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Removal of Colloids from Sewage

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INTRODUCTION. This article summarizes a series of experiments on colloid removal, started in a small way in the spring of 1921 and pursued more or less continuously since that time.

In a previous publication (State Water Survey Bulletin 18) we compared the evidence in favor of two opposing theories concerning the removal of colloids from sewage, namely: the Hampton doctrine enunciated by Travis, according to which the precipitation of colloids as brought about by sewage filters and other contact surfaces is purely physical in character; and the Dunbar theory, which maintains that microbial action is essential to the process. From our observations previously reported (Bulletin 18, chapter VI) we concluded that the flocculated material either on trickling filters or in activated sludge was composed principally of microbial growth and that the process of colloid precipitation is dependent upon the presence of microscopic organisms. Physical and chemical conditions affect the process through their action on the organisms. In view of these conclusions it seemed advisable to direct our attention more particularly to the character of the microbial organisms that effect the removal of colloids, rather than to the purely physicochemical conditions.

Microscopic examination had shown that the organisms in activated-sludge flocs and on the surface of the rocks of trickling fiters belong to a group that is commonly found in nature under conditions of very low oxygen. This observation naturally raised the question as to whether the highly aerobic condition commonly considered necessary for the growth of activated-sludge flocs was really essential to the process. A consideration of this question led to the following analysis of the reactions occurring during sewage purification.

Colloidal organic matter may be removed in two ways: it may be *decomposed* into inert substances, or it may be *precipitated. Decomposition* may be brought about by purely chemical reagents, but the amounts of reagents required are so great that this method has never even been suggested for sewage treatment. *Bacterial decomposition,* which is well known and frequently employed, may be brought about under either aerobic or anaerobic conditions. Under aerobic conditions the principal products of decomposition are carbon dioxide and an insoluble humus residue which will settle out and is not capable of much further oxidation by organisms. Under anaerobic conditions the two principal products are methane, which is relatively insoluble, and an insoluble inert humus. The time required for effective removal of organic colloids by bacteriolytic action is several weeks, and the process is, therefore, not practically applicable.

STEPS IN BIOPRECIPITATION. *Precipitation* of colloids may be brought about by chemical coagulants. As is well known, this process is in use in certain plants, but its usefulness appears to be limited by the cost of chemicals and the problem of the disposal of the sludge. Colloids may also be said to be precipitated if they are taken up as food by micro-organisms of such growth habits as to form large compact flocs that will settle out. This process for the removal of sewage colloids we have called *bioprecipitation.* The steps in this process were analyzed in an earlier paper (Engineering News-Record, May 10, 1923) essentially as follows:

There are apparently four important points involved when bioprecipitation is • brought about by the activated-sludge process, each of which we will represent in Fig. 1 as follows: (I) the water surface, by a straight line; (II) an activated-sludge floc, by a rough oval; (III) a colloidal particle of organic matter, by a large dot; (IV) a dissolved molecule of organic matter, by a small dot. The process involves six reactions:

(1) The air must saturate the liquid surface. The work of Langmuir (J. Am. Chem. Soc. 40: 1361-1403) indicates that enough gas

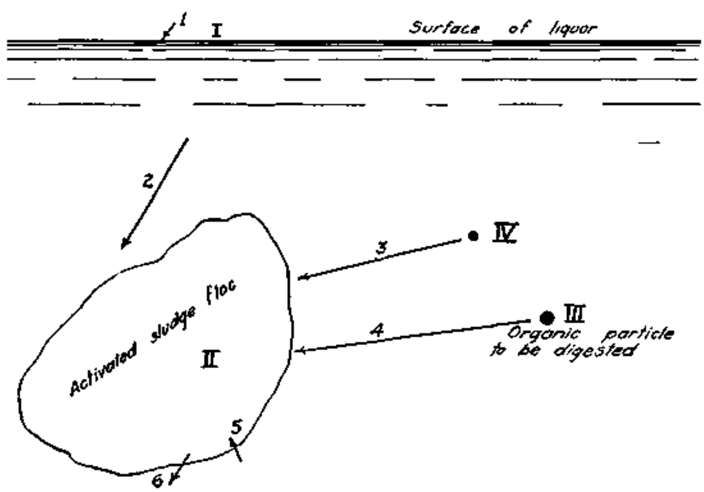

FIG. 1. GRAPHICAL REPRESENTATION OF THE SIX PROCESSES IN THE DIGESTION OP SLUDGE

1. Oxygen rapidly enters skin of liquid. 2. Slow process of getting air to organic particle. 3 and 4. Also slow diffusion process of getting dissolved molecules and colloids to particle. 5. Comparatively rapid action of digestion by organisms of the sludge floc. 6. By-products of biological growth must diffuse away to prevent poisoning the growth. This is a slow process.

molecules strike such a surface to saturate it in an infinitesimally short time; thus a thin layer of water saturated with oxygen always exists at the surface.

(2) This oxygen must then diffuse to the activated-sludge particles. This is an exceedingly slow process, as was pointed out more than thirty years ago by Noyes and Whitney (Z. Phys. Chem. 23: 689) and later emphasized by Black and Phelps in their New York Harbor report.

(3) The dissolved molecular or organic stuff must diffuse to the activated-sludge particles. This, also, being a diffusion process, is slow.

(4) The colloidal particles must get to the activated-sludge floc somehow or other. Since the actual change of position of colloidal particles in a quiet liquid is practically zero, outside mechanical forces must come into play.

(5) The organic material and the oxygen must be taken up and worked over by the organisms of the sludge floc. As far as we are able to tell, this is a comparatively rapid process.

(6) The by-products of the biological growth must diffuse away from the sludge floc; otherwise they will accumulate and poison it.

IMPORTANCE OF STIRRING AND AERATION. Of the six steps that must take place, all except the first and fifth are comparatively slow. The only way that we can speed up the other four steps in this process is by stirring. Stirring sweeps the saturated surface film down into the liquid, thus bringing oxygen into contact with the activated-sludge particles. Stirring also brings the dissolved and colloidal organic matter into contact with the floc and sweeps away the metabolic products of the sludge organisms.

Air blown into the aeration chamber of an activated sludge plant does three things: (1) it maintains the sludge in suspension; (2) it maintains aerobic conditions; and (3) it stirs up the mixture, allowing fresh liquor to come into contact with the sludge. The same considerations apply to mechanical aeration. In Haworth's process, for example, a critical velocity, namely, 1.5 feet per second, in his circulation channels was found necessary. The question arises, therefore, which one of these three factors determines the critical minimum air requirement. The relative importance of aerobic conditions and stirring cannot be balanced by means of any previous data.

The principal value of theoretical speculation, according to the late Professor Remsen, is to furnish a basis for experimental investigation. The analysis given above suggested several points requiring confirmation concerning the mechanism of the microbial removal of colloids from sewage. These points are:

(1) To determine the relative efficiency of mechanical agitation and compressed air for introducing oxygen from the atmosphere.

(2) To determine whether or not it is possible to precipitate colloidal

and dissolved organic substances through the agency of micro-organisms, that is, whether bioprecipitation really occurs.

(3) To determine the minimum amount of oxygen required to maintain bioprecipitation.

(4) To determine whether the experimental apparatus used in answering the first three questions might be modified and enlarged so as to be useful in practice.

The study of mechanical methods of aeration is reported in detail in State Water Survey Bulletin 25, now in preparation. In brief, it may be summarized as follows:

Early observations by various investigators had shown that a comparatively small portion of the air introduced into sewage through porous plates was actually taken up by the liquor. The reason for this appears to be that air bubbles, in rising to the surface of a liquid, carry with them a thin film of the liquid and it is only this film which becomes saturated with the gas. Mechanical agitation results in the continual breaking-up of such saturated films and the formation of new surfaces which in turn are quickly saturated by the gas to be dissolved. If we wish to produce a solution of air in water, mechanical agitation is the efficient method to use.

DEMONSTRATION OF BIOPRECIPITATION. That bioprecipitation actually occurs was demonstrated in the following manner:

Solutions of peptone were seeded from a pure culture of *B. subtilis* and incubated under various conditions for periods of 24 to 72 hours. The results of these experiments are described in detail in Bulletin 25. They may be summarized by stating that from 10 to 20 per cent of the nitrogen in the media was precipitated in the form of flocs consisting of filaments of the organism. It is interesting to note that during these experiments the phenomenon of "bulking" was observed under conditions that pointed clearly to the cause of this in the particular instance. It was observed that, when the cultures matured and began to produce spores, the organism no longer formed large compact flocs but broke up into fine feathery particles which did not settle. This observation suggests that, in some cases at least, "bulking" of activated sludge may be due to the age of the organisms in the sludge.

MINIMUM AIR REQUIREMENT. The minimum air requirement for bioprecipitation was determined by introducing into the sewage liquor a measured amount of oxygen either as compressed air or by means of stirring. Small-scale experiments for determining this factor are described in detail in Bulletin 25. They indicate that bioprecipitation occurs with as little as .002 cubic feet of air per gallon.

The amount of oxygen present in the liquor during these tests was seldom sufficient to be determinable by the Winkler method, but there was enough to give a blue color with methylene blue. At this very low oxygen level the same organisms that appear in activated sludge were able to grow. No nitrification occurred under these conditions, even when the period of contact was greatly extended. The question of the possibility of the modification of the apparatus used in these experiments for practical application on a large scale was naturally considered next. A review of previous attempts at the use of similar devices indicated the direction in which changes and improvements were to be made.

USE OF SUBMERGED CONTRACT SURFACES. The usefulness of contact surfaces for the removal of colloids was early recognized. Their practical application was developed along the line of filters rather than of submerged surfaces. (A detailed discussion of the evolution of the trickling filter will be found in Bulletin 26 of this series.) Of the earlier experimenters, Travis seems to have been the most active advocate of the use of submerged surfaces. A tank at Hampton, England, was described in 1906 by Jones and Travis (Proc. Inst. C. E. 164: 68-94) as follows:

"It has been shown that the viscous matters of sewage are deposited on surfaces. In the case of land-treatment these matters are spread over a large surface area; they are exposed to the drying influnce of the atmosphere, whereby they become far less bulky; they become incorporated with the soil as real 'humus' and produce crops. The removal of vegetable matters, and the necessary farming manipulations, tend to prevent the clogging of the porous medium incomparably more effectually than is the case in 'artificial' processes, under any circumstances short of removing and washing the whole of the filtering media....

"In introducing the Exeter tank in 1897, Mr. Cameron said that the sewage flowing into the tank was subjected to no screening whatever; on the contrary, special provision was made for the uninterrupted passage to the tank of the contents of the sewer. He affirmed that the action of the tank was to liquefy all animal and vegetable solids, so that no sludge would be formed; and his statement was supported by many eminent chemists and bacteriologists.

"Others have suggested chemical precipitation, as well as septic tanks, as necessary for securing that really clear liquid which alone can be passed, with or without sprinklers, through continuous filters or contact-beds, without early clogging.

HYDROEYTIC TANK AT HAMPTON-ON-THAMES. "The most novel means to this end and the one advocated in this communication, is the hydrolytic tank system as installed at Hampton-on-Thames. . . . The apparatus consists of two parts, the hydrolytic tank and the hydrolysis-chambers, having different functions. The tank is so constructed as to permit the chief bulk of the sewage to flow onwards, and to pass through the tank in the shortest time necessary to free it from its suspended matter; while the remaining portion of the liquid passes downwards assisting deposition, and carrying the deposited matters into a special compartment of the tank, where they remain for resolution or subsequent withdrawal. The liquid portion joins the main bulk on leaving the tank. The capacities of the tank are at all times maintained.

"The hydrolysing-chambers are designed so as to present as large a surface area as possible to the flowing liquid, in order, not only to cultivate organisms thereon, and to attract finely-divided or other suspended matter overflowing from the tank, but also to abstract from the liquid such substances in colloidal or other condition of solution, or pseudo-solution, as are depositable upon material with which they come into intimate contact. Provision is made for the withdrawal of the deposited matters when necessary.. .

"The sewage flowing over the weirs at the end of the tank enters a channel which leads to the hydrolysing-chambers. The hydrolysing-chambers are four in number, arranged in sequence. The sewage is conducted to the bottom of each chamber by nine 6-inch stoneware pipes, where it is delivered below three arches, three of the pipes passing through each arch. These arches support the material, and are constructed of bricks arranged so as to leave 2¼ inch openings between them for the passage of the liquid. The floor under each arch is concave, and forms with the arch a space for the reception of sludge; under each concave floor a line of pipes is laid, having two valved openings,

TABLE I

15 December, 1904, to 30 September, 1905. (Average of 128 Series of Samples.)	Temp. ° C.	Parts per 100,000.								Percentage Beduc--tion in Albuminoid Nitrogen
		Solids.		Chlorine.	Nitrogen.				Oxygen Absorption.	
		In Suspension.	In Solution.		Ammo-n iacal.	Albuminoid.	Nitrous	Nitric.		
Crude sewage	14.2	32.1	97.6	14.2	7.56	1.16	nil	nil	8.1	..
Hydrolytic effluent.	14.3	3.7	95.0	15.1	7.42	0.42	nil	nil	7.4	63.8
Thirdcontact effluent .	16.0	nil	87.3	15..0	0.91	0.08	0.01	2.50	0.7	93.1

TABLE II

May to August, 1005. (Average of Eight Series of Samples.)	Farts per 100,000.							
	Solids.		Chlorine.	Nitrogen.		Oxygen Absorption. 4 Hours	Settled.	
	In Suspension.	In Solution.		Ammoniacal.	Albuminoid.		Albuminoid Nitrogen.	Oxygen Absorption. 4 Hours
Crude sewage . .	20.7	91.3	13.5	7.09	1.09	8.9	0.50	5.7
Hydrolytic tank .	1.2	92.0	9.7	6.21	0.46	5.8	0.42	5.2
Hydrolysing-chambers	6.0	90.0	10.5	7.29	0.37	8.1	0.31	7.4

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

by means of which the deposit is removed. . The material is broken flints, varying in diameter between 3 inches and 6 inches. The liquid passes upwards through the openings between the bricks, and through the material to the surface, where it flows over a weir, and enters the downward stoneware pipes of the next chamber? After the operation has been repeated in the four chambers, the liquid, having taken 3 hours in its passage, enters the lower covered channel which conducts it to the contact-beds. ..

"The work done by the hydrolytic tank and the hydrolysing-chambers is shown by Tables II and X [shown here as Tables I and II]. As previously stated, the quantity of sewage which has passed through the system has been 78,500,000 gallons. The average reduction effected in albuminoid nitrogen is seen to be 63.8 per cent. The weight of sludge which has been removed is 783.3 tons, equal to 10 tons per million gallons, or 47.6 per cent of the total quantity received. The cost of the tank installation, including ventilating-machinery, ejector and buildings, was 2,800 pounds."

SHORTCOMINGS OF TRAVIS "COLLOIDERS." Later, Travis modified this type of installation by introducing laths placed vertically in the sedimentation chamber of his hydrolytic tank. These laths were placed on centers spaced from 6 to 9 inches apart, and the material which collected upon them was allowed to remain until it dropped off into the lower portion of the sedimentation chamber where it was conducted by a current into the sludge chamber. The analytical results did not appear to justify the cost of the Travis type of installation. Numerous other attempts have been made to remove colloids in a similar way.

Previous experiments led us to believe that the limited success of the Travis "colloiders," as his devices were called, was due to three factors. First, the small amount of surface afforded by these colloiders could not be expected to be very effective. Our experiments on activated sludge showed that in the aeration chamber the sludge particles presented a surface of 500 square feet per cubic foot of tank volume. An increase in the amount of surface, therefore, should increase the purification. The second factor which apparently limited the success of the Travis colloiders was the lack of any provision for the removal of the precipitated material from the contact surfaces after it had collected there. Failure to provide such arrangement was due, no doubt, to Travis' fixed opinion that bacteria had nothing to do with the purification process. When bacteria are taken into account, one would normally expect that the organic matter, once precipitated on the contact surfaces, would be subject to the attack of putrefying organisms which characteristically liquefy organic matter. Apparently, the material allowed to remain on the surface of the colloiders became septic and partly liquefied and was thereby redispersed in the liquid; thus the precipitation was largely offset. The third reason for the limited success of the Travis colloiders, namely, failure to maintain aerobic conditions, was also overlooked on account of a lack of recognition of biological principles. It is commonly known that organisms growing in large compact masses are aerobic, while anaerobic activities are essentially liquefying in their results. With a fresh, well-aerated sewage a considerable growth of colloid-precipitating organisms would appear on the colloiders, but with a slightly stale liquor such growth would not appear or would be very slight.

FIG. 2. SMALL NIDUS TANK, OPERATED 1921-1922

SMALL-SCLE EXPERIMENTS. During 1921 and 1922, several types of devices were experimented with on a small scale to determine the usefulness of submerged contact surfaces when the above three factors were taken into account. One of these devices, shown in Fig. 2, consisted

TABL

SUMMARY OF RESULTS OF OPERATION OF NID

Period	Date	Feed Gallons per day	Air Cu. ft. per gal.	Average detention Hrs.	Suspended solids Infl. p.p.m.	Suspended solids Effl. p.p.m.	Suspended solids Per cent removed	Turbidit Infl. p.p.m.	Turbidit Effl. p.p.m.
	1923								
I.	July 23 to 29	8648[a]	*	3.6	---	---	---	228	133
II.	Nov. 8 to 21	9601[a]	**	3.2	81	36	55.5	151	79
	1924								
III.	April 21 to May 11	6344[b]	.18	5.0	93	21	77.4	160	53
IV.	June 9 to 22	5114[b]	.29	6.0	98	26	70.6	158	88
V.	July 16 to Aug. 4	5057[b]	.16	6.0	---	---	---	227	93
VI.	Aug. 5 to 18	5041[b]	*	6.0	---	---	---	230	128
VII.	Sept. 5 to 18	21541[b]	.23	1.4	160	48	69.5	257	121
VIII.	Sept. 19 to Oct. 7	21543[b]	.22	1.4	186	56	69.5	274	120

* Aeration by gentle stirring. ** Compressed air was added, to supp
changed 3 times per day to stimulate practical conditions.

of a trough 8 inches wide, 18 inches deep, and 20 feet long. The first 2 feet were divided off for the removal of heavier solids by sendimentation. After sedimentation the sewage flowed past a series of 20 frames wound with heavy cord, the cord furnishing surfaces for the growth of colloid-precipitators. Arrangements were made to shake these frames by hand at desired intervals. Heavy growth accumulated on the upper portions of the frames, but there was no growth on the more deeply submerged portions, because anaerobic conditions existed in the bottom of the trough. For the purpose of producing aeration, a 2-foot wheel wound with cord was revolved in this trough during a portion of the experiment; but on account of the crudeness and small size of the device, no quantitative data could be obtained.

Another small-scale experiment of an intermittent type was carried out by means of a rack of 80 cords, each 16 inches long, so arranged as to be alternately immersed in, and withdrawn from, the sewage in a 20-gallon vessel. This dipping type of contact surface provided circulation and aeration and produced considerable purification in the liquid.

EXPERIMENTAL PLANT OPERATION. These small-scale qualitative experiments were followed by the construction of an experimental plant large enough to be operated continuously and subjected to adequate analytical control. Details of the construction and operation of this experimental plant will be found in Bulletin 25, State Water Survey Series.

Briefly, the plant consisted of a tank, 8 feet in diameter and 4 feet deep, in which were placed 8 screen-wire racks of triangular cross-section so designed that, when stood on end within the circular tank, they filled the entire volume except for a central octagonal well, 18 inches in diameter," and 8 peripheral segments.

Sewage was introduced into the central well of this tank and was caused to circulate through the racks. During some of the experiments this circulation was brought about by means of a revolving pro-

: III

us Tank, July 23, 1923 to October 7, 1924

r cent moved	Oxygen consumed from $KMnO_4$			Ammonia nitrogen		Alb. NH_3 nitrogen		Nitrite nitrogen		Nitrate nitrogen	
	Infl. p.p.m.	Effl. p.p.m.	Per cent removed	Infl. p.p.m.	Effl. p.p.m.	Infl. p.p.m.	Effl. p.p.m.	Infl. p.p.m.	Effl. p.p.m.	Infl. p.p.m.	Effl. p.p.m.
4.2	---	---	---	---	---	---	---	---	---	---	---
45.5	51	33	34.2	28	29	5.2	4.0	.159	.017	.94	.42
66.7	35	25	30.9	43	37	10.0	5.5	.626	.105	4.67	.66
44.3	51	48	4.3	24	30	10.5	8.2	.590	.050	5.27	.49
58.4	56	44	24.8	53	63	11.3	7.5	.050	.006	1.51	.61
44.9	73	54	26.0	50	51	9.9	6.1	.051	.003	.98	.46
52.9	73	54	26.0	50	47	9.9	8.7	.056	.004	1.05	.43
56.2	66	47	28.7	37	37	7.3	5.7	.033	.002	.66	.33

ly .0015 cubic feet of dissolved oxygen per gallon. [a] Constant. [b] Rate peller in the central well and in other experiments by means of compressed air introduced through a filtros plate at the bottom of this well. The operation of the plant was divided into 8 separate periods, or experiments.

Since the object of the experiments was to study the factors influencing the removal of colloids, the tank was fed with sewage from which the coarser solids had been removed as completely as possible by means of two or three wire screens of 1/4 to 1/16 inch mesh. No facilities were available for preliminary sedimentation, but data on the amount of screenings removed, and on the liquor before and after screening, indicated that the amount of material removed was practically equivalent to that ordinarily removed by one-hour sedimentation. The operating schedules during the eight periods are given below.

Period I—(July 23-29, 1923)—The tank was fed at a constant rate amounting to 8,640 gallons of screened sewage per day. The detention period was 6 hours. Aeration and circulation were provided by means of a propeller in the central well, which imparted an upward velocity of 1 foot per second to the liquid. During this period, all of the racks were shaken at 8 a. m. and 5 p. m. in order to dislodge the growths of colloid-precipitating organisms that had accumulated. Because of the constant flow, an experiment of this sort could not give results entirely comparable with practical conditions, the sewage flow during the night being exceedingly weak; however, the sampling periods were arranged to offset this error as far as possible, as will be seen from the detailed description of these experiments. Difficulty was experienced in removing from the tank the sludge which was dislodged from the racks. Changes in subsequent experiments were made to offset this difficulty.

Period II—(November 8-21, 1923)—The rate of flow was increased to 10,000 gallons per day, cutting down the detention period to 3 hours, and the direction of the propeller was reversed. Arrangements were also made to return 25 gallons of liquor per minute from a secondary sedimentation tank, so as to increase the velocity through the tank and prevent the accumulation of sludge. Arrangements were also made to saturate a portion of the liquor with air by means of a separate aerator. This aerator was a cylindrical tank, 2 feet in diameter and 10 feet deep, provided with a filtros plate at the bottom. The separate aerator was used as an experimental means of determining the amount of dissolved oxygen introduced into the process, with no thought of its practical application. The amount of oxygen used during the process was estimated from determinations of the amount of dissolved oxygen entering with the liquor which had passed through the aerator.

Period III—(April 21-May 11, 1924)—For the purpose of demonstrating the disadvantage of contact surfaces from which growths could not be removed at regular intervals, the tank was operated without shaking the racks during this period. Aeration and circulation were provided by means of air introduced through filtros plates set in the central well. The air used amounted to 0.18 cubic feet per gallon.

Period IV—(June 9-22, 1924)—Operation without the removal of growth from the racks was continued. The rate of flow was changed three times a day in order to simulate practical conditions; that is, the relative amounts of night and day sewage used were proportioned to the previously determined rates of flow in the city sewer. The detention period during this experiment was S hours, and circulation was provided as before by the use of 0.16 cubic feet of air per gallon. As a result of not shaking the racks, the tank became septic, and it was impossible to establish aerobic conditions with as much as one cubic foot of air per gallon.

Period V—(July 16-August 4, 1924)—During the fifth period, the operation was similar to that in the fourth period except that the racks were shaken three times a day to dislodge the growths, with the result that good operating conditions were restored.

Period VI—(August 5-18, 1924)—During the sixth period, the propeller was used, as in the first experiments, instead of compressed air. Under these conditions results about equal to those in the fifth period were obtained.

Period VII—(September 5-18, 1924)—The flow was practically doubled to determine what effect, if any, the length of the detention period had upon the purification. During this period, 0.2 cubic foot of air per gallon was used, one-sixth of the air being introduced through a filtros plate in the central well and five-sixths through the separaate aerator.

Period VIII—(September 19-October 7, 1924)—Inasmuch as the previous experiments had showed definitely that bioprecipitation could be maintained with only 0.2 cubic feet of air per gallon, the outside aerator was discarded and the plant was operated with the introduction of 0.2 cubic feet of air per gallon through a filtros plate placed in the central well. Observations had confirmed the prediction that a larger supply of air would be required while treating the relatively strong day sewage than was required for the weak night sewage. The flow of air, therefore, was regulated so that 0.3 cubic foot of air per gallon was used during the day and 0.1 cubic foot at night, giving an average treatment of 0.2 cubic foot per gallon. During this period the interval between the times of shaking the racks was shortened to 4 hours.

The results of these experiments are summarized in Table III. Briefly, they indicate that submerged surfaces, when used in a ratio of surface to volume of 20 or more to 1, will remove 30 per cent of the *nonsettleable* or *colloidal organic* matter from domestic sewage, provided (1) that the accumulated matter is removed from the surfaces at frequent intervals (note period III) and (2) that aerobic conditions are maintained. They also show that bioprecipitation occurs even though the oxygen supply is very low.

NEED FOR INTERMEDIATE METHOD OF TREATMENT OF SEWAGE

Both activated sludge and sprinkling filters produce effluents of very high quality, often carrying less organic matter than the streams into which they are discharged. Tanks, on the other hand, remove only a third of the organic matter. There are many cases where an intermediate degree of purification would be satisfactory. Partial treatment with filters is impracticable, but partial treatment with activated sludge has been employed to relieve the load on trickling filters.

An intermediate device between activated sludge and trickling filters is also needed. In the filter the amount of active surface per cubic foot is low, while in activated sludge it is high. An activated-sludge plant of given capacity is from one-tenth to one-fifteenth as large as a tank and filter installation of like capacity. The operating costs of the former are high, as is also the construction cost of the latter. A device more compact and less costly to build than filters and not expensive to operate would find wide use. The colloiders of Travis, with laths placed in the sedimentation chamber on 6-inch to 9-inch centers, represented a step in the right direction; but the amount of surface was small and the accumulated growths became septic and redispersed. The lath filters of Black and Phelps (N. Y. Harbor Report, 1911, pp. 64-78) were subject to the same limitation. Many filters made of rather fine-grained material have been used in experimental and large-scale installations from time to time but have not come into general use because of the danger of clogging. Brushwood has frequently been employed. Favorable results were reported on a large brush filter in Toronto (Eng. Rec. 75:376). Richards and Weeks (J. Soc. Chem. Ind. 40:2S2R) have experimented with straw filters, and we are operating a small corn cob filter (Eng. Contr. 65:2). Woody vegetable material will decompose in time, and at

FIG. 3. GENERAL VIEW OF EXPERIMENTAL SEWAGE TREATMENT PLANT NOW IN OPERATION

present data are not available to determine whether the cost of replacement of cobs will offset the saving in cost of installation. A recent experiment with an aerated sand filter has been reported by Basiakine (Report of the Commission of Moscow, 1925).

An outline, or suggested classification, of the various types of contact surfaces is given in Figure 4. Slow sand filters, earth filters, and sewage farms were the earlier developments. Their action is more nearly true filtration. The coarser-grained types of surfaces are of more recent development. Several of the types listed in the classification have not passed the experimental stage. Sprinkling filters and contact beds are widely used, and there are many activated-sludge plants in use. Travis colloiders have been installed in a number of tanks, and there are now five installations of Imhoff's "Tauchkorper" (contact aerators) in use in Germany. Imhoff in his *Fortschritte Abwasserreinigung* (1926) points out that there is a loss of head through all of those types

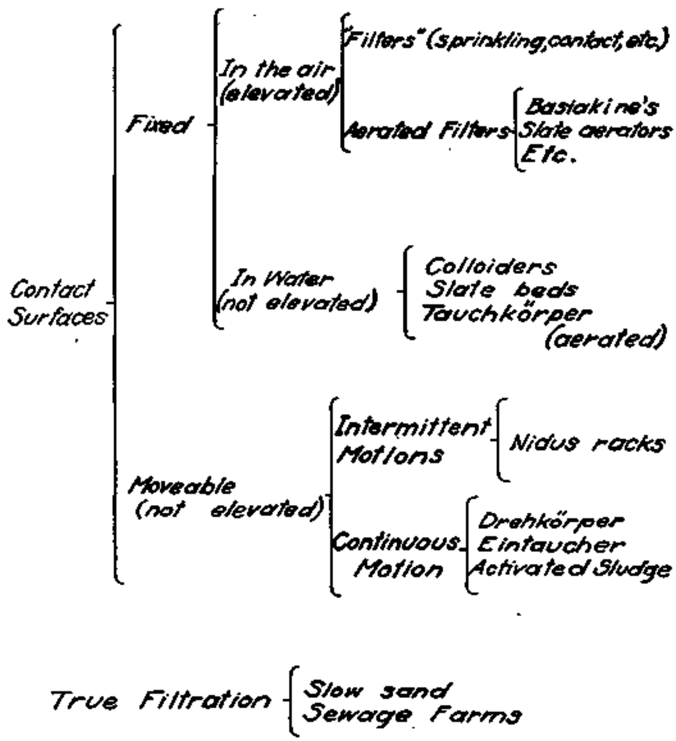

FIG. 4. DIAGRAMMATIC CLASSIFICATION OF DEVICES FOR TREATMENT OF SETTLED SEWAGE

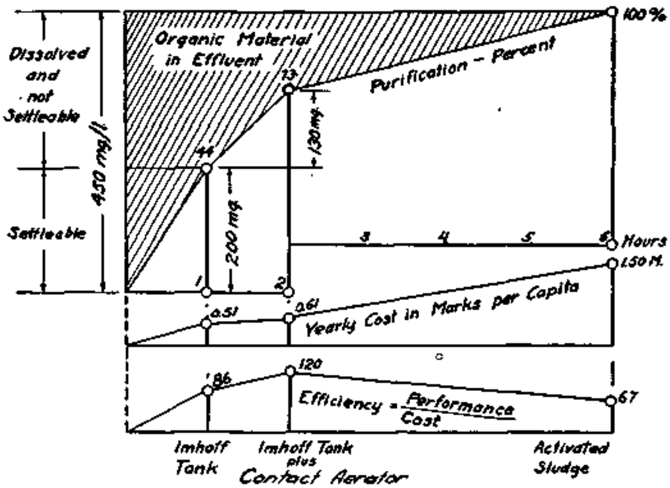

FIG. 5. DIAGRAM (AFTER IMHOFF) SHOWING RELATIVE EFFICIENCY OF IMHOFF TANK ALONE, IMHOFF TANK PLUS CONTACT AERATOR, AND ACTIVATED SLUDGE

Note that the efficiency is calculated on a cost basis.

in which the active surfaces are exposed to the atmosphere, while this is not the case with immersed surfaces like activated sludge, "Tauchkorper," etc.

In the "Tauchkorper" installations the middle third of the sedimentation chamber of an Imhoff tank is filled with brushwood, underneath which an oscillating aerator introduces compressed air. The intermittent aeration removes the growth accumulations, which settle in the last third of the chamber. Using 0.1 cubic feet per gallon, Imhoff obtains about the same degree of purification as in our experiments. Figure S (after Imhoff) gives the relative efficiency by this method.

Subsequent to the work of Shive, experiments with contact surfaces have been continued by the State Water Survey, using tanks constructed to provide for more effective removal of sludge. (These tanks are described in detail in Part III of the forthcoming bulletin.) The result of these experiments confirm the conclusions drawn from Shive's experiments. The data are summarized in Table IV, showing 41 per cent decrease in the B. O. D. and 4S per cent decrease in the organic nitrogen. If the decrease in B. O. D. due to plain sedimentation is considered as 30 per cent, the contact surfaces may be said to have increased the efficiency of the installation by 30 per cent.

TABLE IV

DATA ON THE OPERATION OF LATH NIDUS TANK FROM JANUARY VD TO APRIL 19, 1927

Temperature	Approximate flow in gallons per minute			Average detention period 2 hours
	Maximum	*Medium*	*Minimum*	
12°—15°C.	16	13.6	9.4	Volume = 2040

Composite Samples January 14 to April 19, 1927

	Influent p. p. m.	Effluent p. p m.	Per Cent Removal
*Settling Solids	101.4	49.2	51.4
Oxygen Consumed	53.6	39.6	26.4
Organic Nitrogen	3.24	1.86	45.7
B. O. D.	112.	65.6	41.2

Grab Samples

	Influent p. p. m.	Effluent p. p m.	Per Cent Removal
B. O. D. 6. a. m.			
January 15, 1927 to April 19, 1927	22.7	16.8	26.
B. O. D. 8:30 a. m.			
January 14, 1927 to February 7, 1927	214.	148.	31.
B. O. D. 11 a. m.			
February 8, 1927 to March 15, 1927	213.	119.	44.

* Estimated by weight.