments on this point in a 40-cm. cylinder the removal of suspended solids by sedimentation was found to be about 25 per cent in five minutes, 50 per cent in thirty minutes, and 75 per cent in twenty-four hours. Steurnagel studied the same phenomenon in a deeper layer (2 meters) and found the removal of suspended organic matter to be 42 per cent in five minutes, 61 per cent in twenty-five minutes, 75 per cent in six hours, and 80 per cent in twenty-four hours.

Whether the suspended organic solids in sewage must be removed by some special process depends largely on the general method of purification. With intermittent filters, if there be ample areas of sand available, crude sewage may be handled without preliminary treatment, as is the case at most of the Massachusetts areas. When, on the other hand, suitable sand is difficult to obtain, it may be advisable to remove the suspended solids as far as possible in order to obtain more rapid rates. With the contact filter it seems probable that some method of sludge removal will be generally necessary in order to maintain the capacity of the beds. With the trickling filter it may often be possible to handle crude sewage without preliminary treatment. If a clear, as well as a nitrified, effluent is desired, however, sedimentation must follow the oxidizing process. Whether the removal of solids should precede or follow filtration in this case must be determined by experiment.

If the organic suspended solids are to be removed from sewage, there is a choice of three different methods—namely, sedimentation, chemical precipitation, and straining. For a comparison of the three methods, experiments at Lawrence furnish some useful data. Table LVIII has been compiled from the annual reports of the Massachusetts State board of health for the years 1893–1903.

Table LVIII.—*Effect of various processes of preliminary sewage treatment at Lawrence, Mass. (Massachusetts, 1894–1904).*

[Parts per million.]

Process and material.	Date.	Nitrogen as—				Oxygen consumed in 2 minutes' boiling.
		Albuminoid ammonia.			Free ammonia.	
		Total.	In solution.	In suspension.		
Alum precipitation:						
Sewage	1893–1897	6.3	2.6	3.7	29.7	40.3
Effluent		2.8	2	.8	30.7	20.9
Hard-coal strainer:						
Sewage	1901–1903	5.5	2.9	2.6	42.1	38.1
Effluent		3	2.1	.9	43.3	23.6
Coke strainer:						
Sewage	June, 1894, to September, 1898.	6.4	2.5	3.9	30.8	38.8
Effluent		3.3	2.3	1	31.8	22.2
Septic tank A:						
Sewage	1901–1903	6.4	2.9	3.5	39.1	47.7
Effluent		3.3	2.1	1.2	36.7	29.4
Sedimentation:						
Sewage	1893–1897	6.3	2.6	3.7	29.7	40.3
Effluent		4.2	2.7	1.5	33	30.7

The samples of effluent from chemical precipitation with alum represent the supernatant liquor obtained by treating the sewage with sulphate of alumina at a rate of 1,000 pounds per million gallons and allowing the mixture to settle for four hours in a barrel. The sedimentation experiments were made by settling the sewage for four hours without other treatment. The coke strainer was a layer of coke breeze 6 to 8 inches deep and was operated at a rate of about 1 million gallons per acre per day. The coal strainer was a 12-inch layer of "buckwheat" coal and was run at a rate of approximately 1 million gallons per acre per day. Some septic-tank results for 1900–1903 have been included, the septic tank being considered in this place as a variant of sedimentation. The important conclusion from these experiments is that the results of the various processes are not very dissimilar. The small differences observed are in favor of the chemical-precipitation process, plain sedimentation showing the poorest results.

Martin (1905) has compiled, from the testimony given before the royal sewage commission, figures from various sources relating to the removal of suspended solids by chemical precipitation, septic tanks, and coarse filters. While the coarse filter is not strictly a preliminary treatment for the removal of suspended solids, since it is also a true process of purification, the comparative results obtained by these three processes are of interest in this connection. The average suspended solids in effluents from chemical precipitation plants are, at Kingston 14 parts per million, at Chorley and Richmond from 40 to 70, and at London 112. Similar figures from septic-tank installations are, at Salford 29 to 71, Manchester 100 to 286, Leeds 114 to 143, Burnley 130, Oldham 143, Sheffield 157, Accrington 178, and Birmingham 244. The average suspended solids in coarse-bed effluents are at Sheffield 43 to 57, Sutton 45, Blackburn 60, Aylesbury 111, and Leeds 151 to 196.

In general it is clear that chemical precipitation and straining will produce effluents which as regards suspended solids only are somewhat superior to those from either plain sedimentation or septic treatment. In the case of precipitation the cost of the chemical treatment and the necessary disposal of an increased volume of sludge must be considered. In straining processes sludge is produced in varying quantity according to the conditions under which the strainer is operated. A strainer run at so low a rate that anaerobic processes are carried out within it is practically a septic tank and can be so operated that there is little accumulation of organic matter. Such a strainer is septic tank No. 6 at this station, described on page 124, where it is pointed out that here the tank operates like a simple septic tank, the stone filling playing no important part. Again, with still lower rates and with resting periods, the strainer becomes practically an oxidizing filter and disposes of considerable sludge in much the same way as does a contact bed. On the other hand, true strainers, run at rapid rates with the object simply to remove suspended solids without destroying them, come in a different class. Their surfaces require constant care, while not only the accumulated sludge itself but that part of the surface which is necessarily removed at the same time must be disposed of. Sedimentation, although it does not give quite such perfect removal, is generally preferable to either of these methods, since it avoids the expense of chemicals and of renewing or treating the surface of strainer beds; it will probably prove in general the most practical and economical process of preliminary treatment for removing fine suspended material.

Under the term sedimentation is included septic treatment, since the septic process is really plain sedimentation with the additional anaerobic fermentation of the sludge produced. Such a process seems to combine the best features of all the preliminary treatments thus far proposed, since it effects an adequate removal of suspended solids with no expense for chemicals and produces a minimum of sludge. Furthermore, the actual removal of suspended solids is somewhat greater with the septic tank than with plain sedimentation, from the solution of particles too small to settle easily. The only disadvantage in septic treatment is that if it be too prolonged changes may be set up which make subsequent treatment difficult. The problem is to combine the maximum liquefying action with the minimum production of toxic substances. If that can be done, the septic tank offers in general the best solution of the problem.

PRELIMINARY TREATMENT IN THE SEPTIC TANK.

It having been assumed that if any preliminary treatment were necessary in the purification of Boston sewage the septic tank would probably furnish the most available method, the next problem was to determine the best conditions under which a septic tank could be operated. In particular, it was desired to compare the efficiency of different periods of storage, the results obtained from open and closed tanks, and the effect of filling a tank with stone in order to increase the amount of surface action.

Tanks Nos. 5, 6, 8, and 10, all closed tanks, were started in June, 1903, and open tanks Nos. 7 and 9 in March, 1904. All were operated continuously until June, 1905. Tank No. 5 was operated for the first six months at a forty-eight hour rate and for the remaining eighteen months at a twelve-hour rate. Tank No. 7 had a twelve-hour period, tanks Nos. 6, 9, and 10 a twenty-four hour period, and tank No. 8 a forty-eight hour period. In each case the linear distance traveled was about 6 feet and the depth 3 feet, making the

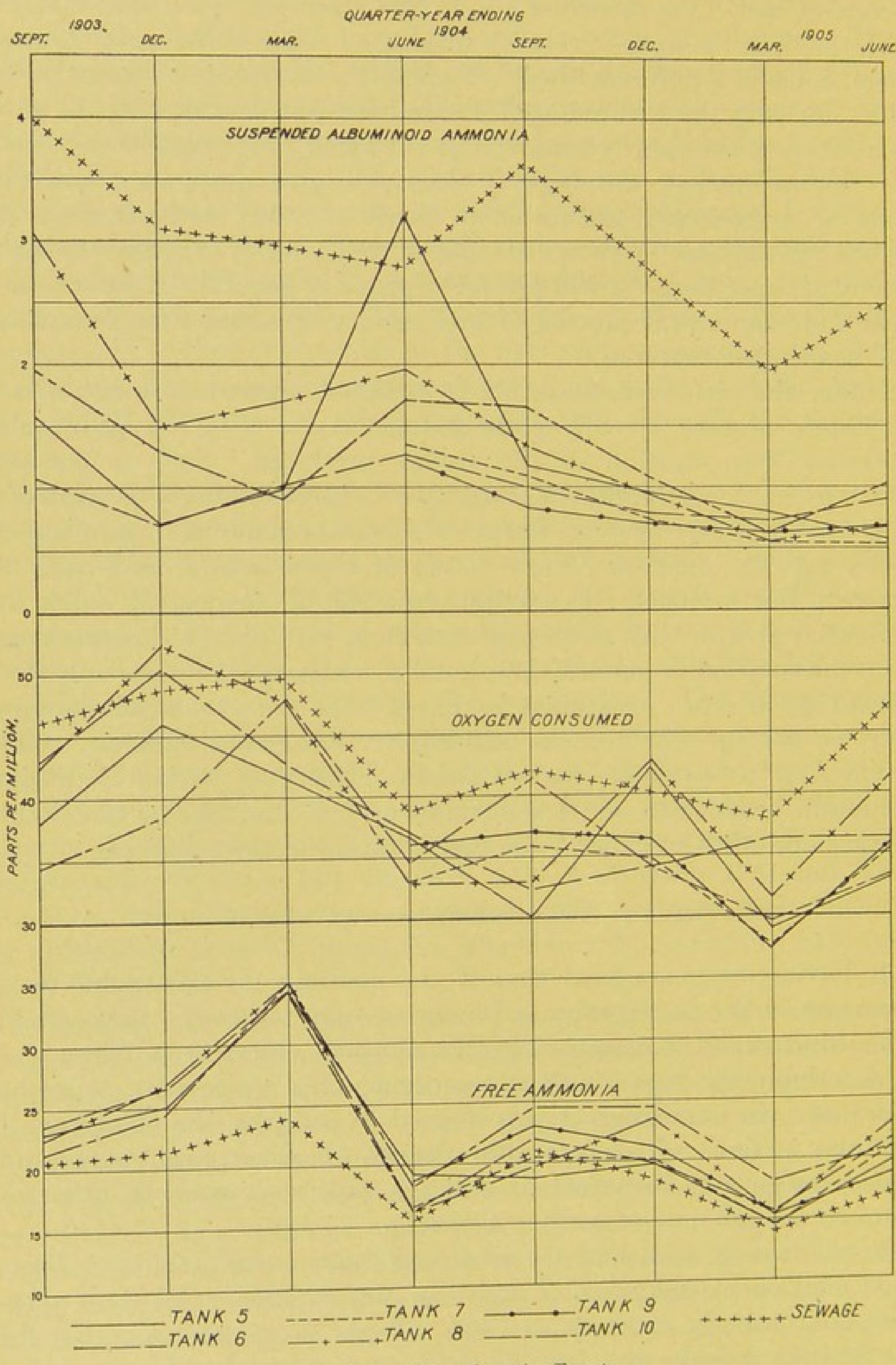

Fig. 16.—Composition of septic effluents.

ratio of l:d equal 2:1. The importance of this factor has recently been pointed out by Hazen (1904). Tank No. 6 was filled with

1½-inch crushed stone. Septic action began in all the tanks very soon after they were started, the effluent being free from gross turbidity and much darkened. The dark color and offensive odor of these septic effluents are undoubtedly due in part to the formation of sulphides from the large amount of sulphates introduced with the sea water. This phenomenon has been noticed by Clark in the treatment of hard waters at Lawrence (Barbour, 1904). Hoppe-Seyler (1886) believed the reaction to be a direct reduction of calcium sulphate by methane. It is of some importance, aside from the foul odors produced, since it has been found at Burton-upon-Trent that the formation of H_2S has a serious effect on subsequent purification on land (Smith, 1901). Scum formed at first on the open tanks, but later disintegrated and sank and did not re-form. In the closed tanks a scum 1 inch thick was found when they were finally opened.

The most important constituents of the effluents from the various tanks are plotted in fig. 16. It will be noticed in the first place that the various effluents are much alike in composition. All show a general improvement during the course of the two years, but this is accounted for rather by the decreasing strength of the sewage than by increased efficiency. The septic-effluent curves follow the crude sewage closely all through, rising in the late autumn of 1903, in the summer of 1904, and in the spring of 1905, when the sewage strengthened with diminishing rainfall. In absolute values, oxygen consumed shows a slight decrease in the septic tanks and free ammonia a slight increase. No doubt the reduction in carbonaceous matter is really considerably greater than it appears, since the septic decomposition tends to break up the more stable compounds and increases that proportion of the total carbonaceous matter which is revealed by the oxygen-consumed test. The hydrogen sulphide also interferes seriously with the value of this test. The chief difference between the sewage and septic effluents, aside from the reduction in turbidity, appears in the albuminoid ammonia. The nitrogen in this form was diminished to from two-thirds to one-half its sewage value. The diminution of dissolved albuminoid ammonia was slight but distinct, while the suspended portion was reduced to a little over one-third its original amount. The suspended albuminoid ammonia is plotted with the total oxygen consumed and free ammonia in fig. 16.

Table LIX.—*Quarterly averages of analyses of effluent from septic tanks.*

TANK 5, CLOSED TANK; STORAGE PERIOD, TWELVE HOURS.[a]

Date.	Temperature (° F.).	Turbidity.	Analyses (parts per million).					
			Nitrogen as—				Oxygen consumed.	
			Albuminoid ammonia.			Free ammonia.		
			Total.	In solution.	In suspension.		Total.	Dissolved.
1903-4.								
June to August	68	....	4.2	2	1.6	22.9	38	....
September to November	59	....	3.1	2.4	.7	25	45.9	....
December to February	48	....	3.9	2.9	1	34.2	41.3	....
March to May	52	240	6	2.8	3.2	19	36.5	26.5
Yearly average	58	240	4.1	2.6	1.5	24.3	41.7	26.5
1904-5.								
June to August	67	220	3.8	2.7	1.1	18.7	30.1	23.8
September to November	57	190	3.6	2.6	1	19.6	42.1	34.3
December to February	44	190	3.6	2.8	.8	14.6	28.9	22.9
March to May	46	200	3.2	2.6	.6	19.7	33	28.1
Yearly average	56	200	3.6	2.7	.9	18.1	33.2	26.9
General average	57	200	3.8	2.6	1.2	20.7	36.9	26.9
TANK 6, CLOSED SEPTIC TANK FILLED WITH STONE; STORAGE PERIOD, TWENTY-FOUR HOURS.								
1903-4.								
June to August	68	....	3.7	2.6	1.1	23.5	42.8	....
September to November	59	....	2.9	2.2	.7	26.5	50.3	....
December to February	47	....	3.6	2.6	1	34.2	42.7	....
March to May	52	180	4.1	2.9	1.2	16	37	26.2
Yearly average	58	180	3.4	2.5	.9	24.3	44.9	26.2
1904-5.								
June to August	67	170	3.2	2.2	1	21.9	32.4	27.2
September to November	59	190	3.3	2.5	.8	19.6	34	29.7
December to February	44	190	3.9	3.2	.7	15.7	29.6	22.8
March to May	46	160	3.3	2.4	.9	20.8	33.3	24.7
Yearly average	54	180	3.4	2.6	.8	19.5	32.2	26
General average	57	180	3.4	2.5	.9	21.5	37.8	26
TANK 7, OPEN SEPTIC TANK; STORAGE PERIOD, TWELVE HOURS.								
1904-5.								
March to May	52	170	3.9	2.5	1.4	16.5	33.1	26.5
June to August	69	160	2.8	1.7	1.1	20.3	35.8	31.4
September to November	54	170	3.1	2.3	.8	20.1	34.9	31.7
December to February	45	180	3.5	3	.5	14.5	27.7	21.4
March to May	46	190	3.7	3.1	.6	16.8	35.5	29
Yearly average, June to June	56	170	3.2	2.5	.7	17.9	33.2	28.1
General average	55	170	3.4	2.5	.9	17.6	33.2	27.9
TANK 8, CLOSED SEPTIC TANK; STORAGE PERIOD, FORTY-EIGHT HOURS.								
1903-4.								
June to August	66	....	5.6	2.5	3.1	22.4	42.4	....
September to November	58	....	3.6	2.1	1.5	26.8	52.3	....
December to February	47	....	5	3.3	1.7	35	47.7	....
March to May	51	230	4.3	2.3	2	16.1	32.8	26.5
Yearly average	57	230	4.3	2.4	1.9	25.1	46.1	26.5
1904-5.								
June to August	67	200	3.7	2.3	1.4	19.5	32.9	26.3
September to November	38	210	3.5	2.5	1	23.5	42.9	35.6
December to February	45	180	3.7	3.1	.6	15.3	31.6	25.1
March to May	45	170	3.5	2.8	.7	23	41.6	33.8
Yearly average	56	190	3.6	2.7	.9	20.5	37.3	30.3
General average	57	190	3.8	2.6	1.2	22.1	40.7	29.9

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[a] Before Dec. 7, 1903, 48 hours.

TABLE LIX.—*Quarterly averages of analyses of effluent from septic tanks*—Continued.

TANK 9, OPEN SEPTIC TANK; STORAGE PERIOD, TWENTY-FOUR HOURS.

Date.	Temperature (° F.).	Analyses (parts per million).						
		Turbidity.	Nitrogen as—				Oxygen consumed.	
			Albuminoid ammonia.			Free ammonia.	Total.	Dissolved.
			Total.	In solution.	In suspension.			
1904–5.								
March to May	52	170	3.6	2.4	1.2	18.6	36	26.6
June to August	68	160	2.7	1.8	.9	22.9	36.9	29.1
September to November	55	170	2.9	2.2	.7	21.2	36.3	32.1
December to February	45	190	3.6	2.9	.7	15.3	27.3	21.9
March to May	46	160	3.9	3.2	.7	18.8	36	29.8
Yearly average, June to June	56	170	3.2	2.4	.8	19.6	33.7	27.7
General average	55	170	3.2	2.4	.8	19.4	34.1	27.5

TANK 10, CLOSED SEPTIC TANK; STORAGE PERIOD, TWENTY-FOUR HOURS.

1903–4.								
June to August	66	....	4.5	2.6	1.9	21.3	34.3	....
September to November	58	....	3.4	2.1	1.3	24.3	38.5	....
December to February	49	....	3.8	2.9	.9	35	48	....
March to May	51	270	4.2	2.4	1.8	18.2	34.6	26.4
Yearly average	57	270	3.8	2.4	1.4	23.4	37.9	26.4
1904–5.								
June to August	67	190	3.5	1.9	1.6	24.6	41.3	23.2
September to November	57	220	3.9	2.8	1.1	24.4	34	23
December to February	43	250	3.9	3.2	.7	18.1	36.3	23.6
March to May	45	170	3.7	2.7	1	20.8	36.3	27.5
Yearly average	56	210	3.7	2.6	1.1	21.9	37.3	24.1
General average	56	210	3.8	2.5	1.3	22.5	37.5	24.5

TABLE LX.—*General averages of analyses of crude sewage and septic effluents.*

Material.	Date.	Storage period (hrs.).	Temperature (°F.).	Analyses (parts per million).						
				Turbidity.	Nitrogen as—				Oxygen consumed.	
					Albuminoid ammonia.			Free ammonia.	Total.	Soluble.
					Total.	In solution.	In suspension.			
Sewage	June, 1903, to June, 1905.	....	59	305	5.9	3	2.9	18.5	43.1	24.4
Do	March, 1904, to June, 1905.	....	58	305	5.7	3	2.7	17.6	41.5	24.7
Effluent from tank No. 5	June, 1903, to June, 1905.	[a]48–12	57	200	3.8	2.6	1.2	20.7	36.9	26.9
Effluent from tank No. 6	do	24	57	175	3.4	2.5	.9	21.5	37.8	26
Effluent from tank No. 7	March, 1904, to June, 1905.	12	55	170	3.4	2.5	.9	17.6	33.2	27.9
Effluent from tank No. 8	June, 1903, to June, 1905.	48	57	190	3.8	2.6	1.2	22.1	40.7	29.9
Effluent from tank No. 9	March, 1904, to June, 1905.	24	55	170	3.2	2.4	.8	19.4	34.1	27.5
Effluent from tank No. 10	June, 1903, to June, 1905.	24	56	210	3.8	2.5	1.3	22.5	37.5	24.5

[a] Changed Dec. 7, 1903, from 48 hours to 12 hours.

The average analyses of the effluent from each tank for the whole period of operation, with the average analyses of the sewage for the fifteen-month and the two-year periods, are indicated in Table LX. The figures on the whole show a remarkable uniformity of results for open and closed tanks and for twelve, twenty-four, and forty-eight hour periods. Even the figures for suspended albuminoid ammonia and total oxygen consumed bring out only slight differences. In a comparison of tanks Nos. 5 and 10 (closed) with the corresponding twelve and twenty-four hour open tanks, the open-tank effluents appear to be slightly better. It must be remembered, however, that the open tanks were operated during the last fifteen months only, when the sewage was weaker. This factor being taken into account, the work of the open and closed tanks is practically equal.

With regard to period the figures are no more conclusive. A comparison of tanks Nos. 7 and 9 (open) apparently shows no important difference between the effect of twelve and of twenty-four hours' storage. Similarly, tanks Nos. 5, 8, and 10 (closed) produce almost the same results, although operating with periods varying from twelve to forty-eight hours. Tank No. 6, filled with 1½-inch crushed stone, produces a somewhat greater reduction in suspended albuminoid ammonia than do the other tanks, but the difference is too slight to be of practical importance.

TABLE LXI.—*Analyses of septic-tank contents, including sludge and scum, at close of experiment.*

No. of tank.	Date.	Storage period (hrs.).	Depth of sludge (in.).	Analyses (parts per million).								
				Solids.		Nitrogen as—				Oxygen consumed.		Fats.
				Total.	Loss on ignition.	Free ammonia.	Albuminoid ammonia.		Total.	Total.	Soluble.	
							Total.	Soluble.				
5......	June, 1903, to June, 1905.	[a]48–12	8.4	17,000	6,580	35	145	10	425	1,000	130	1,590
6......	.....do............	24	....	....	....	6	66	10	......	640	48	3,008
7......	March, 1904, to June, 1905.	12	3.3	10,600	3,040	34	42	10	250	680	100	620
8......	June, 1903, to June, 1905.	48	8.7	14,900	6,068	50	80	10	400	940	110	870
9......	March, 1904, to June, 1905.	24	4.4	12,500	3,912	40	70	7	325	680	110	1,090
10.....	June, 1903, to June, 1905.	24	5.4	16,900	5,952	50	102	7	400	1,020	100	900

[a] Changed Dec. 7, 1903, from 48 hours to 12 hours.

When this series of experiments was closed in June, 1905, the inlet and outlet of each tank were closed and the contents, including scum and sludge, were thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the material which had accumulated during the whole period of operation. The results are shown in Table LXI. The analyses refer to the total liquid and solid contents of the tank at the time its operation ceased, a suspension containing about 98 per cent of water. The sludge was estimated by allowing the mixed tank contents to settle in a cylinder for twenty-four hours and observing the relation between the thick sediment produced and the clear supernatant liquid. The thickness of the sludge (which as measured by this method includes the scum also) was 3.3 and 4.4 inches for the tanks which had run for fifteen months and 5.4, 8.4, and 8.7 inches for those which had run for two years. With regard to total solids the loss on ignition is important and measures fairly the total storage of organic matter by the septic tank. This is seen to be from 3,000 to 4,000 parts per million after fifteen months and about 6,000 parts after two years. The effect of the storage period on the accumulation of sludge is striking. As already shown, the tanks in which the flow was more rapid appear to exercise quite as much purifying power as the slower ones. Since twice as much sewage passed through tank No. 7 as through tank No. 9 and twice as much through tank No. 10 as through tank No. 8, with the production of a comparable effluent, more sludge might be expected in tanks Nos. 7 and 10. We actually find less, which suggests that the decomposing action of the tank is favored by a shorter storage period. In tank No. 7, with a twelve-hour period, there were 3.3 inches of sludge, corresponding to 0.6 cubic yard per million gallons of sewage passed. In tanks Nos. 5, 9, and 10, with a twenty-four-hour period, the depth of sludge was respectively 8.4, 4.4, and 5.4 inches, equivalent to 1.4, 1.7, and 1.5 cubic yards per million gallons. In tank No. 8, with a forty-eight hour period, there were 8.7 inches of sludge, or 4.7 cubic yards per million gallons.

It has been pointed out above that a prolonged septic action diminishes the number of bacteria and probably interferes with sludge reduction. Another interesting suggestion, which may help to explain the results herein recorded, has recently been made by Stoddart (1905). He finds, in a septic tank of several compartments, a considerable deposit of sludge in the first compartment, giving a fairly clear supernatant liquid, which in the last chamber of all undergoes a secondary decomposition, leading to the throwing down of an additional precipitate of offensive sludge.

From the data in Tables LX and LXI have been calculated, in Table LXII, the actual amounts of certain constituents, which were (*a*) allowed to enter the tanks, (*b*) discharged in the effluents, (*c*) stored in the tanks as sludge and scum, and (*d*) removed by septic decomposition. About 50 pounds of nitrogen as albuminoid ammonia per million gallons of sewage entered the tanks. Roughly, 30 pounds were discharged and 20 pounds remained behind, of which 15 to 17 pounds were decomposed. The last columns in the table show the total volatile solids and fats stored in the various tanks, calculated in relation to the sewage treated. These figures bring out very sharply the superior decomposing power of the tanks operated at short periods. Tank No. 7 (twelve hours) and tank No. 5 (twelve hours for the last eighteen months) exhibit the lowest values. Tanks Nos. 9 and 10 (twenty-four-hour period) come next, with 90 and 101 pounds, respectively. Tank No. 8, with its forty-eight-hour storage, gave 206 pounds of stored organic matter per million gallons of sewage treated. The large proportion of fats shown in the last column is notable, amounting to one-fourth or one-eighth of the total stored organic matter.

Table LXII.—*Storage and decomposition of organic matter in septic tanks.*

No. of tank.	Flow (gallons).	Storage period (hours).	Nitrogen as albuminoid ammonia.				Solids stored.		Fats stored.
			Entering. (*a*.)	Leaving (*b*.)	Stored. (*c*.)	Decomposed. (*d*=*a*−*b*−*c*.)	Total.	Loss on ignition.	
			Pounds per million gallons of sewage passed.						
5	445,000	[a] 48–12	49.2	31.7	1.3	16.9	178	69	16
6	135,000	24	49.2	28.3	[b] 10.1	11.9	....	....	101
7	393,000	12	46.7	28.3	.4	18.1	115	35	6
8	133,000	48	49.2	31.7	2.6	15.9	510	206	29
9	197,000	24	46.7	26.7	1.5	17.8	279	90	25
10	266,000	24	49.2	31.7	1.6	17.3	282	101	15

[a] Changed December 7, 1903, from 48 hours to 12 hours.

[b] Estimated from loss of capacity in tank due to sludging up of the space between the stones and from analysis of a sample of the sludge.

Altogether it may be concluded from these experiments that the septic tank will effect a considerable removal of solids from Boston sewage, amounting to about two-fifths of the nitrogen as measured by albuminoid ammonia. Its effluent is free from gross turbidity, but dark and offensive from the liberation of hydrogen sulphide. Of the organic matter retained in the tank, a very large proportion, amounting to well over three-fourths if measured by the albuminoid nitrogen, is decomposed, and the accumulation of stored material in the tank is slight after two years of operation. Apparently such tanks might operate for several years without being cleaned. The covering of tanks is nonessential, since closed and open tanks work equally well. Storage periods varying from twelve to forty-eight hours give similar effluents, but there is an increasing tendency to accumulate sludge as the period is lengthened. The filling of a septic tank with stone is of only slight advantage.

It is believed, therefore, that open tanks with a capacity not exceeding the flow for twelve hours would prove the most favorable preliminary treatment for Boston sewage.

PURIFICATION BY INTERMITTENT SAND FILTRATION.

The early Lawrence experiments indicated pretty clearly what may be effected by intermittent sand filters operating under the most favorable conditions. They showed that a 4 to 5 foot bed of sand of an effective size of 0.04 to 1.4 mm. would take sewage at rates varying from 0.02 to 0.06 million gallons per acre per day, producing a clear and odorless effluent in which the nitrogenous constituents had been almost entirely converted into the mineral form. In the line of a modification of the process in order to secure more rapid rates than these the only important step has been the installation of preliminary septic tanks, and septic effluent has been treated in the Middle West at rates up to 0.4. Exact data are scarce, however, as to the comparative operation of sand filters with crude sewage and with septic effluent. It was therefore planned, in this investigation, to determine how far the preliminary septic process would be of advantage in the treatment of Boston sewage, and—with or without its use—to what extent the required area of sand could be diminished by the use of rates of filtration over 0.1 million gallons per acre per day. It was desired also to find out how far the depth of sand could be decreased with safety, since this may be an important economic consideration when artificial sand areas must be constructed.

The first sand filters, Nos. 1 and 2, began operation in June, 1903. Both were cypress tanks, 6 by 4 feet by 3 feet deep, underdrained with 6 inches of material ranging from 3-inch stones up to the sand. No. 1 contained, over the underdrain material, two feet, and No. 2 one foot of drift sand with an effective size of 0.17 mm. and a uniformity coefficient of 3.5. Both were started at a rate of 0.1 and so operated until December, 1903. At that time the rate on No. 1 was doubled, while that of No. 2 remained the same in amount but was divided into two daily doses with twelve hours' interval between them. In June, 1904, both rates were doubled, No. 2 receiving 0.2 million gallons per acre per day in two doses and No. 1 receiving 0.4 million gallons per day in four doses. Both filters received crude sewage.

This experiment gave conclusive results as to the minimum depth for a sand filter. While the 2-foot filter worked satisfactorily, No. 2, with half that depth, was a failure. Its effluent was dark and turbid and of an offensive odor. Not one of the samples tested passed the incubator test. The analytical results in Table LXIII show marked variations from time to time, but the free ammonia present was generally from 15 to 20 parts per million—nearly as high a value as that of the crude sewage. The albuminoid ammonia was usually between 2 and 3 parts and the oxygen consumed about 20 parts—in each case about half the sewage value. Nitrates were always low.

The operation of the 2-foot bed, on the other hand, was eminently satisfactory. The effluent was clear and bright and entirely free from turbidity and odor. Every sample tested successfully passed the incubator test and even bacteriologically the effluent appeared well, having an average of 1,220 bacteria per cubic centimeter. The bacterial composition of the various effluents obtained in these experiments has been fully discussed elsewhere (Winslow, 1905 a). The analytical characters of the effluent from tank No. 1 are given in Table LXIII. The free ammonia once reached 9 parts per million in the summer quarter of 1904, just after the increase in rate, but has been generally under 4 parts. The albuminoid nitrogen has been under 1 part, and the oxygen consumed under 8 parts except in one quarter. The nitrates, on the other hand, have not fallen below 20 parts, indicating a very high degree of purification, and dissolved oxygen has constantly been present. The increase in rate from 0.1 to 0.2, and again from 0.2 to 0.4, did not appreciably alter the quality of the effluent.

The surface of the filter, even at these high rates, has not required excessive care. It was scraped in August, 1903, and November, 1904, and raked once and scraped once in March, 1905. The total material removed in three scrapings during two years of operation amounted to a layer 0.48 inch thick, or 1,600 cubic inches. This is equivalent to 0.36 cubic yard per million gallons of sewage filtered.

Tanks Nos. 24 and 25 were put in operation in March, 1904, in order to compare the treatment of septic effluent with the purification of crude sewage as conducted in tank No. 1. All three were alike in construction. Tanks Nos. 24 and 25 were throughout operated at a rate of 0.4 million gallons per acre per day, taking four daily doses at six-hour intervals. Tank No. 24 received the effluent from tank No. 7, which had been septicized for twelve hours; tank No. 25 that from tank No. 9, which had been septicized for twenty-four hours. The analyses of the effluents from tanks Nos. 24 and 25 are shown in Table LXIII. In each of the three tanks studied the nitrates increased rapidly during the first months of operation (nine months in the case of tank No. 25, six months in the other two cases) and then fell to a somewhat lower value.

Fig. 17 brings out more clearly the relative quality of the three effluents, showing that from tank No. 1, which took crude sewage, to be the best. In the figure the blocks for sewage constituents represent not the septic effluent applied, but the crude sewage before treatment. It will be noticed that the average sewage applied to tank No.1 was stronger than that treated by septic tanks Nos. 7 and 9 and filters Nos. 24 and 25. Nevertheless, the free and albuminoid ammonia values are lower and the nitrates higher after sand filtration alone than after combined septic and sand treatment.

In the condition of the surface, the filters receiving septic effluent showed a slight but distinct advantage. During fifteen months of operation tank No. 25 was raked over twice, in September, 1904, and March, 1905, but not scraped. Tank No. 24 was raked on the same dates and also scraped once in March, 1905. This scraping was rendered necessary by a rather unusual phenomenon, the deposition of a thin layer of finely divided sulphide of iron formed by decomposition of sulphates in the septic tank. After one removal this layer did not again form. It is probable that experiments extending over a longer period might have shown greater advantages in the septic process in relation to the permanency of filtering surface.

TABLE LXIII.—*Quarterly averages of analyses of effluents from slow sand filters.*

TANK NO. 1, 2 FEET DEEP, TAKING CRUDE SEWAGE.

Date.	Temperature (° F.).	Analyses (parts per million).							
		Color.	Turbidity.	Nitrogen as—				Oxygen consumed.	Oxygen dissolved.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
June to August, 1903	65	0	....	0.4	4.7	0.17	5.1	3.9	....
September to November, 1903	57	0	....	.5	1.9	.67	20.9	3.9	3.5
December, 1903, to February, 1904	39	4	....	1.5	2.9	.57	41.7	4.5	....
March to May, 1904	54	15	....	.4	2.1	.35	23.5	5.5	9.6
Yearly average	56	4	....	.6	2.9	.48	19.6	4.3	5.3
June to August, 1904	67	26	....	.8	9.3	.27	26.8	8.5	6
September to November, 1904	54	47	....	.5	3.5	.27	22.3	7.4	5.4
December, 1904, to February, 1905	41	0	....	.4	3.8	.34	24.7	4.3	8.1
March to May, 1905	43	8	....	.8	5.4	.38	22	7.2	5.6
Yearly average	52	26	....	.6	5.4	.32	23.9	6.8	6.3
General average	54	19	....	.6	4.2	.39	22.3	5.6	6.1
TANK NO. 2, 1 FOOT DEEP, TAKING CRUDE SEWAGE.									
June to August, 1903	64	....	....	0.2	20	0.18	8.5	11.6	0
September to November, 1903	54	....	....	1.9	19.4	.31	3.1	25.8	0
December, 1903, to February, 1904	40	....	210	1.8	25.3	0	0	35.7	0
March to May, 1904	54	....	350	2	20.1	.01	0	17.7	.2
Yearly average	54	....	255	1.9	17.6	.20	4.6	21.2	0
June to August, 1904	67	....	110	2.5	17.6	.55	1.2	17.9	0
September to November, 1904	56	....	165	3.5	18.3	.33	4.5	25.6	3.5
December, 1904, to February, 1905	42	....	165	3.5	12.6	.23	2.9	28.3	1.9
March to May, 1905	44	....	45	2.8	16.5	.57	2.3	19	0
Yearly average	54	....	135	3.2	16.1	.36	2.9	23.7	1.8
General average	54	....	170	2.5	16.9	.28	3.5	22.4	.9
TANK NO. 24, TAKING 12-HOUR SEPTIC EFFLUENT.									
March to May, 1904	53	18	....	1.6	10.4	0.25	0.1	6.8	8.5
June to August, 1904	68	20	0	.5	2.7	.60	19.2	7.1	6.6
September to November, 1904	52	6	5	.8	4.7	.17	28.5	5.4	8.5
December, 1904, to February, 1905	42	18	0	.7	3.9	.14	17.9	6.2	8.8
March to May, 1905	45	8	0	.6	5	.29	20	7.1	4.8
Yearly average, June 1904, to June, 1905	53	15	0	.6	4	.32	21.3	6.5	7.4
General average	53	15	0	.8	5	.31	19.9	6.5	7.5
TANK NO. 25, TAKING 24-HOUR SEPTIC EFFLUENT.									
March to May, 1904	53	18	....	1.6	10.5	0.28	1.5	7.1	4.7
June to August, 1904	68	17	0	.5	4.1	.24	15.7	6.2	5
September to November, 1904	53	20	5	.9	5.6	.10	14.6	7	10.8
December, 1904, to February, 1905	42	53	0	.8	3.2	.12	26.4	4.3	9.3
March to May, 1905	45	21	0	.7	7.3	.25	18.4	8.5	3.4
Yearly average, June 1904, to June, 1905	54	44	0	.7	4.9	.18	18.8	6.4	7.5
General average	54	43	0	.9	5.6	.19	16	6.5	7.2

In general, the results obtained indicate that in reducing the depth of a sand filter it is not safe to go below 2 feet. One foot of sand is insufficient to effect purification, while a 2-foot bed may yield admirable results. With regard to the value of preliminary septic treatment of Boston sewage before sand filtration, it appears that effluents from the combined process are slightly inferior to those obtained by the sand process alone, while the care of the surface is more difficult when crude sewage is treated. These experiments, it is believed, suggest that it may be possible to treat crude sewage by sand filtration at higher rates than have heretofore been recommended. The operation of filter beds under practical conditions is of course more difficult than in small-scale experiments. In the first place the distribution on large beds is often incomplete, while it is easy in small tanks to obtain perfect distribution. Again, the effect of winter weather was minimized in these experiments. It will be noticed in the tables that the quarterly temperature averages for the sand-filter effluents did not fall below 39° F. In order to estimate the actual importance of this point in outdoor filters, the ratios which the values of free and

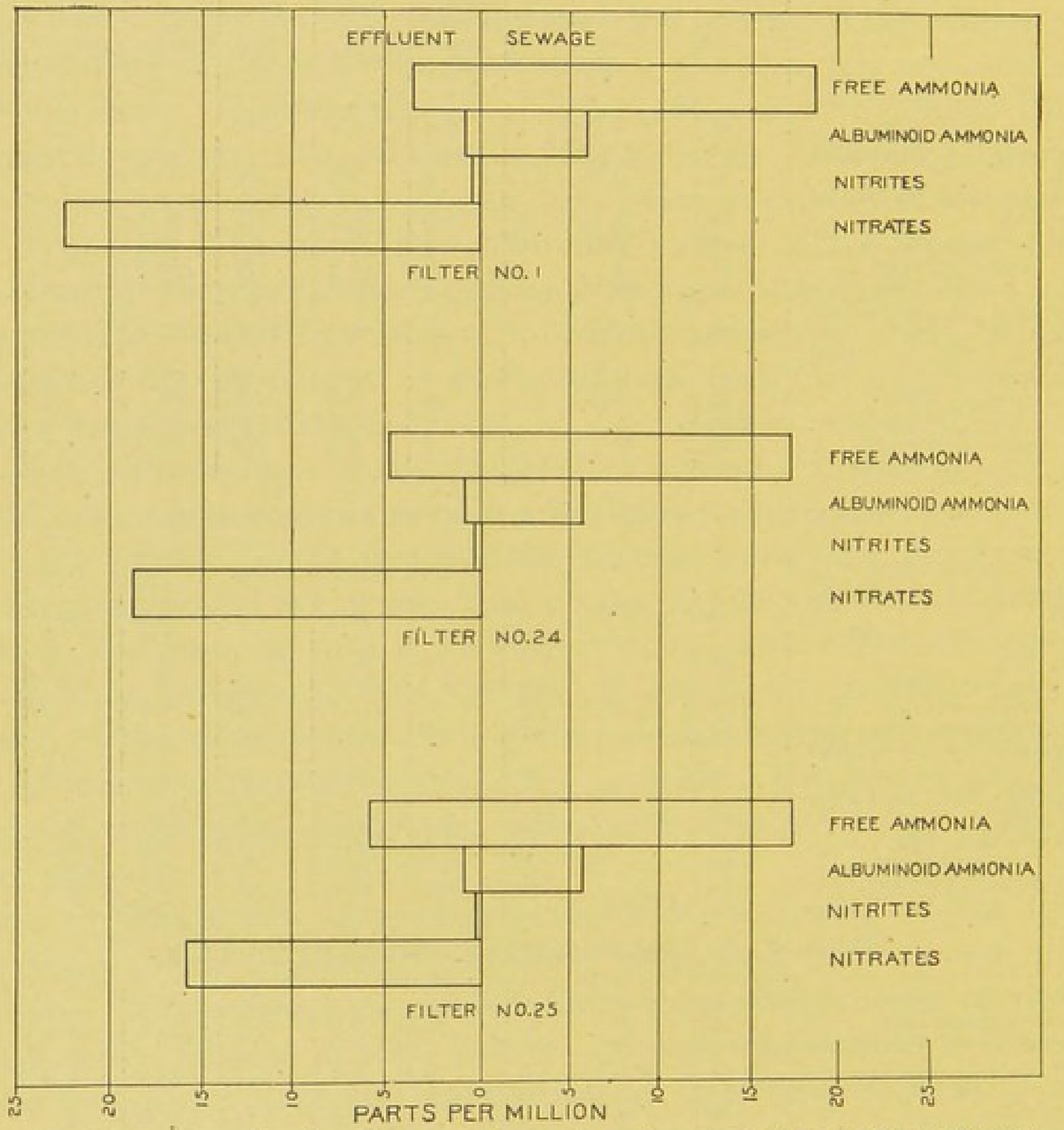

FIG. 17.—Comparison of various forms of nitrogen in crude sewage and sand-filter effluents.

albuminoid ammonia, oxygen consumed, and nitrates for each month bear to the yearly average at Lawrence and Brockton have been calculated and are given in Table LXIV.

TABLE LXIV.—*Monthly variations in sand-filter effluents at Brockton and Lawrence, Mass.*

[Yearly average=100.]

FREE AMMONIA.

	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Brockton	100	163	192	171	134	92	79	63	50	50	50	83
Lawrence	213	269	204	168	84	48	16	6	8	14	32	120

ALBUMINOID AMMONIA.

	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Brockton	87	130	130	174	87	87	87	87	87	87	87	87
Lawrence	175	171	150	132	92	76	67	58	62	49	62	117

NITRATES.

	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Brockton	85	70	67	81	90	112	118	115	133	129	110	96
Lawrence	48	38	59	100	139	140	120	116	128	125	109	75

OXYGEN CONSUMED.

	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Brockton	84	132	152	178	100	84	72	68	68	84	92	108
Lawrence	170	167	149	122	84	70	69	61	62	64	61	124

The Lawrence figures are the averages of the ratios for tanks Nos. 1, 2, 3, 4, 6, and 10, from 1895 to 1900, calculated from Clark's analyses (1896–1901). For Brockton the figures used cover the period 1897 to 1904 (Brockton, 1898–1905). A regular seasonal variation is indicated, the organic constitutents reaching their maximum in February with the small Lawrence tanks and in March with the large Brockton filter. The nitrates show a reciprocal curve, being lowest in February. The maximum monthly deviation amounts to about 100 per cent, the worst monthly averages being twice as high as the average in organic matter. This probably furnishes a fair measure of the amount of damage to effluents by winter weather.

The interference with the surface of the beds by winter weather is much more serious, and the treatment of crude sewage by intermittent sand filtration at a rate of 0.4 million gallons per acre per day can not be recommended. It is believed, however, that experiments out of doors and on a larger scale are well worth making in order to see if the common rates of 0.06 to 0.1 can not be somewhat increased. No doubt beds operated at higher rates will require more attention paid to their surfaces, but it is a question if the raking and scraping incident to the filtration of a given volume of sewage will be increased by filtering it through a smaller area. It seems probable that the stable material deposited on the surface of a sand filter bears a fixed ratio to the amount of sewage filtered; the same thing is very likely true of the fatty material which, as Clark has pointed out, penetrates below the surface and gradually decreases the efficiency of an old sand bed. These inevitable deposits will not be increased by higher rates, but will be simply concentrated on a smaller area, while the oxidizable organic material can apparently be nitrified under proper conditions at considerably higher rates than 0.1. The difficulty of scraping during severe winter weather will probably furnish the most serious obstacle to increased rates of filtration.

As a rule, sand filters have been constructed without special care and operated at haphazard. As this process comes into competition with the more elaborate modern methods, it is evidently worth while to see what can be done by applying to it the same expert care which is understood to be required by a contact or a trickling filter. For example, the difficulty of distribution may largely be overcome on a practical scale by careful grading and the use of proper distributors, if it is clear that this is worth doing. The division of the entire daily dose into three or four portions, applied at equal intervals during the twenty-four hours, is an expedient which would certainly largely increase the capacity of any of the Massachusetts beds now operated on the principle of daily or even less frequent dosing. This could be accomplished by the use of automatic devices, as at Wauwatosa and other plants in the Middle West. It has been tacitly assumed that the good results obtained at these filtration areas were wholly due to the preliminary treatment of the sewage in the septic tank. It is possible that they may be in part the result of careful operation and the application of several doses during the twenty-four hours.

PURIFICATION IN CONTACT BEDS OF COARSE MATERIAL.

The experiments at this station on the contact bed were planned to bring out the influence on the results of the treatment of each of the following points: Size and kind of filling material; depth of material; double and single contact process; treatment of crude and septic sewage; and rate of operation. The filters themselves have already been described in full detail (pp. 103–105). For convenience of reference, however, the main facts concerning the filter and its operation will be restated in each case.

Of the seven primary contact beds all are 4 feet square in area. Tanks Nos. 11, 12, 13, 14, and 16 are each 6 feet deep, and Nos. 18 and 20 are each 4 feet deep.

In all cases the method of operation was as follows: The bed was filled during the course of an hour, allowed a two hours' contact, emptied in about half or three-quarters of an hour, and allowed to stand empty until the next filling. The filling was in all cases continuous, and after the first six months two or more fillings of the tank per day were evenly distributed over the twenty-four hours.

Tanks Nos. 11, 12, 13, and 14 were run alike throughout the experiments. During July and August, 1903, they received one filling per day. The rate was doubled August 31, 1903, increased to four fillings January 1, 1904, and reduced to three fillings June 24, 1904. During the whole period after August, 1903, tank No. 16, the counterpart of No. 13, was run at three fillings. Owing to the superior results obtained from tank No. 16 at three fillings over tank No. 13 at two the rate of the first four filters was increased to four fillings. This, after a fair trial, was found to be excessive, and the rate of three fillings per day was adopted as the most favorable.

Tank No. 11 was filled with coke about 2 inches in diameter. During the period from June, 1903, to June, 1905, it was run at an average rate of 1.8. No material was removed from the surface during the experiment and no serious clogging occurred. The effluent as a rule was turbid and putrescible and not satisfactorily purified.

Tank No. 12 was filled with crushed stone 1 inch to 1½ inches in diameter. During the two-year period it was run at an average rate of 1.4. No material was removed from the surface, although toward the end of the period a considerable deposit had accumulated, which would have required removal in a short time. The quality of the effluent improved steadily during the second year and was at its best at the conclusion of the experiment. During the spring of 1905 the effluent generally passed the incubator test. The purification effected by this filter was largely due to the straining action of the sludge layer on its surface.

Tank No. 13 was filled with crushed stone one-fourth to one-half inch in diameter. It was run throughout the two-year period at an average rate of 1.2. April 6, 1904, ten months after starting this filter, it was necessary to remove a 2-inch layer of deposit from the surface. This material was earthy in appearance and odor, and was easily removed without appreciably disturbing the stones. The clogging material extended to a depth of a few inches within the bed, but below the surface of the stones was not disturbed. The total weight of the substance removed was 26 pounds; its composition on analysis was as follows: Moisture, 41 per cent; loss on ignition, 6.9 per cent; organic nitrogen, 0.1 per cent. March 21, 1905, 2 inches of mixed deposit and filter material were removed. The material of the filter was clogged badly to a depth of 6 inches, below which the stones were clean. This material was similar to that first removed and was not analyzed, except that the stones were separated from the deposit in a sample of the mixture. The total weight removed was 141 pounds, of which 56 per cent, or 79 pounds, was deposit. The effluent from this filter has been uniformly good and those incubator tests which were made on it showed it to be always nonputrescible. Here still more than with tank No. 12 the straining effect of the surface deposit played an important part.

Filter No. 14 was filled originally with crushed stone one-half to 1 inch in diameter. During the year of its operation, from July, 1903, to June, 1904, it received sewage at an average rate of 1.4. No material was removed from its surface, although at the end of the year there was a considerable accumulation of deposit. The effluent was at all times intermediate between those of No. 12 (1½-inch stone) and No. 13 (one-half inch stone). At the end of the first year the filter was discontinued to make room for an experiment with a brick filter, No. 14A, on the plan of Dibdin's multiple-surface bed, the construction of which has already been described (p. 105). This filter was run throughout the second year at an average rate of 2. No material has accumulated on the surface, owing to the very open construction. The effluent of the filter has been uniformly turbid and putrefactive.

Filter No. 16 is exactly like No. 13, and was planned originally to run parallel with it except as to rate, in order to study the effect of two different rates under otherwise like conditions. As already stated, it was concluded from the work of this filter that three fillings per day were better than two and later that three were better than four. This point having been established the filter was used for experiments of a special character, the results of which have already been published (Phelps and Farrell, 1905). During the second year it was run like No. 13 in all respects. Tank No. 16, however, was not cleaned at the beginning of the second year, and therefore effected a somewhat higher purification from its greater straining action. Its average rate was 1.6.

Tanks Nos. 19 and 20 are each 4 feet deep and filled with crushed stone 1 inch to 1½ inches in diameter. They were run from June, 1903, to January 1, 1904, with two fillings per day. From January 1, 1904, to the conclusion of the experiments they were given three fillings per day. In all respects they were run as nearly alike as possible, No. 19 receiving septic sewage from septic tank No. 10 (thirty hours old) and No. 20 receiving crude sewage. The effluents from these filters were treated on secondary tanks Nos. 17 and 18, respectively. The purification by No. 19, which took septic sewage, has never been satisfactory, the effluent being at all times foul and dark colored and generally putrescible. The effluent of No. 20 has been much more satisfactory from the start. It is also a striking fact that the effluent from No. 20 has been fully as good as that from the fine-stone filters Nos. 13 and 16, and always superior to that from No. 12, from which it differs only in depth and in its consequent lower rate.

Capacity measurements were made on each bed once a week by discharging the effluent into a measuring tank as described above (p. 106). The average results by quarters are brought together in Table LXV. The results are all expressed in percentages of the total cubic capacity of the empty tank. The initial liquid capacity varied from 39 to 48 per cent, the highest values of course being found in the brick and coke beds. The single-contact beds taking crude sewage all decreased in capacity rather steadily, reaching a final value after two years of 26 to 33 per cent. The figures do not furnish evidence that the falling off had reached its limit, as was shown at Manchester. The Dibdin brick filter still showed 40 per cent of open space after one year of operation. The capacity of tank No. 19, which received septic effluent, was maintained at 38 per cent, and the secondary beds, Nos. 17 and 18, retained a capacity of over 35 per cent. The capacity of tank No. 20, which had fallen from 41 to 26 per cent in two years, was measured in August, 1905, after three months of rest, and had risen to 32 per cent.

TABLE LXV.—*Capacity of contact filter, by quarters.*

[Percentage of cubic capacity of empty tank.]

No. of filter.	Initial.	1903–4.				1904–5.			
11	46	......	44	41	39	38	38	35	32
12	40	37	......	35	33	33	32	31	30
13	44	37	......	36	36	35	34	......	33
14A	48	......	......	......	......	48	47	47	40
16	42	34	......	30	......	......	......	31	30
17	39	36	......	34	37	37	37	......	35
18	42	......	37	36	38	38	37	......	37
19	41	40	......	......	39	39	38	......	......
20	41	39	37	......	33	32	31	......	26

It is necessary to distinguish clearly between the surface clogging, due to the accumulation of material on the surface of the bed, and the true loss of capacity which affects the lower part of the filter. Since in these capacity measurements the tank was always filled just to the original surface of the stones, the former phenomenon in no way affects the results. The surface clogging depends directly on the size of material used, being greatest with the fine beds. In the present experiments it was necessary to clean the one-half-inch stone beds once a year, while the 1½-inch beds were just clogging so seriously as to render cleaning necessary at the end of the second year. The surface layer does not extend more than a few inches into the bed, and its removal is a simple matter which could be managed as easily as the scraping of a sand filter. It must, however, be reckoned with in the cost of operation.

The true loss of capacity, on the other hand, affected tanks Nos. 11, 12, 13, and 16 about equally, amounting in each case to a reduction of about one-fourth of the original open space. The ratio of the final to the initial capacity was 70 per cent for No. 11, 75 per cent for No. 12, 75 per cent for No. 13, and 71 per cent for No. 16. Tank No. 20 showed a greater reduction, to 63 per cent of its original capacity, probably because the material carried into the interstices is proportionately greater with a shallow bed. On the other hand, the secondary beds lost only about one-tenth of their open space, the ratio of final to initial capacity being 90 per cent for No. 17 and 88 per cent each for Nos. 18 and 19. The primary bed taking septic effluent lost only 7 per cent of its original capacity in twenty months of operation.

TABLE LXVI.—*Quarterly averages of analyses of contact-filter effluents.*

TANK NO. 11, PRIMARY-CONTACT BED OF 2-INCH COKE.

Date.	Temperature (°F.).	Analyses (parts per million).									
		Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.	
			Total.	In solution.	In suspension.						
June to August, 1903	67	......	4.2	2.7	1.5	30.8	0.07	0	23.8	......	0
September to November, 1903	60	......	3.1	2.3	.8	23.6	.44	0	28.8	......	0
December, 1903, to February, 1904	45	......	4.4	3.3	1.1	30.3	.40	0	30.7	......	0
March to May, 1904	52	150	3.6	2.1	1.5	13.8	.06	0	20.5	18.2	0
Yearly average	57	150	3.7	2.5	1.2	23.1	.24	0	25.7	18.2	0
June to August, 1904	69	160	2.7	1.8	.9	19.3	.25	0	23.7	20.1	0
September to November, 1904	59	120	3.1	2.1	1	14.5	1.60	5	20.6	15.9	.4
December, 1904, to February, 1905	44	90	2.4	1.7	.7	14	.30	1.3	15.6	11.4	2
March to May, 1905	43	140	2.8	2.1	.7	13.8	.35	1.2	16.7	13.2	.5
Yearly average	57	130	2.8	1.9	.9	15.4	.61	1.9	19.1	15.2	.7
General average	57	130	3.2	2.2	1	18.9	.45	1.1	22.1	15.5	.5

TANK NO. 12, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE.

June to August, 1903	67	......	4.6	2.9	1.7	20.4	0.01	0	30.9	......	0
September to November, 1903	60	......	3.3	2.4	.9	25.5	.66	0	40.6	......	0
December, 1903, to February, 1904	46	......	3.6	2.5	1.1	24.3	1.25	0	32	......	0
March to May, 1904	52	120	3.2	1.9	1.3	9.9	.02	0	22	19.2	0
Yearly average	57	120	3.7	2.5	1.2	20.6	.41	0	32.7	19.2	0
June to August, 1904	69	210	3	1.9	1.1	20.7	.02	0	28.7	22.8	0
September to November, 1904	59	140	3.3	2.1	1.2	15.9	1.43	2.3	21.4	14.9	0
December, 1904, to February, 1905	45	110	3	2	1	15.4	.30	1.5	18.1	15.2	.7
March to May, 1905	44	80	2.1	1.6	.5	11	.68	3.7	14.4	12	1.8
Yearly average	56	130	2.8	1.9	.9	15.4	.61	1.9	20.1	15.9	.6
General average	57	130	3.2	2.1	1.1	17.6	.52	1.3	25.3	16.3	.4

TANK NO. 13, PRIMARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE

June to August, 1903	68	......	4.5	2.8	1.7	19.1	1.03	0	20.7	......	0
September to November, 1903	60	......	1.8	1.3	.5	12.7	1.33	3.5	21	......	.4
December, 1903, to February, 1904	45	......	1.7	1.3	.4	16.8	.47	1.3	14	......	0
March to May, 1904	52	70	1.9	1.3	.6	7.3	.36	5	12.3	11.2	.1
Yearly average	57	70	2.5	1.7	.8	13.6	.98	2.2	18.2	11.2	.3
June to August, 1904	68	90	1.6	1.2	.4	12.9	.18	1.9	16.6	13.7	0
September to November, 1904	59	70	1.6	1.2	.4	11.2	.73	15	11.9	9.5	2.1
December, 1904, to February, 1905	44	30	1.7	1.6	.1	5.7	.51	12.3	7.4	6.4	3.5
March to May, 1905	41	40	1.2	1.1	.1	6	.48	8.1	9.4	8.7	.7
Yearly average	56	60	1.5	1.3	.2	8.9	.46	9.5	11.3	9.6	1.5
General average	56	60	2	1.5	.5	11	.69	7.2	14.3	9.8	1.4

Table LXVI.—*Quarterly averages of analyses of contact-filter effluents*—Continued.

TANK NO. 14, PRIMARY-CONTACT BED OF ONE-HALF TO 1 INCH STONE.

Date.	Temperature (°F.).	Turbidity.	Analyses (parts per million).								
			Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
			Total.	In solution.	In suspension.				Total.	Soluble.	
June to August, 1903	67	......	4.9	3	1.9	19.9	0.03	0	32	......	......
September to November, 1903	60	......	2.9	2.2	.7	24	.89	0	31.8	......	0
December, 1903, to February, 1904	45	......	3.4	2.3	1.1	22.5	.87	0	31	......	0
March to May, 1904	51	160	3.3	2.1	1.2	11.4	.13	.8	16.3	14	2.5
Yearly average	57	160	3.6	2.4	1.2	20	.49	0	28.3	14	.4

TANK NO. 14A, PRIMARY-CONTACT BED OF BRICK.

June to August, 1904	68	250	4.1	2.5	1.6	18.1	0.09	0.1	31	21.8	0.1
September to November, 1904	59	190	4.7	2.5	2.2	16.2	.27	.6	25.1	18.6	1.6
December, 1904, to February, 1905	45	170	3.3	2.5	.8	14.8	.25	.7	25.8	21	3.7
March to May, 1905	43	180	3.5	2.1	1.4	16 4	.23	.2	27.7	19.9	.2
Yearly average	57	200	3.9	2.4	1.5	16.4	.23	.4	27.5	20.4	1.4

TANK NO. 16, PRIMARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

June to August, 1903	67	......	3.7	2.7	1	16.4	1.08	0	20	......	0
September to November, 1903	61	......	1.9	1.4	.5	11.8	.85	0	16.8	......	.7
December, 1903, to February, 1904	51	......	2	1.2	.8	23.5	1.50	0	15	......	0
March to May, 1904	54	70	1.8	1.2	.6	5.9	.60	1	14.3	12.2	.3
Yearly average	60	70	2.2	1.6	.6	12.4	.90	.1	16.5	12.2	.6
June to August, 1904	69	90	1.6	1.3	.3	6.6	1.34	5.2	13.4	11.3	1.2
September to November, 1904	58	90	1.6	1.3	.3	5.6	.63	27.4	11.7	10.3	1.7
December, 1904, to February, 1905	45	50	1.3	1.1	.2	3.9	.46	11.1	7.8	7	2.3
March to May, 1905	......	20	1	.9	.1	4.7	.38	8	7.5	7	0
Yearly average	57	70	1.4	1.2	.2	5.2	.78	13.1	10.4	9.1	1.6
General average	58	70	1.7	1.3	.4	8.1	.83	9.8	13.1	9.6	1.3

TANK NO. 17, SECONDARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

June to August, 1903	66	......	3.1	2.1	1	20.3	1.37	0	22.3	......	0
September to November, 1903	56	......	2.5	1.9	.6	21.3	3.38	0	24.5	......	0
December, 1903, to February, 1904	49	......	2.3	1.9	.4	28.8	0	0	18.5	......	0
March to May, 1904	51	70	3.1	2.1	.9	13.6	.07	0	16.8	13.8	0
Yearly average	55	70	2.7	1.9	.8	19.7	.42	0	21.6	13.8	0
June to August, 1904	67	90	2	1.5	.5	14.3	.16	2	13.9	11.5	.3
September to November, 1904	66	50	1.3	1.1	.2	13.5	.75	8.9	11.3	10.4	.9
December, 1904, to February, 1905	43	100	2.3	1.9	.4	12.1	.28	5	14.8	12.9	1
March to May, 1905	......	90	2	1.6	.4	9.2	.02	1.6	12.8	9.5	1
Yearly average	55	80	1.9	1.5	.5	12.4	.31	6	13.3	11.2	.8
General average	55	80	2.3	1.7	.6	15.5	.35	5.2	16.9	11.7	.6

TANK NO. 18, SECONDARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

June to August, 1903	67	......	3.5	2.4	1.1	18.4	0.30	0	20.4	......	0
September to November, 1903	62	......	2.1	1.3	.8	15.2	.43	0	22.8	......	0
December, 1903, to February, 1904	49	......	2.6	1.8	.8	17.5	.63	0	14	......	0
March to May, 1904	58	80	2.8	1.7	1.1	12.9	.08	.4	17.2	14	.6
Yearly average	61	80	2.6	1.7	.9	15.8	.34	.1	19.8	14	.2
June to August, 1904	66	110	2.5	1.6	.9	12.9	.33	1.9	16.6	13.3	.8
September to November, 1904	57	90	1.9	1.4	.5	9	2.23	12.1	15.9	14.9	1.7
December, 1904, to February, 1905	45	70	1.2	1.1	.1	4.6	.13	15.0	10.6	10.1	2.3
March to May, 1905	......	60	1.3	.9	.4	6.5	1.26	10	10	9.3	2.4
Yearly average	54	80	1.7	1.3	.4	8.1	.89	12.1	13.4	10.7	1.7
General average	57	80	2.1	1.5	.6	11.5	.67	8.6	16.1	12.4	1.3

TABLE LXVI.—*Quarterly averages of analyses of contact-filter effluents*—Continued.

TANK NO. 19, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE TAKING SEPTIC EFFLUENT.

Date.	Temperature (° F.).	Turbidity.	Analyses (parts per million).								
			Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.	
			Total.	In solution.	In suspension.						
June to August, 1903	65	......	3.5	2.6	0.9	20.8	0.08	0	32	......	0
September to November, 1903	57	......	3.1	2.4	.7	24.6	.38	0	31	......	0
December, 1903, to February, 1904	47	......	3.3	1.6	1.7	42.5	0	0	36.5	......	0
March to May, 1904	52	130	2.9	2.1	.8	11.2	0	0	25.8	20.2	0
Yearly average	56	130	3.2	2.3	.9	22	.21	0	30.4	20.2	0
June to August, 1904	67	140	3.1	1.8	1.3	25.5	.17	.8	29.1	21.6	0
September to November, 1904	57	170	3.4	1.7	1.7	17.5	.62	2.3	23.6	16.3	0
December, 1904, to February, 1905	43	150	3.8	2.5	1.3	16.9	.09	1.4	23.4	18.5	1.3
March to May, 1905	......	190	3.5	2.8	.7	19.8	0	0	30	17.4	0
Yearly average	56	160	3.5	2.2	1.3	20.1	.22	1.2	26.3	18.7	.6
General average	56	160	3.3	2.3	1	20.9	.21	.9	28	19	.4

TANK NO. 20, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE.

June to August, 1903	67	......	5.7	4.4	1.3	20.4	0.12	0	29.7	......	0
September to November, 1903	60	......	3.9	2.7	1.2	17	.40	0	25.2	......	0
December, 1903, to February, 1904	51	......	4.7	3.1	1.6	23	.05	0	32	......	0
March to May, 1904	56	130	3.7	2	1.7	16.9	.08	0	24	17.6	.6
Yearly average	59	130	4.3	3	1.3	18.4	.23	0	26.7	17.6	.1
June to August, 1904	68	150	3.8	2.3	1.5	16.9	.07	.7	23.4	17.1	.2
September to November, 1904	57	140	3.5	2.3	1.2	16.1	2.05	7.6	20.3	16.4	.8
December, 1904, to February, 1905	46	100	2.4	1.8	.6	7.5	.33	9.3	15.3	13.5	2.2
March to May, 1905	......	110	2.7	2	.7	12.6	.30	2.3	15.8	12.8	2.9
Yearly average	55	120	3	2.1	.9	12.7	.74	6.1	18.6	15	1.3
General average	57	120	3.6	2.5	1.1	15.4	.50	4	22.4	15.4	.8

TABLE LXVII.—*General averages of analyses of contact-filter effluents.*

No. of tank.	Date.	Material.	Size of material (inches).	Average rate (million gallons per acre per day).	Temperature (° F.).	Analyses (parts per million).										Capacity (per cent of cubic contents).	
						Turbidity.	Nitrogen as—						Oxygen consumed		Oxygen dissolved.	Initial.	Final.
							Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.			
							Total.	In solution.	In suspension.								
11	June, 1903, to June, 1905	Coke	2	1.8	57	130	3.2	2.2	1	18.9	0.45	1.1	22.1	15.5	0.5	46	32
12	do	Stone	1 -1½	1.4	57	130	3.2	2.1	1.1	17.6	.52	1.3	25.3	16.3	.4	40	30
13	do	do	¼-½	1.2	56	60	2	1.5	.5	11	.69	7.2	14.3	9.8	1.4	44	33
14	June, 1903, to June, 1904	do	½-1	1.4	57	160	3.6	2.4	1.2	20	.49	0	28.3	14	.4	42	....
14A	June, 1904, to June, 1905	Brick	....	2	57	200	3.9	2.4	1.5	16.4	.23	.4	27.5	20.4	1.4	48	40
16	June, 1903, to June, 1905	Stone	¼-½	1.2	58	70	1.7	1.3	.4	8.1	.83	9.8	13.1	9.6	1.3	42	30
17[a]	do	do	¼-½	1.2	55	80	2.3	1.7	.6	15.5	.35	5.2	16.9	11.7	.6	39	35
18[a]	do	do	¼-½	1.1	57	80	2.1	1.5	.6	11.5	.67	8.6	16.1	12.4	1.3	42	37
19[b]	do	do	1 -1½	1.2	56	160	3.3	2.3	1	20.9	.21	.9	28	19	.4	41	38
20	do	do	1 -1½	1.1	57	120	3.6	2.5	1.1	15.4	.50	4	22.4	15.4	.8	41	26

[a] Secondary-contact bed.

[b] Septic effluent applied.

The quarterly analyses of the effluents from the several contact beds are given in Table LXVI, and the average analyses for each bed for the whole period of operation are brought together in Table LXVII. An inspection of the latter table and of figs. 18 to 22 will bring out the comparative results attained with filling of different material and different size, with different depths of beds, with different rates of operation, with single and double contact beds, and with the treatment of crude and septic sewage.

First, as to the kind of filling material, it was desired to see if the particularly favorable results reported with the use of coke at London would be obtained with Boston sewage. Tank No. 11, filled with 2-inch coke, is fairly comparable with tank No. 12, filled with 1½-inch broken stone. The initial capacity of No. 11 was considerably higher than that of No. 12 (46 per cent against 40 per cent), and it decreased much more slowly, so that the rate on No. 11 was higher than on No. 12 with the same number of fillings. As clogging occurred in tank No. 12 during the last year of operation, its effluent improved and at the end was much better than that of No. 11. A comparison of the average analyses for the whole period, however, shows that the effluent of No. 11 was slightly better than that of No. 12, in spite of the larger size of material and the higher rate. Thus it appears that coke is somewhat superior to stone.

On the more important question of the size of material, a comparison of tanks Nos. 12 (1½-inch stone), 13 (one-half-inch stone), and 14 (1-inch stone) is instructive. The average analyses given in Table LXVII are not comparable, because tank No. 14 was operated under the conditions mentioned for one year only, and during that year the applied sewage was strongest. In fig. 18, however, the quarterly values may fairly be compared.

As might be expected, both efficiency and clogging increase as the size of the material used diminishes. Tank No. 13 gave a better effluent than tank No. 14; No. 14 a better effluent than No. 12. The effluents from the 1-inch and 1½-inch stone were never of satisfactory quality, except, in the latter case, at the very end of the experiment, while that from the one-half-inch stone was almost always clear and nonputrescible. The efficiency with half-inch material was reached, however, only at the expense of a serious clogging which necessitated the removal of 4 inches of sludge from the surface during two years of operation, leaving the body of the filter for some distance below the surface still badly clogged. These results correspond with those obtained by Dunbar and other German investigators (Dunbar and Thumm, 1902). They show that with beds of fine material a good effluent may be obtained by a single contact, but at the cost of such clogging as to necessitate somewhat frequent removal of the upper portion of the bed. Even the 1½-inch stone showed some clogging after two years, and with such coarse filling a single contact will not, of course, produce a stable effluent.

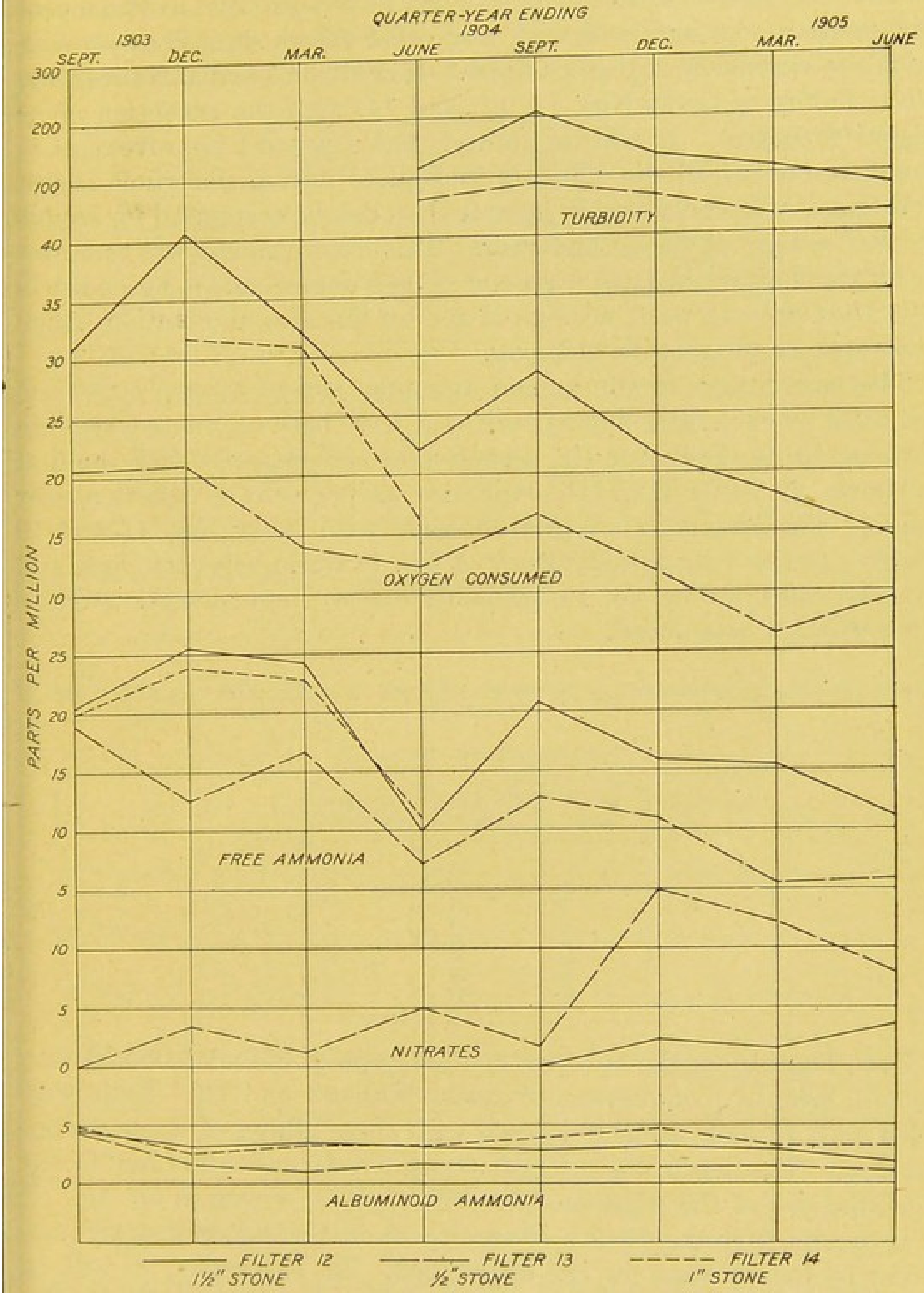

FIG 18.—Comparison of effluents from primary-contact beds of various-sized stone.

Tank No. 14A, constructed on Dibdin's plan of multiple-surface contact (Dibdin, 1904), represents a logical outcome of the desire to secure permanence by increasing the size of the material. It was filled, as described above, with bricks laid in regular tiers with the largest obtainable open space, doing away as far as possible with all straining action. Its original capacity of 48 per cent fell in a year only to 40 per cent, and with three fillings a day gave a rate of 2 to 50 per cent higher than was obtained with any other filters similarly operated, with the exception of the coke bed. Its effluent compares favorably with that from tanks Nos. 11, 12, and 14, with the exception of its higher turbidity. It will be noticed that a general improvement in the character of all the effluents took place during the whole period and that it was considerably greater than can be accounted for by the weaker sewage of the second year. This improvement was manifest in all the contact beds to a greater or less degree, and is no doubt in part, but only in part, accounted for by the straining action which accompanies progressive clogging.

The percentages of albuminoid ammonia and of oxygen consumed removed by each filter during each year have been calculated, and the increase in the figures in the second year as compared with the first is shown in Table LXVIII, expressed as per cent of the first-year value. The anomalous results obtained with tanks Nos. 17 and 19 are due to the very low efficiency of No. 17 during the first year and to a deterioration of No. 19, probably due to the overseptic effluent with which it was dosed.

Table LXVIII.—*Improvement in percentage efficiency of contact filters in second year of operation.*

[Per cent of first-year value.]

No. of tank.	Albuminoid ammonia.	Oxygen consumed.
11	20	40
12	25	83
13	24	23
16	18	17
17	20.8	71
18	18	13
19	19	9
20	45	32

Data bearing on the effect of contact beds of different depths may be obtained by comparison of tanks Nos. 12 and 20. Both were filled with 1½-inch stone and dosed with three fillings of crude sewage per day. The depth was 6 feet for tank No. 12 and 4 feet for No. 20. The analyses of the representative effluents are shown in fig. 19. It is apparent that the results of treatment in the 4-foot bed are consistently better than in the 6-foot bed. In particular, it will be noticed in Table LXVI that the nitrification is more complete in the shallow filter, but the difference is scarcely great enough to compensate for the diminished rate.

With regard to the rate of operation it has been found, as stated above, that three daily fillings give the most satisfactory results.

Between August, 1903, and January, 1904, tanks Nos. 13 and 16, otherwise similar in all respects, were operated with two and three daily fillings, respectively. Tank No. 16, with three fillings, gave the best effluent, as indicated in fig. 20. In January, 1904, the rate on tank No. 13 was doubled to four fillings. During the next few months, while the effluent from tank No. 16 was steadily improving, that from tank No. 13 deteriorated. Apparently two fillings are insufficient to maintain the maximum efficiency of the purifying organisms in the bed, while four fillings put a somewhat undue strain on their powers. After June, 1904, both beds were operated with three fillings and gave approximately the same results. Those from

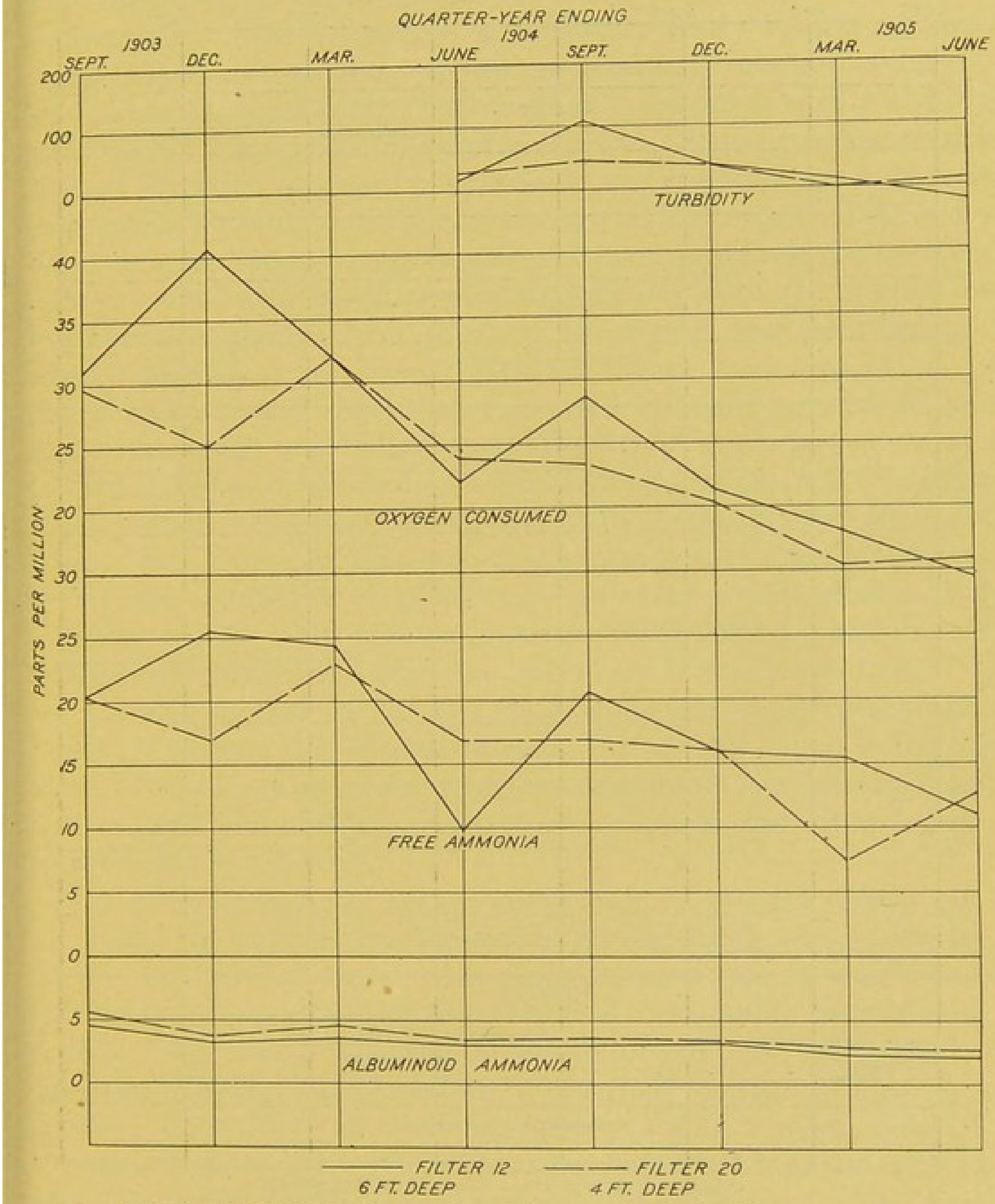

FIG. 19.—Comparison of effluents from primary-contact beds of different depths.

tank No. 16 were a little better, probably because its surface was not cleaned and a considerable straining effect was exerted.

A comparison of the operation of tanks Nos. 19 and 20 furnishes interesting results with respect to the value of preliminary septic treatment. Both were 4-foot beds of 1½-inch stone, receiving, first, two fillings, later, three fillings a day. Tank No. 19 received septic effluent from tank No. 10, which had been subjected to twenty-four hours of septic action and six hours' additional storage in a small dosing tank, into which the effluent from No. 10 flowed continuously. The analyses of the effluents from Nos. 19 and 20, as well as from their secondary

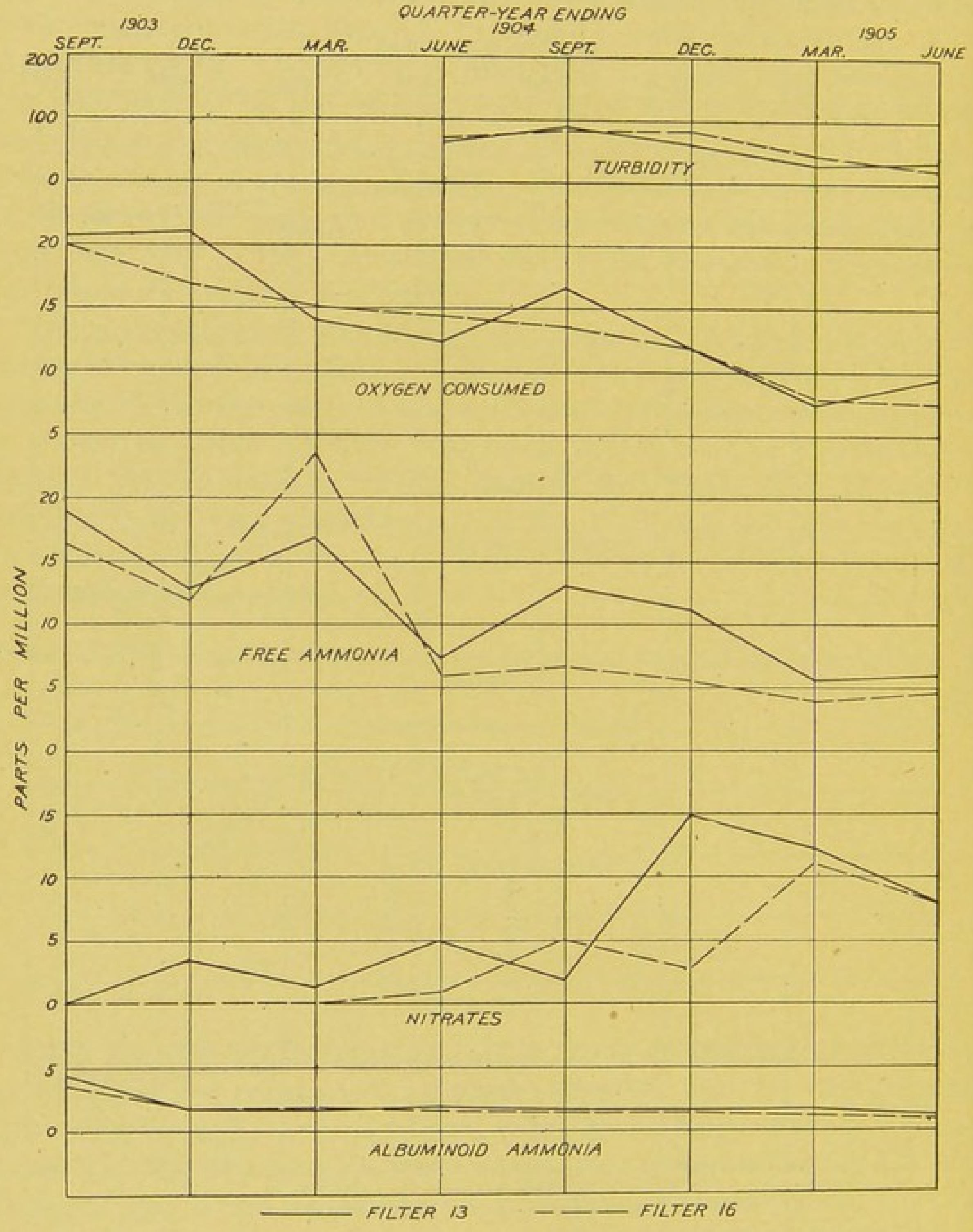

FIG. 20.—Comparison of effluents from primary-contact beds at different rates.

beds, Nos. 17 and 18, are shown in fig. 21. It will be noticed that the effluent of tank No. 20 was markedly superior to that of No. 19 in every respect, except, for part of the time, in its albuminoid-ammonia content. The effluent from No. 20 was often nonputrescible, while that from No. 19 was always foul and offensive. As pointed out above, the septic treatment was efficient in preventing clogging, the final capacities of tanks Nos. 19 and 20 being 38 and 26 per cent, respectively. This advantage is, however, dearly bought, since the septic effluents from Boston sewage evidently contain substances inimical to bacterial action, which seriously interfere with subsequent purification. The possibilities of preliminary septic treatment before contact filtration can not be considered as exhausted, since only this long period (twenty-four hours' storage in the septic tank and six hours in the dosing tank) has been tried; a shorter period might remove solids without interfering so seriously with the contact bed. Furthermore, the harmful effect of the septic treatment might be largely minimized by special aeration before final treatment. All that the experiments have so far shown is that thirty hours of septic treatment yields unsatisfactory results, while crude sewage may be treated with the production of a good effluent at the risk of clogging, which would necessitate the renewal of the beds at intervals of some years. It is probable that a shorter septic period approaching more nearly the condition of plain sedimentation would maintain the capacity of the beds without corresponding harmful effects. The analyses of the effluents from the secondary filters, tanks Nos. 17 and 18, are also plotted in fig. 21. In nitrogenous constituents and in available oxygen the effluent of tank No. 18 was much better than that of No. 17. The former was clear and stable, the latter generally dark-colored and smelling of hydrogen sulphide and often failing to pass the incubator test.

The general results of these experiments on contact treatment, as measured by oxygen consumed, are plotted in fig. 22. Like fig. 7 (p. 68), for experiments at other places, it shows that a single contact will remove from one-third to one-half of the organic constituents of sewage, with the production of an improved but still putrescible effluent. Tanks Nos. 13 and 16, of one-half inch stone, form an exception, since their effluents were fairly stable toward the end of the experiments. This efficiency, as has been explained (pp. 133–134), was obtained at the expense of serious surface clogging. The double-contact treatment effected a removal of one-third to one-half of the remaining organic matter, producing a satisfactory effluent in the case of the treatment of crude sewage.

To summarize the conclusions arrived at in regard to the construction of contact beds, it appears that a 4-foot depth gives somewhat better results than a 6-foot depth, but with greater capacity loss and lower rates. Either coke, brick, or broken stone, or probably any other hard material, may be used for filling, with a slight advantage

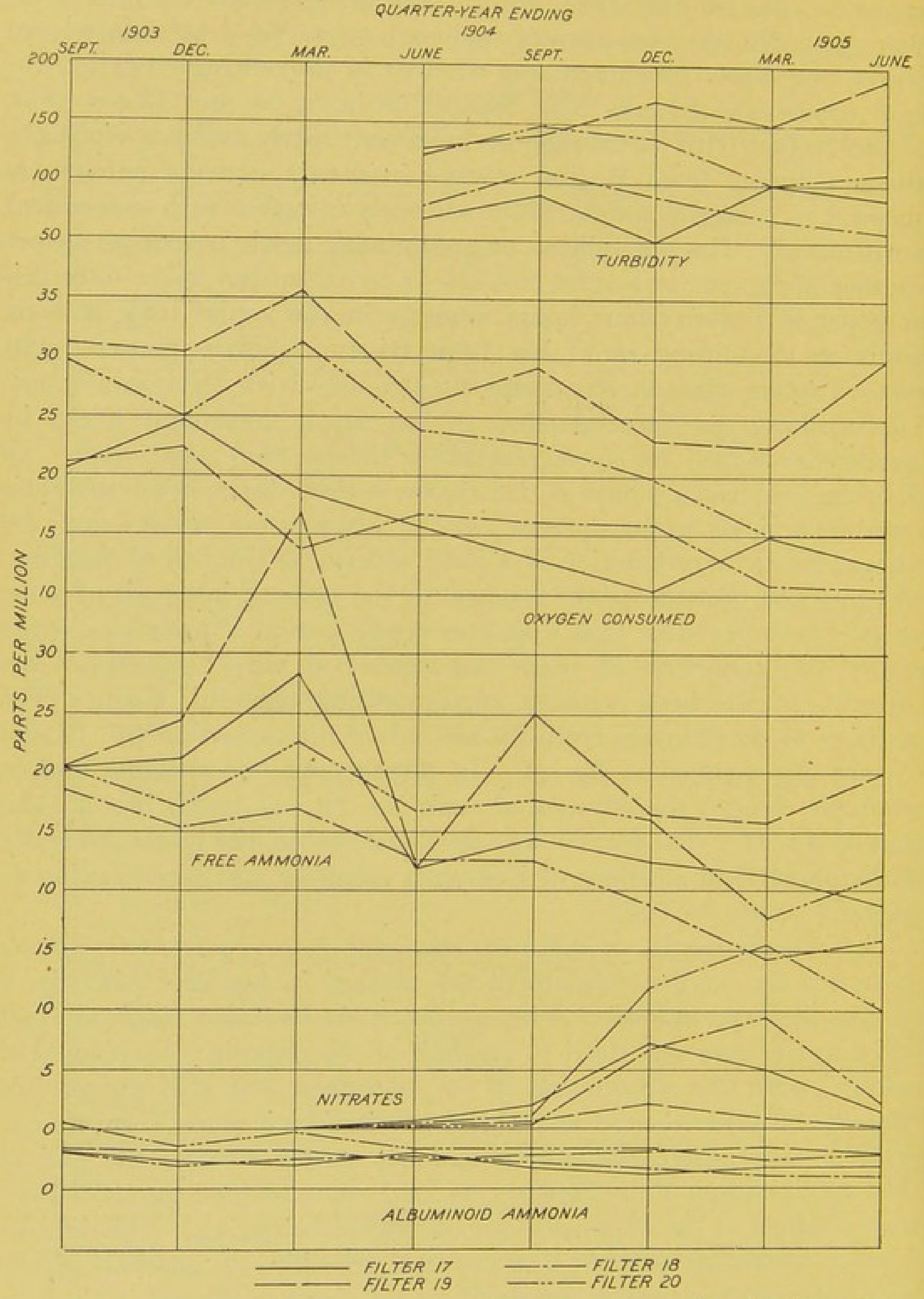

FIG. 21.—Comparison of effluents from double-contact systems taking crude and septic sewage.

for coke. The size of the material is more important than the kind. Half-inch stone gives much better results than coarser material, yielding a nonputrescible effluent even with a single contact. The surface of such beds must be cleaned once a year or oftener. With 1½-inch stone the surface deposits need not be removed so frequently, and with still coarser material, such as 2-inch coke, the surface needs practically no attention; but all effluents from beds of material over one-half inch in diameter require treatment in secondary beds. In every case the beds treating crude sewage will lose capacity so rapidly as to necessitate renewal.

The contact beds have been operated most satisfactorily with three fillings a day, giving a single-contact rate for 6-foot beds of 1.2 with fine-stone filling, 1.4 with coarse stone, 1.8 with 2-inch coke, and 2 with brick. The brick bed might be built, according to Dibdin's original plan (Dibdin, 1904), of slate, so as to gain a still larger capacity. With any material other than the one-half inch stone a second contact would be necessary, reducing the rate on the double system, as a whole, to between 0.6 and 1.

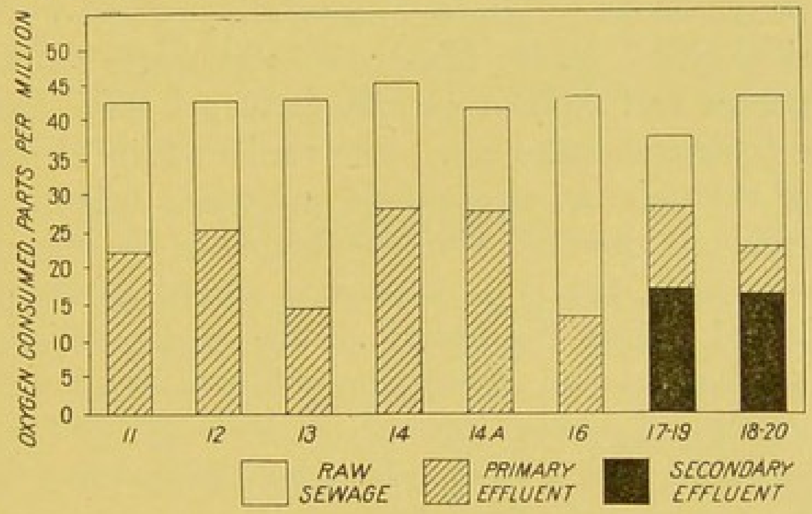

Fig. 22.—Comparison of sewages and effluents from single and double contact beds.

CONCLUSIONS BEARING ON THE TREATMENT OF BOSTON SEWAGE.

Nothing has so far been said about the process of purification by trickling over beds of coarse material. According to the results of recent English experiments this should be the most promising method of all. Three of the tanks have been operated on this principle—No. 15 for the whole two years and Nos. 22 and 23 during 1904–5. They were operated at high rates—from 1.5 to 2.5 million gallons per acre per day—and produced somewhat turbid effluents which after sedimentation were nonputrefactive. They were entirely free from surface clogging. It does not seem justifiable however to lay stress on the results obtained. The two most important points in the operation of the trickling filter are the distribution system and the effect of weather conditions. While sand filters and contact beds may fairly be tested in experiments like those recorded in this paper, it is apparent that trickling filters of only 16 square feet area, dosed with tipping buckets and operated under cover, do not furnish a criterion of actual conditions. It has therefore been decided to conduct during 1906 a series of experiments on a larger scale, out of doors, and to postpone any discussion of trickling-filter results until those experiments are completed. The conclusions in this paper will, therefore, be limited to the discussion of the septic, sand, and contact processes.

It will be necessary in any treatment to screen out large floating bodies and to settle out mineral detritus. This process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to about 1,600 pounds per million gallons of sewage and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected if desired by treatment in the septic tank. An open tank operates as well as a closed tank, and there is no marked advantage in filling the tank with stone. Varying the storage period from twelve to forty-eight hours produces no difference in the effluents which is measurable by analytical results. All the tanks removed nearly two-thirds of the suspended matter and yielded an effluent which was clear but much darkened by hydrogen sulphide. The tanks on an average received 50 pounds of nitrogen as albuminoid ammonia (dissolved and suspended), of which 30 pounds were discharged in the effluent, 15 to 17 pounds decomposed and 3 to 5 pounds stored as sludge. In the decomposition of sludge the length of the septic period is of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed, is twice as great with a forty-eight-hour period as with a twenty-four-hour period and four times as great as with a twelve-hour period.

Under the conditions of these experiments crude Boston sewage has been successfully filtered through a 2-foot bed of sand with an effective size of 0.14 millimeter, at a rate of 0.4 million gallons per acre per day, divided into four doses in the 24 hours. Such high rates should not be expected in actual practice, but it is believed that with care in construction and operation the sand filter may be efficient at higher rates than have been generally advocated. The effluents obtained from the sand beds were clear, bright, and well purified. The depth of the beds can not safely be reduced below 2 feet. Preliminary septic treatment for twelve or twenty-four hours does not improve the effluents obtained with sand filtration, although it makes the care of the surface of the beds somewhat easier.

Crude Boston sewage may be treated in single-contact beds of fine stone (one-half inch in diameter) at a rate of about 1.2 million gallons per acre per day. The effluent is only partially purified, but is generally so stable as to be discharged into a considerable volume of water without any tendency to create a nuisance. The beds clog rapidly and the surface needs much attention. The double-contact system of treatment, in primary beds of 2-inch material and secondary beds of one-half-inch material, yields a fairly well purified and stable effluent at a rate on the combined double system of about 0.7 million gallons per acre per day with beds 6 feet deep. Such a system clogs much less seriously, but nevertheless loses sufficient capacity to require renewal every few years. Preliminary septic treatment obviates this capacity loss to a considerable extent. In these experiments a thirty-hour septic period produced an effluent which without aeration was so difficult to purify as to interfere seriously with the efficiency of the contact beds. There is little doubt that this difficulty could be overcome by aeration or by shortening the septic period. The most practical of the methods which have been studied would appear to be the treatment of sewage, either sedimented or subjected to a very short period of septic action, in double-contact beds. The process of trickling filtration remains to be considered in a further report, but incomplete results obtained at the present time indicate that this method will probably prove superior to any so far tested.

ACKNOWLEDGMENTS.

The writers desire to express their acknowledgments to Mr. E. S. Dorr, of the Boston sewer department, for many courtesies; to Messrs. W. S. Johnson and Leonard Metcalf for advice in regard to certain points in the conduct of the experiments; to Prof. L. P. Kinnicutt and Mr. G. W. Fuller for suggestions concerning the presentation of results; and to Messrs. G. R. Spalding, W. H. Beers, and W. T. Carpenter for assistance in analytical work and in the preparation of tables and diagrams.

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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 185.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress, for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at practically cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities thruout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the fifteenth in Series L, the complete list of which follows (WS= Water-Supply Paper):

SERIES L, QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls. (Out of stock.)
WS 22. Sewage irrigation, Pt. II, by G. W. Rafter. 1899. 100 pp., 7 pls. (Out of stock.)
WS 72. Sewage pollution near New York City, by M. O. Leighton. 1902. 75 pp., 8 pls.
WS 76. Flow of rivers near New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.
WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp., 15 pls.
WS 103. Review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp.
WS 108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.
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WS 161. Quality of water in upper Ohio River basin and at Erie, Pa., by S. J. Lewis. 1906. 114 pp., 6 pls.
WS 179. Prevention of stream pollution by distillery refuse, based on investigations at Lynchburg, Ohio, by Herman Stabler. 1906. 34 pp., 1 pl.
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NOVEMBER, 1906.