STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE WATER SURVEY
A. M. BUSWELL, Chief

BULLETIN NO. 25

BIOPRECIPITATION STUDIES
1921-1927

BY
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AUG. 26TH 1818

[Printed by authority of the State of Illinois]

URBANA, ILLINOIS

ORGANIZATION

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LETTER OF TRANSMITTAL

STATE OF ILLINOIS
DEPARTMENT OP REGISTRATION AND EDUCATION

STATE WATER SURVEY DIVISION

URBANA, ILLINOIS, June 11, 1928.

A. M. Shelton, Chairman, and Members of the Board of Natural Resources and Conservation Advisers:

GENTLEMEN : Herewith I submit a report of our studies of bio-precipitation of sewage colloids which have been carried out over a period of seven years from 1921 to 1927. As pointed out in our Bulletin 24, the question of sewage treatment is one of great importance in Illinois at the present time. We believe that the data here presented will assist in the solution of this problem.

Since the Directors' report includes a statement of the general activities of all divisions, it has seemed advisable to discontinue the publication of an annual report of this division and to prepare instead summaries of our various investigations as they are completed. This policy was adopted with the publication of Bulletin No. 18 in May of 1922 and has been followed since that date.

Respectfully submitted,

A. M. BUSWELL, *Chief.*

INTRODUCTION AND SUMMARY

By A. M. BUSWELL

This bulletin reports 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 (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 physico-chemical conditions.

Microscopic examination had shown that the organisms in activated-sludge flocs and on the surface of the rocks of trickling filters 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 microorganisms of such growth habits that they form large compact flocs which 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 Figure 1 as follows: (I) the water surface (bubble or top of tank), 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 (1918) indicates that enough gas 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 (1897) and later emphasized by Black and Phelps (1911).
>
> (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.

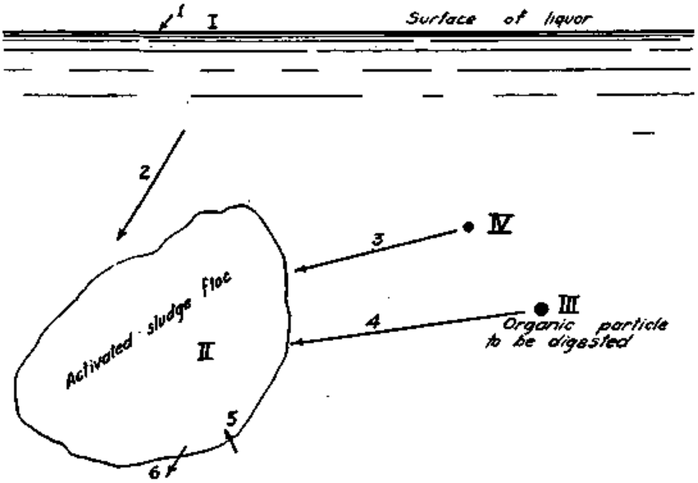

FIG. 1. GRAPHICAL REPRESENTATION OF THE SIX PROCESSES IN THE DIGESTION OF SLUDGE

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.

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 1921 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 Part I of this bulletin. 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 Part II. 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 in this 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 Part I. 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 Contact 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 by Jones and Travis (1906) 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 influence 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.

Hydrolytic 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 hydrolysing-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 pipe is laid, having two valved openings, 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. . .

TABLE I

15 December, 1904, to 30 September, 1905. (Average of 128 Series of Samples.)	Temp. °C.	Parts per 100,000.								Percentage Reduction in Albuminoid Nitrogen
		Solids.		Chlorine.	Nitrogen.				Oxygen Absorption.	
		In Suspension.	In Solution.		Ammoniacal.	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
Third contact 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, 1905. (Average of Eight Series of Samples.)	Parts 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.

"The work done by the hydrolytic tank and the hydrolysing-chambers is shown by Tables I and II (Tables II and X in the original.) 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 785.3 tons, equal to 10 tons per million gallons, or to 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."

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. (See Kershaw, 1915.) 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.

Shortcomings of the Travis Colloiders

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.

Small-scale 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 Figure 2, consisted of a trough 8 inches wide, 18 inches deep, and 20 feet long. The first 2 feet was divided off for the removal of heavier solids by sedimentation. 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.

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

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. (See Figure 3.) Details of the construction and operation of this experimental plant will be found in Part II of this bulletin.

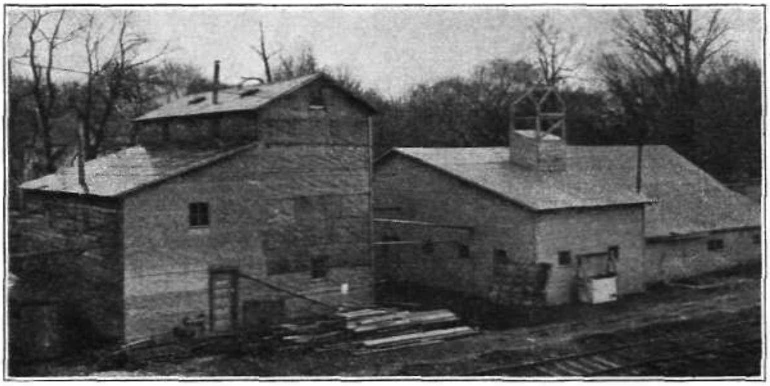

FIG. 3. GENERAL VIEW OF EXPERIMENTAL SEWAGE TREATMENT PLANT, 1928

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. These racks could be lifted up and down in the liquor by means of suitable handles. This was. done at intervals as noted below, for the purpose of removing the accumulated bacterial growths.

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 propeller 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 eight 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 ¼-inch 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. Change's" 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 three 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 five 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 feet 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 separate 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 in the central well. Observations had confirmed the predic-

TABLE III

SUMMARY OF RESULTS OF OPERATION OF NIDUS TANK, JULY 23, 1923 TO OCTOBER 7, 1924

Period No.	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	Turbidity Infl. p.p.m.	Turbidity Effl. p.p.m.	Turbidity Per cent removed	Oxygen consumed from KMnO4 Infl. p.p.m.	Oxygen consumed from KMnO4 Effl. p.p.m.	Oxygen consumed from KMnO4 Per cent removed	Ammonia nitrogen Infl. p.p.m.	Ammonia nitrogen Effl. p.p.m.	Alb. NH3 nitrogen Infl. p.p.m.	Alb. NH3 nitrogen Effl. p.p.m.	Nitrite nitrogen Infl. p.p.m.	Nitrite nitrogen Effl. p.p.m.	Nitrate nitrogen Infl. p.p.m.	Nitrate nitrogen Effl. p.p.m.
	1923																				
I.	July 23 to 29	8648[a]	*	3.6	---	---	---	228	133	41.2	---	---	---	---	---	---	---	---	---	---	---
II.	Nov. 6 to 21	9601[a]	**	3.2	81	36	55.5	151	79	45.5	51	33	34.2	28	29	5.2	4.0	.159	.017	.94	.42
	1924																				
III.	April 21 to May 11	6344[b]	.18	5.0	93	21	77.4	160	53	66.7	35	25	30.9	43	37	10.0	5.5	.626	.105	4.67	.66
IV.	June 9 to 22	5114[b]	.29	6.0	98	26	70.6	158	88	44.3	51	48	4.3	24	30	10.8	8.2	.590	.050	5.27	.49
V.	July 16 to Aug. 4	5057[b]	.16	6.0	---	---	---	227	93	58.4	58	44	24.9	53	63	11.3	7.5	.050	.006	1.51	.61
VI.	Aug. 5 to 18	5041[b]	*	6.0	---	---	---	230	128	44.9	73	54	26.0	50	51	9.9	6.1	.051	.003	.98	.46
VII.	Sept. 5 to 18	21541[b]	.23	1.4	160	48	69.5	257	121	52.9	73	54	26.0	50	47	9.9	8.7	.056	.004	1.05	.43
VIII.	Sept. 19 to Oct. 7	21543[b]	.22	1.4	186	56	69.5	274	120	56.2	66	47	28.7	37	37	7.3	5.7	.033	.002	.66	.33

* Aeration by gentle stirring.

† Compressed air was added, to supply .0015 cubic feet of dissolved oxygen per gallon.

[a] Constant.

[b] Rate changed 3 times a day to simulate practical conditions.

tion 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 feet of air per gallon was used during the day and 0.1 cubic feet at night, giving an average treatment of 0.2 cubic feet per gallon. During this period the interval between the times of shaking the racks was shortened to four hours.

The results of these experiments are summarized in Table III. Briefly, thev 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 periods III and IV) 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 or 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 (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, Richards and Weeks (1921) have experimented with, straw filters, and we are operating a small corn-cob filter. Woody vegetable material will decompose in time, and at 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 was reported by Basiakine (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

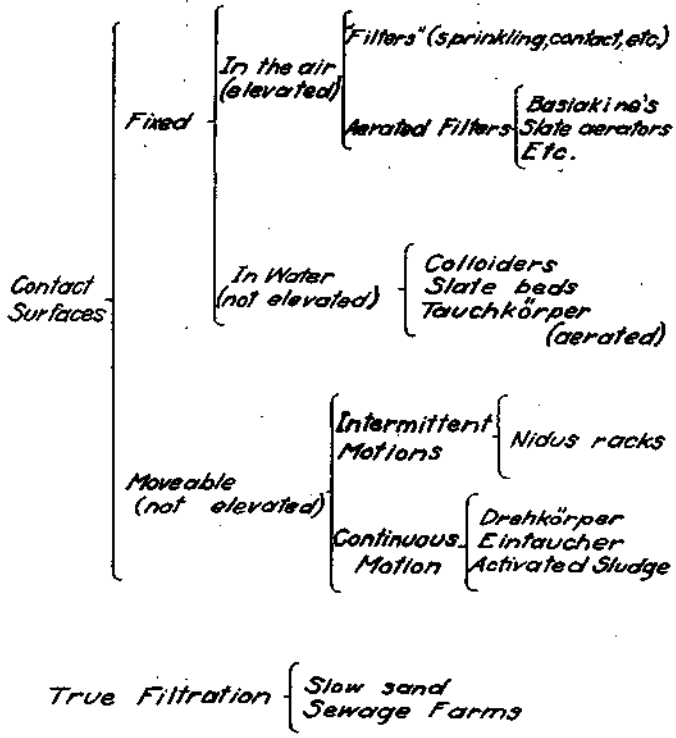

FIG. 4. DIAGRAMMATIC CLASSIFICATION OF DEVICES FOR TREATMENT OF SETTLED SEWAGE

of Imhoff's "Tauchkorper" (contact aerators) in use in Germany. Imhoff (1926) points out that there is a loss of head through all of those types in which the active surfaces are exposed to the atmosphere, while this is not the case with immersed surfaces.

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. (See Figure 5.) 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 is reported in this bulletin. Figure 6 (after Imhoff) gives the relative efficiency by this method.

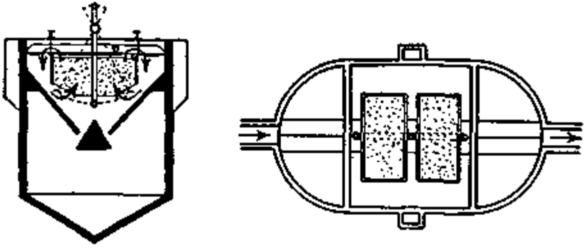

FIG. 5. DIAGRAM SHOWING CONTACT AERATOR INSTALLED IN AN IMHOFF TANK.

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 this bulletin. The results 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 biochemical oxygen demand and 45 per cent decrease in the organic nitrogen. If the decrease in biochemical oxygen demand 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.

Equally good, and even better results are being obtained in our present experiments with racks made of veneer, or basket wood, which have a larger surface area and a relatively smaller displacement, besides being lighter and more easily handled. The construction of such racks is described on pages 85-86, following which will be found a discussion of mechanisms for operating them and estimates of the cost of installations.

The estimated cost, $3,500 per million gallons, or even twice that figure, would seem a reasonable amount to pay for the increased efficiency obtained by nidus racks.

TABLE IV

DATA ON OPERATION OF LATH NIDUS TANK, 1927

Approximate flow in gallons per minute: maximum, 16; medium, 13.6; minimum, 9.4. Average detention period, 2 hours. Volume, 2040 gallons. Temperature, 12° —15° C.

	Influent p.p.m.	Effluent p.p.m.	Per cent removal
Composite samples January 14 to April 19			
*Settling Solids	101.4	49.2	51.4
Oxygen Consumed	53.6	39.6	26.4
Organic Nitrogen	3.24	1.86	45.7
Biochemical Oxygen Demand	112.	65.6	41.2
Grab Samples			
B. O. D. 6 a.m. January 15 to April 19	22.7	16.8	26.
B. O. D. 8:30 a.m. January 14 to February 7	214.	148.	31.
B. O. D. 11 a.m. February 8 to March 15	213.	119.	44.

* Estimated by weight.

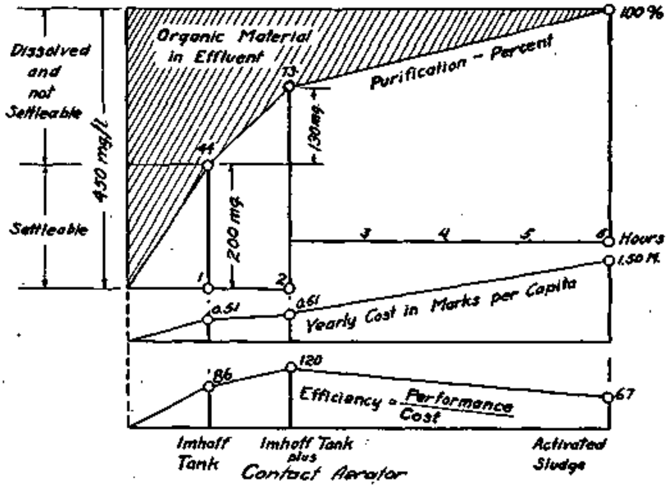

FIG. 6. DIAGRAM (AFTER IMHOFF) SHOWING RELATIVE EFFICIENCY OF IMHOFF TANK ALONE, IMHOFF TANK PLUS CONTACT AERATOR, AND ACTIVATED SLUDGE

Note that the efficiency is calculated on a cost basis.

PART I

AERATION*

By A. M. BUSWELL and S. L. NEAVE

All problems of aeration are questions of diffusion, whether from the saturated surface layer of a body of water or from the surfaces of gas bubbles within. This diffusion is accurately expressed by Fick's law. $\frac{dx}{dt}=K\ (c-x)$. where c=saturation and x= concentration at time *t,* as shown by Roth (1909). The application of this knowledge to a practical problem is, however, far from easy. In a natural body of water the aeration is accelerated by convection currents, by wind and wave action, and by a "streaming effect" first observed by Adeney, Leonard, and Richardson (1923) which was shown by Becker and Pearson (1923) to be caused by an increase in density due partly to cooling of the surface by evaporation and partly to an increased salt content arising from the evaporation. In artificial aeration by compressed air or stirring, the problem is further complicated by a continuous change of the air-water interface.

At present our knowledge is wholly inadequate to make possible the accurate calculation of aeration rates in practice. For ideal cases, however two expressions have been derived for this calculation: first by Phelps in this country and secondly by Adeney and Becker in Ireland.

Black and Phelps in their report of investigations of the capacity of New York harbor to handle untreated sewage discharged into it from the adjoining cities chose dissolved oxygen as the most important index of pollution. In this report Phelps discussed at length the question of re-aeration of the water by natural agencies and developed a mathematical expression for the calculation of oxygen absorption in an ideal case starting with the diffusion law of Fick and the assumptions (1) that the surface layer of water was instantly saturated and (2) that no mixing by convection or streaming occurred. Since accelerated re-aeration due to various internal

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* From a thesis submitted by S. L. Neave for the degree of bachelor of arts in chemistry, University of Illinois, 1924.

motions is always found in practice, Phelps recognized that the calculation gave only the minimum absorption rate but he considered this entirely adequate for his purpose. The same mathematical treatment was applied by Streeter and Phelps (1925) to the reaeration of streams.

Adeney and Becker have investigated the rate of air absorption under conditions in which mixing is assumed to be perfect, i. e., the opposite extreme to that assumed by Phelps. From a consideration of the rate of passage of the gas into the liquid, and its rate of escape from a partly or wholly saturated solution, an expression was derived which again is applicable only to the ideal case assumed.

In cases such as the aeration of sewage by a large number of small bubbles, the expression derived by Adeney and Becker gives fairly trustworthy results, not because mixing is necessarily perfect, but because the imperfect mixing is offset by the rapid utilization of oxygen by the sewage. This utilization increases the concentration gradient through any given layer of sewage adjacent to the bubble and consequently accelerates the process of diffusion, since by the law of Fick the diffusion rate is directly proportional to the concentration gradient.

In sewage aeration, the economy and practicability of the process depend upon the rapidity with which the requisite oxygen can be supplied. Compressed air is forced into a tank of sewage through a porous tile or other diffuser to break it up into small bubbles of large total surface, and the oxidation process is dependent upon a certain minimum amount of air. Crawford and Bartow (1916) found from a study of the effluent air from such an aeration tank that only 5 per cent of the oxygen supplied was actually absorbed by the sewage; other writers have given even lower efficiencies than this. Since air compression is costly, various attempts were made by sanitary engineers to increase the aeration efficiency; a number of these are cited by Buswell (1922) and by Martin (1918). At present there is a tendency in some localities to substitute some form of mechanical agitation for the excess of air, and to supply only a minimum of compressed air or to depend wholly upon absorption of oxygen at the surface of the tank.

In view of this tendency, it became of interest to compare air agitation and mechanical agitation as means of supplying the requisite oxygen to sewage, and also to determine as accurately as possible the minimum air requirement of the flora commonly found in the activated-sludge process. The experiments described in the following pages were the outcome of this interest.

Bubble Aeration

Photographically, a small bubble can be shown to rise through a column of liquid with very little agitation of water particles not directly in its path. It is probable, therefore, that such bubbles carry a nearly intact shell of water which prevents any change of the air-water interface while the bubble is ascending. The absorption of air is thus again dependent upon diffusion from the shell to the adjacent water body during the transit of the bubble. An attempt was made to demonstrate the existence of such a shell and, if possible, to determine its dimensions.

With a glass tube 3 cm. diameter and 60 cm. effective depth, of the shape shown in Figure 1, experiments were carried out in which bubbles were liberated into a layer of chloroform, salt, etc., and then allowed to pass up through a superimposed water column, finally bursting at the surface and liberating their shells. Chloroform is readily transported in this manner, a 1/16-inch bubble carrying a shell equivalent to a 17 per cent increase in bubble diameter, while with a ¼-inch bubble the shell is equivalent to a 10 per cent increase; however, the high specific gravity and low surface tension of chloroform render a comparison of its films with those of oxygenated water very hazardous. Strong solutions of alkali and alkaline-earth chlorides in the bottom of the tube, with sodium nitrate of equal specific gravity, or even distilled water, above, showed chloride at the surface after the passage of sixteen bubbles of 1/16 inch diameter. By sampling down the tube, definite concentration gradients were obtained as a result of lateral diffusion from the bubble shell, and with a given number and size of bubbles, when the chloride solutions of the alkalis and alkaline-earths had equal surface tensions (against air), the salt concentration at a given depth was directly proportional to the known diffusion coefficients for the salts used. Although the gradients seem to be consistent and reproducible, indeterminate

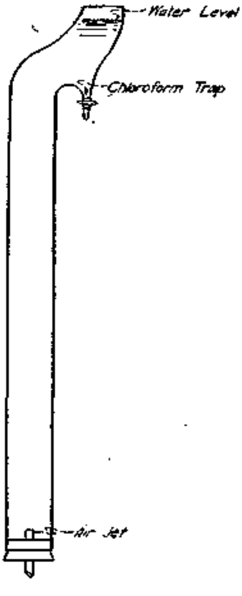

FIG. 1. DIAGRAM SHOWING SHAPE OF AERATION TUBE.

factors in this method prevent any calculation of shell thickness from the data. The mere presence of a shell can be further demonstrated by timing the passage of a bubble between fixed points on the upper part of the tube, first, when liberated into distilled water and, second, into concentrated magnesium chloride solution; the bubble is slightly heavier in the second case and the retardation in rate of rise is detectable.

In another series of experiments an attempt was made to increase the rate of oxygenation of water by interposing screens in the bubble path, the aim being to "scrape off" the shells before the bubble reached the surface. For this purpose a cylindrical glass tank (1 foot diameter and 2 feet effective depth) was equipped with a porous tile diffuser, which was fed with a controlled amount of air from a system of aspirator bottles. After establishing the aeration rate for water in which the bubble ascent was unhindered, one, and then two ¼-inch-mesh screens were placed in the bubble path in the lower half of the tank, and the' aeration rates redetermined. The retarded rate of bubble ascent due to the screens necessitated a calculated increase in depth of water in the control tests, so that increased aeration rates would not be due merely to longer bubble contact in the screen tests; all dissolved oxygen determinations were, however, recalculated to a uniform volume for comparison. Each run was made in triplicate, and the results were averaged. An unmistakable increase in the absorption rate is shown by the graphs in Figure 2.

Experimentation on bubble absorption was abandoned at this point, for it was learned that similar studies were being made by Ledig and Weaver (1924) at the Bureau of Standards with far more adequate and refined apparatus than our present interest in the problem would justify.

In summarizing our present knowledge of oxygenation by air bubbles, the following points deserve mention:

Not more than 5 per cent of the air introduced is actually absorbed by the sewage, the remainder serving only to mix the contents of the tank. The absorption of oxygen is a process of diffusion from an oxygen-saturated layer surrounding the bubble to the adjacent liquid; this diffusion follows Fick's law and is a slow process even though the concentration gradient is increased by the natural avidity of the sewage for oxygen. From actual operating data extending over an 8-month period (Water Survey Bull. 18), the average amount of free air used in an experimental activated-sludge plant was 1 cubic foot per 8.3 cubic feet of sewage treated;

if this air were all supplied as bubbles ⅛ inch in diameter whose rate of rise through the 12-foot tank is 0.7 feet per second (Flinn, Weston, and Bogert, p. 591), Adeney's equation shows that each cubic foot of air should impart 12 per cent of its oxygen to the liquid under these conditions. Inasmuch as this calculation assumes that perfect mixing of the air and water takes place, the result is in fair agreement with the actual 5 per cent found by Crawford and Bartow (1916).

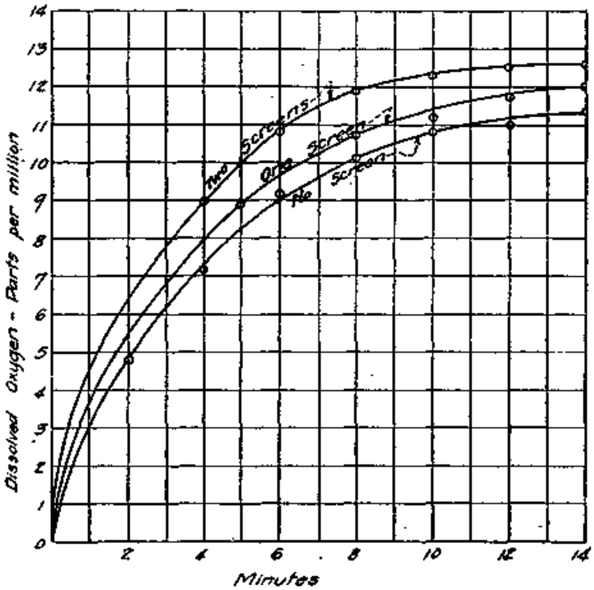

FIG. 2. GRAPHS SHOWING OXYGENATION RATES OF WATER AERATEP BY BUBBLES.

The experimental evidence also supports the view that complete mixing does not occur; on the contrary, each bubble tends to carry a complete shell of oxygen-saturated liquid with it and to release this shell only at the surface where a plentiful supply of atmospheric oxygen is already available. On the other hand, the carrying of such a shell assists in stirring the tank contents. Even though the dimensions of the water shell were not found, the results of Brunner (1904) may be taken for a rough calculation. Brunner found that a solid dissolving in a stirred solution was covered with a stationary water film 0.018 to 0.052 mm. thick when the peripheral velocity of his rotating solution was about 103 cm. per second; he found, further, that the film thickness varied as the two-thirds power of the rate of stirring. Accepting, therefore, his larger result, 0.052 mm., and assuming again that in practice ⅛-inch bubbles are used, these bubbles rise at a rate of 21 cm. per second, or 42 cm. per second relative to the water flowing past them. On the basis of Brunner's findings, this velocity corresponds to a shell thickness of 0.036 inches (0.093 cm); accordingly, a cubic" foot of air in the form of ⅛-inch bubbles could transport 5.25 gallons of water to the surface. Stirring by compressed air, however, is not an economical expenditure of power, and certain tank designs of recent invention employ a central well, a baffle, or some other device to utilize the air-lift effect of the bubbles ; for even in a properly designed pump the air-lift has an efficiency of only 16 to 18 per cent based on indicated horsepower in the steam cylinder (Flinn, Weston, and Bogert, p. 250).

The demands of economy are, therefore, (1) that stirring be effected by some means more efficient than excess of air, and (2) that the flow of liquid be opposed to the ascent of the bubble in order to reduce stagnation at the air-water interface. The possibility of partly or wholly replacing bubble aeration by some form of mechanical stirring, led to the following preliminary experiments.

Mechanical Aeration

. Two alternatives suggest themselves: either mechanical stirring can be sufficiently vigorous to hold the activated-sludge flocs in suspension; or the sludge flocs can be made to form on, and remain attached to, suitably moving supports. This latter method was used in the present investigation on minimal air requirements of the micro-organisms.

If bubble aeration is to be wholly eliminated, surface absorption must be depended upon. It is commonly assumed that thin layers of water become almost instantly saturated with oxygen when exposed to the air; indeed, this is deducible from the kinetic theory of gases; but no reference was found in the literature to substantiate this view excepting by inference from some work by Langmuir (1918) on heterogeneous reactions in gases at very low pressures. Accordingly, the following experiment was made in order to give a rough idea of how thin the film might be and how nearly instantaneous the saturation.

With the apparatus shown in Figure 3, a stream of oxygen-free water was allowed to flow over a carefully cleaned glass bulb; a

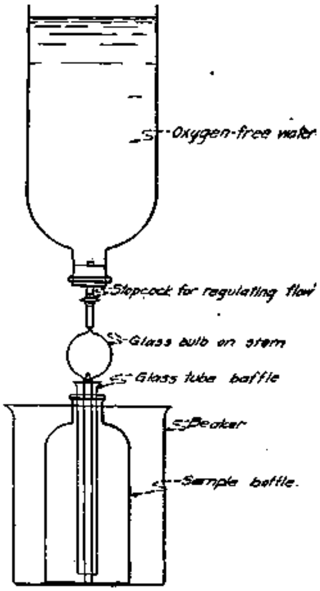

FIG. 3. APPARATUS FOR MEASURING THE OXYGENATION RATES OF THIN FILMS OF WATER.

small spherical electric light bulb with a surface area of 43.53 sq.cm. attached to a glass handle was used for this purpose. After exposure to the air by flowing in a thin sheet over the bulb, the water was collected by displacement in a sample bottle for the determination of dissolved oxygen. The thickness of the water film was varied by altering the flow. For each experiment the' flow "was maintained constant until the sample bottle had filled, and its contents were displaced at least twice before making the dissolved oxygen determination. To obtain the actual film thickness, a film was repeatedly formed on the bulb (without the handle) with the water flowing at a given rate, and the bulb plus film then rapidly transferred to a stoppered weighing bottle; only the greatest and least flows were used, and for intermediate flows the film thickness was assumed to vary directly as the rate of flow. The following film weights were obtained:

Least flow, 60 c. c. per min. Film weight in grams	Greatest flow, 288 c. c. per min. Film weight in grams
0.2069	0.9288
.2288	.9071
.2142	.9147
.2190	.9092
.2182	.9209
Average .2170	Average .9161

2170/43.53=0.005 cm. average thickness for least flow.

.9161/43.53=0.021 cm. average thickness for greatest flow.

With a flow of 60 c.c. per minute, or 1 c.c. per second, film forms in 0.217 seconds. Similarly, for the greatest flow, the time required to form the film is 0.191 seconds.

The mean, .0.2 seconds, was adopted for the average time of contact of the water with the air. The results for these two flows, and for three intermediate rates, are plotted in Figure 4, and tabulated below:

Film thickness in centimeters	Dissolved oxygen absorbed Parts per million	 Per cent saturation
0.021	1.90	19.9
0.016	*2A5*	22.5
0.011	2.70	28.3
0.008	3.25	34.1
0.005	4.10	43.0

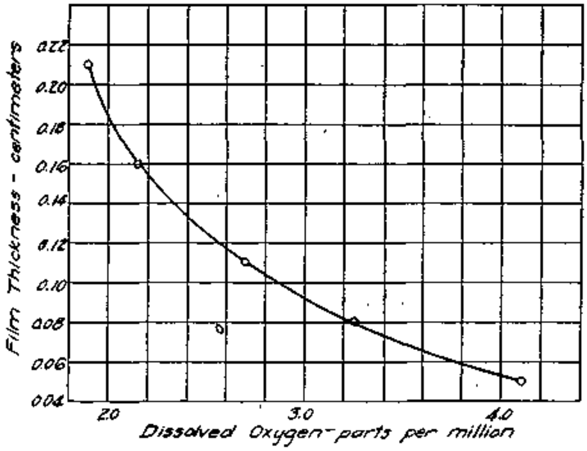

FIG. 4. GRAPH SHOWING RELATION OF FILM THICKNESS TO OXYGENATION RATE.

By a mathematical extrapolation of this curve, it can be shown that only films of 8.8 microns, or less, in thickness can become 100 per cent saturated in 0.2 seconds, and the saturation time for a film 1 millimeter thick becomes quite appreciable.

For engineering practice, however, the statement that thin films are immediately saturated is a convenient working basis, and all mechanical aeration methods rest primarily upon an attempt to continually draw off or in some other way incorporate this surface layer in the bulk of the liquid. With this idea in mind, some experiments were carried out to compare the relative efficiencies of a number of mechanical devices which either mixed the surface layer with the bulk of the liquid or caused thin layers of the liquid to be repeatedly exposed to the air.

Throughout this series of experiments, the glass tank previously referred to (see p. 25) was used to contain the air-free water, and the progress of aeration was determined by periodic analyses for dissolved oxygen. The following mechanical devices were used:

(1) A propeller composed of three nearly circular blades 2⅜ inches by 2 inches with a pitch of 1 inch. For some of the tests the propeller was surrounded by a well 7¾ inches in diameter and 9½ inches long.

(2) A rack composed of 80 vertical strings supported by two perforated end-plates 5½ inches by 6½ inches; total effective area = 275 sq. in. This rack was lifted out of the liquid at regular intervals by a suspension wire connected over a pulley to a motor-driven crank.

(3) An endless canvas belt operating half-submerged in a vertical position around two rollers, one in the tank bottom and the other above the water level. This belt was 61 inches long and 8½ inches wide, with a total area of 1037 sq. in. It could be operated at a constant linear velocity by a motor drive.

The results obtained by these devices are tabulated below and shown graphically in Figure 5. In this tabulation, the time required to reach the 50 per cent saturation point of the water is given, rather than that for complete saturation, for three reasons:

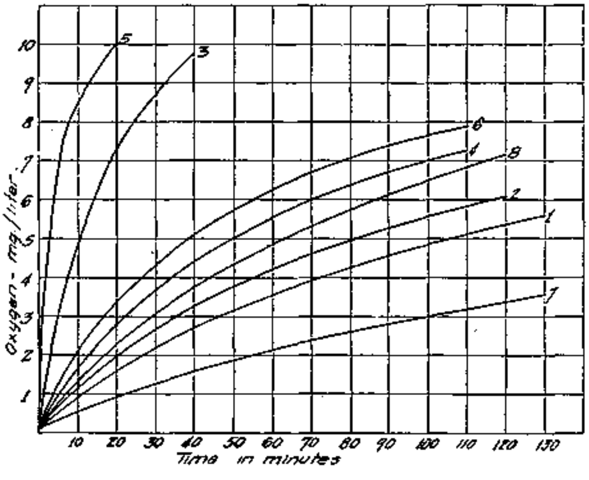

FIG. S. GRAPHS SHOWING OXYGENATION RATES OF VARIOUS AERATING DEVICES.

temperature changes from day to day alter the saturation concentration of water; complete saturation is neither customary nor necessary in practice; and, by some of the experimental methods, supersaturation masked the 100 per cent point.

Comparison of Aeration Devices

Device used		Time in minutes for 50 per cent saturation
Propeller alone,	400 r.p.m. (up-current)	87
Propeller alone,	600 r.p.m. (up-current)	66
Propeller alone,	600 r.p.m. (down-current)	9 (sucking air)
Propeller plus well,	600 r.p.m. (up-current)	41
Propeller plus well	600.r.p.m. (down-current)	2 (sucking air)
String Rack, operating at 16 dips per min.		31
String Rack, operating at 5 dips per min.		231
Canvas Belt, linear velocity 3 inches per sec.		53

As indicated by these results, the propeller can be made a very efficient means of introducing air, but the agitation was too violent in the small vessel in which it was installed. The string rack, however, combined the advantages of smooth operation and rapid aeration, and it was used, therefore, in an attempt to purify sewage in the following manner:

Application to the Activated-sludge Process

Thirty liters of screened domestic sewage from the city of Champaign was placed in the tank, and the string rack dipped in and out of it at the rate of 16 dips per minute by a motor-driven crank; when some clarification became evident, the tank was drained and filled with a fresh charge of sewage. In this way a good growth of activated sludge was soon obtained on the strings. As measures of purification, determinations of turbidity and of oxygen-consuming power from potassium permanganate were made, as described in the American Public Health Association's "Standard Methods". Some of the results are given in Table I. Figure 6 shows the results of one series in which the course of purification was followed by means of periodic samples tested only for oxygen consumed from potassium permanganate, but in which dissolved oxygen determinations were made in order to follow the course of aeration. .

It is evident that a fair degree of purification can be attained even with the comparatively low aeration rate already established by the previous tests on air-free water. Since, however, aeration rates are somewhat dependent upon the avidity of the. liquid for oxygen, this apparatus could not give a minimum value for the

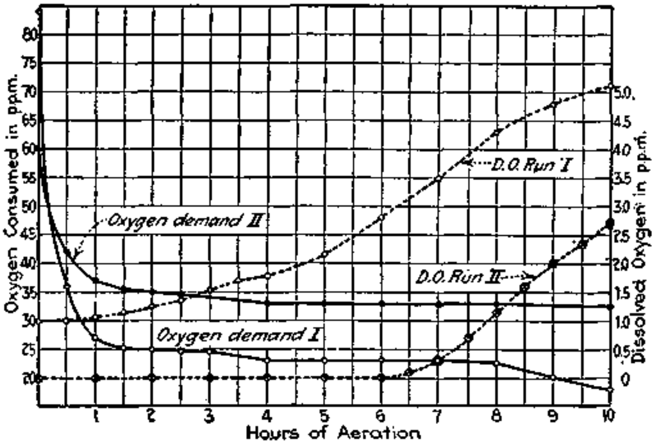

FIG. 6. GRAPHS SHOWING RELATION BETWEEN OXYGEN CONSUMED AND DISSOLVED OXYGEN IN SEWAGE AERATED BY A NIDUS RACK MAKING 16 DIPS A MINUTE.

On raw sewage oxygen consumed was determined on the unsettled samples. Samples taken during the aeration were settled one hour before running oxygen consumed.

TABLE I

DECREASE IN TURBIDITY AND OXYGEN CONSUMED FROM POTASSIUM PERMANGANATE EFFECTED BY DIPPING NIDUS RACK IN SMALL GLASS TANK

Hun No.	Raw Sewage		Per cent decrease					
			2.5 hours		4.5 hours		8.5 hours	
	Tur-bidity p.p.m.	O^2 Cons. p.p.m.	Tur-bidity	O^2 Cons.	Tur-bidity	O^2 Cons.	Tur-bidity	O^2 Cons.
1	240	46.0	40.5	21,2	42.1	31.2	51.4	39.1
2	220	44.0	43.5	20.1	45.2	29.1	....	....
3	210	40.0	44.8	17.3	46.4	33.7	54.0	34.3
4	230	41.6	4S.4	18.8	47.0	24.2	54.6	31.1
6	280	43.5	46.0	14.2	48.0	28.1	55.3	48.1
8	240	41.2	46.8	22.3	50.0	22.7	56.1	45.3
Average	236	42.7	44.5	18.9	46.4	27.7	54.3	39.6

oxygen requirement of the micro-organisms constituting the activated sludge. For this purpose, therefore, a vitrified-tile tank,. 12 inches in diameter and 17 inches effective depth, was fitted with a 6-inch square of filtros tile in a false bottom. By means of a system of graduated aspirator bottles, carefully regulated quantities of air could be introduced into the tank through the porous tile. For supporting the sludge and mixing the tank contents, a rotating spiral of wire screen was used. Sludge was first built up on this screen, and then quantitative runs were made. Table II shows some of the data obtained.

Continued aeration with only 0.001 cubic feet of free air per hour per gallon of sewage finally resulted in a septic condition. With 0.01 cubic feet per hour per gallon, however, considerable bio-precipitation occurred. If treatment is based on a 4- to 6-hour detention period, the quantity of air per gallon is still below 0.1 cubic feet; while in the ordinary activated-sludge tank in which the air has to function also in mixing the tank contents, a consumption of 0.75 cubic feet is considered low.

A number of attempts were made to collect all the effluent air and from its volume and composition to calculate the exact oxygen absorption of the sewage. Dissolved gases already in the sewage, however, interfered to such an extent that no conclusions could be drawn from the effluent air analyses.

Summary

In bubble aeration the bubbles during their ascent are surrounded by a stationary shell of water which hinders oxygen.diffusion into the adjoining liquid. Opposing the water flow to the bubble ascent, or using suitable baffles, will decrease or rupture this water shell and hasten oxygen absorption.

Saturation of thin layers of water requires a measurable time; for saturation to occur in 0.2 second, the film thickness must be less than 0.01 millimeter.

By simple mechanical mixing, a fairly rapid absorption of oxygen takes place. Sewage can be clarified by such mechanical devices without the use of compressed air.

If mixing and sludge suspension are not dependent upon the air introduced, clarification by the activated-sludge process requires less than 0.01 cubic feet of air per hour per gallon of sewage.

TABLE II

DATA ON SEWAGE TREATED IN SMALL TILE TANK WITH REVOLVING RACK OF COPPER SCREEN

Run No.	Duration of run Hrs.	Sewage treated Gals.	Free air used Cu. ft. per gal. per hr.	Peripheral velocity ft. per sec.	Turbidity			Oxygen consumed		
					Initial p.p.m.	Final p.p.m.	Per cent decrease	Initial p.p.m.	Final p.p.m.	Per cent decrease
6	12	3.0	.0019	0.26	240	160	33	48	36	25
10	11	3.2	.0013	0.26	250	170	32	38	35	8
11	6	3.0	.0034	0.26	230	170	26	38	32	16
12	15	3.1	.0011	0.16	210	120	43	42	30	29
14	24	3.1	.0017	0.16	245	140	43	47	34	28
16	24	3.0	.0012	0.16	250	...	..	..	..	..*
22	3	3.0	.0043	0.26	240	190	21	60	40	33
23	3	3.0	.0073	0.26	230	180	22	75	49	35
24	3	3.0	.012	0.16	220	140	36	66	37	44
25	3	3.0	.013	0.26	240	130	46	52	40	23

* Tank became septic.

APPENDIX TO PART I

B. O. D. Experiment with Small Nidus Tanks

As no determinations of biochemical oxygen demand were made by Mr. Neave in his study of aeration, an experiment was undertaken by Mr. Shive with a view to making such determinations, preliminary to the work that is reported in Part II of this bulletin.

In this experiment nidus racks consisting of 1/16-inch mesh copper screen were installed in two small tanks connected in series. The flow of sewage was regulated so as to give a detention period of 2½ hours in each tank, and the effluent was settled in a third tank with a detention period of about 1 hour. Gentle stirring, produced by the slow revolving of the racks, was the only means of aeration. Operation was begun April 30, 1923, and continued for 10 days. Twice a day, at 8:00 a.m. and 5:00 p.m., the racks were shaken in order to remove the accumulated growth, and half an hour later the sludge that had settled in the underdrains was drawn off.

Samples of the influent were taken each day at 10:00 a.m., and of the effluent at 4:00 p.m., since the total detention period of the system was 6 hours. Samples of both influent and effluent were taken also at 8:00 a.m. each day and were considered as being representative of the night sewage, which was of nearly constant strength. Biochemical oxygen demand was determined on all samples according to the procedure outlined by the American Public Health Association (1923). The data on these determinations, together with temperature and turbidity, are expressed in Table III.

TABLE III

DATA ON SEWAGE TREATED IN LABORATORY NIDUS TANKS APRIL 30 TO MAY 9, 1923

Date 1923	Temperature		Turbidity			B. O. D. 2.5 days			B. O. D. 5 days		
	Infl. ° C.	Effl. ° C,	Infl. p.p.m.	Effl. p.p.m.	Per cent removed	Infl. p.p.m.	Effl. p.p.m.	Percent removed	Infl. p.p.m.	Effl. p.p.m.	Per cent removed
					Day Sewage						
April 30	14	14	235	125	46.9	148	96	35.1	155	111	28.3
May 1	15	16	185	115	37.8	1S5	107	30.9	168	127	24.4
May 2	15	16	210	85	59.5	159	111	30.1	175	129	26.2
May 3	15	15	260	170	34.6	189	149	21.1	236	183	22.4
May 4	14	15	210	145	30.9	201	109	45.7	245	198	19.1
May S	14	15	235	87	62.5	142	47	67.6	180	56	68.8
May 6	13	13	175	100	42.8	115	64	44.3	130	97	25.3
May 7	15	14	230	135	41.2	150	109	27.3.	177	127	28.2
May 8	14	14	165	150	9.0	150	115	23.3	186	168	9.6
May 9	11	11	220	140	36.3	222	124	44.1	230	128	44.4
AVERAGE	14	14	212	125	40.1	163	105	36.9	188	132	29.8
					Night Sewage						
April 30	14	14	150	120	20.0	148	119	20.0	190	140	26.3
May 1	15	16	155	105	32.2	148	96	35.1	166	120	27.7
May 2	15	16	160	95 .	40.6	155	114	26.4	175	140	20.0
May 3	15	15	145	100	31.0	129	91	29.4	1S3	129	15.6
May 4	14	15	200	180	10.0	180	162	10.0	257	227	11.7
May 5	14	15	190	130	31.5	183	136	25.6	183	159	13.1
May 6	13	13	160	100	37.5	138	64	53.6	180	91	49.4
May 7	15	14	200	130	3S.0	138	74	46.3	171	97	43.2
May 8	14	14	170	150	12.1	148	130	12.1	207	165	20.0
May 9	11	11	150	130	13.3	138	94	31.9	160	144	10.0
AVERAGE	14	14	168	124	26.3	150	107	28.6	184	141	23.7

PART II

THE ROLE OF BIOPRECIPITATION IN SEWAGE TREATMENT*

By R. A. SHIVE with A. M. BUSWELL

Since the discovery of the activated-sludge process, several theories have been advanced to account for the high nitrogen content of the sludge. Mohlman (1917) suggested that it was due to the complete removal of suspended matter and the "burning out of carbon". Richards and Sawyer (1922) have attributed it to initial absorption of soluble ammonium salts by the sludge, with subsequent assimilation by ammonia-fixing organisms. ' Experiments conducted by Buswell and Neave (Bull. 18, p. 80) showed that nitrates, nitrites, and free ammonia were taken up by the organisms of the sludge and resynthesized into protein, for otherwise the nitrogen balance sheets would have shown a loss. Ardern, Jepson, and Gaunt (1923) drew the conclusion that the high nitrogen of activated-sludge is accounted for, mainly, by the flocculation of the sewage colloids and, secondarily, by the growth of bacteria and higher organisms; they obtained, however, no evidence from their experiments that the increase of the nitrogen of the sludge is due to the absorption and fixation of soluble ammonium salts. In all the previous work done along this line, very little attention has been paid to the nitrogenous materials in solution, other than the ammonium salts, nitrites, and nitrates.

Hatfield (1920) has calculated that the insoluble nitrogen of the feces alone is enough to account for the high nitrogen content of activated sludge. Adler (see Cammidge 1914) drew the conclusion that, normally, whatever the diet may be, most of the nitrogen is present in the feces in a coagulable form and that a very considerable part of it can be attributed to the intestinal bacteria. If the physical theory advanced by Eddy (1921) and by

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* From a thesis submitted by R. A. Shive in partial fulfillment of the requirements for the degree of doctor of philosophy in chemistry in the graduate school of the University of Illinois, 1925.

Fowler for the mechanism of the activated-sludge process is accepted, then it is difficult to avoid the conclusion that the coagulation of the fecal matter accounts for the high nitrogen content of activated sludge; but, in the light of the biological theory advocated by this laboratory, it would be advisable to consider the part played by water-soluble nitrogenous materials, such as amino acids, urea, creatinine, albumins, globulins, proteoses, and peptones in increasing the nitrogen content of activated sludge. Two of the first three of the compounds mentioned above, urea and creatinine, are the most abundant nitrogenous substances in normal urine, and amino acids also may be present in the feces and the urine, although only in small quantities. The last four substances are excreted from the human body only under abnormal conditions, but they are commonly found in the sewage from sinks and from canneries, slaughter houses, corn products plants, and other industrial plants having nitrogenous wastes. Urea is very quickly hydrolyzed by bacteria into ammonium carbonate and in this form it is available for assimilation by ammonia-fixing organisms of the sludge, but what happens to the other soluble nitrogenous compounds is a question for investigation.

Food material in a soluble form is more easily assimilated by bacteria than in the solid form, for the solid food has to be liquefied before it can pass through the wall of the bacterial cell. There is no reason for assuming that the soluble substances cannot be resynthesized into the protoplasm of the micro-organisms as well as the solid suspended matter. This brings up the old question: How are we going to define "solubility" in sewage work? Some investigators have referred to the soluble solids of sewage as being those solids that will pass through filter paper. Others have determined the soluble matter in sewage by filtering though an asbestos mat (Gooch crucible). Recently Buswell and Weinhold in an unpublished work have passed sewage through a nitro-cellulose membrane in an ultra filter under twenty to thirty pounds pressure per square inch and found that the ultra filter removed 9.56 per cent more suspended solids and colloidal matter from sewage than the Gooch crucible. O'Shaughnessy (1923) pointed out that dialysis is not merely useful but essential for the study of the activated-sludge process, and his data indicate that, from the standpoint of oxygen consumption, organic substances in true solution play a very important part in sewage treatment.

Workers in the sanitary field should define their use of the term "soluble" in referring to soluble solids in sewage. There is no sharp line of demarkation to be drawn between solids in pseudo-solution and those in true solution. We might divide the solids according to their ability to dialize through a standard membrane, calling those that will dialize, solids in true solution, and those that will not pass through the membrane, solids in pseudo-solution. The chief objection to such a scheme is that dialysis is a slow process and could not be used very well in routine analysis. In the work recently done by Buswell and Weinhold it appears that the ultra-filter could well be used in differentiating between solids in true solution and solids in pseudo-solution. Being rapid in its action and being susceptible to calibration and standardization, the ultra-filter is to be recommended as a tool for the study of the size of colloidal particles in sewage.

If we used dialysis as a means of separating solids in true solution and those in pseudo-solution, we would have to class water-soluble nitrogenous substances such as albumins and globulins among the colloids, as the latter two substances will not dialize, although from a microscopic inspection they appear to be in true solution. Hawk (1921) states that as a class the proteoses and peptones are very soluble and diffusible bodies.

Proof of Bioprecipitation

In undertaking an investigation to determine what percentage of the nitrogen can be precipitated in the form of bacterial protoplasm from solutions of soluble nitrogen compounds by a common sewage organism as *B. subtilis,* a nutrient broth of beef extract and peptone and distilled water was chosen as the medium for growth, because the major part of the constituents of this broth would dialize and therefore could be considered in true solution.

The following experiments were carried out to determine what percentage of the nitrogen could be precipitated by a common protein-splitting, spore-forming sewage organism, *B. subtilis,* from various concentrations of a nutrient broth composed of beef extract, peptone, and distilled water.

Nutrient broth was made up as specified in the American Public Health Association's Standard Methods (1923), in the following proportions:

3	grams of beef extract.
5	grams of peptone.
1000	cc. of distilled water.

The pure culture of *B. subtilis* used in the experiments was obtained from the Department of Bacteriology of the University of Illinois.

A series of 100-cc. culture tubes containing 50 cc. of sterile nutrient broth were set up, and each tube was inoculated with a loop of a water emulsion of a 24-hour culture with the exception of some blanks. All were incubated at 37° C. At the end of stated periods the cultures and blanks were removed from the incubator and analyzed to determine the amount of nitrogen thrown out of solution from the cultures in the form of bacterial protoplasm. Although *B. subtilis* is a typical pellicle- and sediment-former, it was found necessary to centrifuge the cultures in order to remove the organisms. Kendall and his co-workers (1913) have shown that there is no loss of ammonia nitrogen from standing cultures; therefore, there should be no difference between the total nitrogen of the blank and the total nitrogen of the culture after incubation. After centrifuging the cultures, total nitrogen (organic nitrogen and free ammonia nitrogen) was determined in 5 cc. of the blank and 5 cc. of the supernatant liquor of the culture by the official Gunning modification of the Kjeldahl method for fertilizer, the ammonia being distilled out into standard acid. The amount of nitrogen removed by centrifuging as bacterial protoplasm was calculated by subtracting the total nitrogen in the supernatant liquor of the culture from the total nitrogen in the blank. The results obtained from the series of cultures are expressed in Table I.

From this experiment it was seen that the amount of nitrogen precipitated from the broth by the organism in quiescent cultures was so small that the results were within experimental error.

TABLE I

PRECIPITATION OF NITROGEN FROM NUTRIENT BROTH BY QUIESCENT CULTURES OF B. SUBTILIS

Period of incubation at 37° C. Days	Nitrogen in 5 cc. of blank mg.	Nitrogen in 5 cc of supernation liquor mg.	Nitrogen precipitated mg.	Per cent of total nitrogen precipitated
1	**5.6**	**5.6**	**0.0**	**0.0**
5	**5.6**	**5.2**	**0.4**	**7.1**
6	**5.7**	**5.5**	**0.2**	**3.5**
9	**5.7**	**5.5**	**0.2**	**3.5**
11	**5.7**	**5.5**	**0.2**	**3.5**

Experiments using aerated cultures of *B. subtilis* were discouraged at first by a statement made by Ellis (1909) that agitation killed this organism. Since very little growth was obtained in the quiescent cultures, however, it was decided to set up a liter and a half of sterile nutrient broth in a 2-liter Florence flask, inoculate it with *B. subtilis* and aerate it at room temperature using air sterilized by filtering through a cotton plug. At the same time another liter and a half of the broth was set up under the same conditions with the exception that it was not aerated. After 24 hours of aeration an extremely heavy growth had taken place in the aerated culture, and when agitation was stopped, the bacteria settled to the bottom of the aerating flask within ten minutes in the form of a dense white flocculent sludge, leaving a clear supernatant liquor. Microscopic examination showed that the cells had grown into long chains which were intertwined in flocs as large as those found in activated sludge. At the end of the same period of time and at the same temperature, the quiescent check showed but a faint trace of growth. Agitation, therefore, accelerated the growth of the organisms. The percentage of nitrogen that might be precipitated by aerated cultures was then investigated. .

A series of 2-liter Florence flasks were set up at room temperature (averaging 22° C), each containing 1.5 liters of sterile broth, of concentrations varying from 5 per cent of the strength given in Standard Methods up to full-strength nutrient broth. Each flask was inoculated with 1 cc. of a water suspension of cells from the previous 24-hour aeration culture, and all were aerated enough to keep the organisms from settling out. Along with the aerated cultures two controls containing, respectively, a 10 per cent solution and a 50 per cent solution of nutrient broth, were set up without aeration. At the end of 24 hours a mixed sample of bacteria and liquor was taken from each flask. All the cultures were then allowed to settle for one hour, and the supernatant liquor in each flask was sampled. The size of sample taken for total nitrogen in each case depended upon the concentration of the broth, varying from 1100 cc. of the 5 per cent solutions to 25 cc. of the full-strength broth.

The combined ammonia and organic nitrogen of the mixed samples was determined by the Gunning modification of the Kjeldahl method, followed by distillation of the ammonia into N/20 acid. In the samples of supernatant liquor the ammonia was determined by diluting the samples to 250 cc. with nitrogen-free water, and distilling out 200 cc. into N/20 acid. The remaining 50 cc. was used for the determination of organic nitrogen. Results were expressed in milligrams of nitrogen per liter.

Since all the nitrogen present was in the form of ammonia nitrogent or organic nitrogen, the sum of these two constituted the total nitrogen. The amount of nitrogen precipitated was calculated by subtracting the total nitrogen of the supernatant liquor from the total nitrogen of the mixed sample. The two quiescent cultures showed but a faint trace of growth.

By passing the effluent air from a culture through standard acid in a wash bottle, the loss of total nitrogen in the form of ammonia was found to be only 0.1 per cent. Also the total nitrogen of unaerated blanks was equal to the total nitrogen of broth cultures of equal strength, even after the latter had been aerated for 72 hours. There was, therefore, little loss of volatile nitrogen compounds.

Following the 24-hour cultures, a.series of cultures were aerated for 48-hour and 72-hour periods and were analyzed similarly to determine the amount of nitrogen precipitated. Microscopic examinations and pH determinations were made on samples from these three series of cultures.

The results are shown in Table II, along with the percentage of total nitrogen precipitated. The various concentrations of broth are expressed in terms of their total nitrogen content. The maximum precipitation of nitrogen took place in each case during the first 48 hours of aeration. After this, either spore formation set in or the cells began to break up, part of the nitrogen of the cells going back into solution and part remaining suspended in a form which would not settle out. A microphotograph of a culture in full-strength nutrient broth is shown in Figure 1.

The data in Table II support the theory that spore formation is due to lack of food rather than to the accumulation of products of metabolism. During the first 24 hours of aeration no spores were formed in any of the concentrations of broth used. At the end of 48 hours spore formation had progressed rapidly in the lower concentrations, but no spores were present in the concentration having a nitrogen content of over 500 milligrams per liter. At the end of 72 hours all concentrations showed a nearly complete change of vegetative cells to spores, with the exception of the culture in full-strength broth; this had not yet shown evidence of spore formation although the chains were rapidly breaking up. In fact, spore for-

TABLE II

PRECIPITATION OF NITROGEN FROM NUTRIENT BROTH BY AERATED CULTURES OF B. SUBTILIS

Total nitrogen before centrifuging mg. per 1.	Organic nitrogen of supernatant liquor mg. per 1.	Ammonia nitrogen of supernatant liquor mg. per 1.	Per cent of total nitrogen present as ammonia nitrogen	Nitrogen precipitated mg. per 1.	Per cent of total nitrogen precipitated	pH	Spores
A	B	C	D = C ÷ A	E = A — (B + C)	F = E ÷ A	G	H
			24-hour cultures				
61.37	42.60	17.83	29.0	.94	1.5	7.4	—
73.19	45.41	26.44	36.1	1.34	1.8	...	...
142.80	89.60	44.00	30.8	9.20	6.4	7.4	—
589.71	502.33	59.58	10.1	27.80	4.7	7.8	—
771.6	613.20	121.60	15.7	36.80	4.7	...	...
1223.77	1039.40	107.68	8.8	76.69	6.2	8.4	—
			48-hour cultures				
59.25	31.26	23.38	39.4	4.61	7.7	8.2	++
119.77	60.98	48.63	40.6	10.16	8.4	8.4	++
535.20	279.75	166.19	31.0	85.26	16.0	...	...
545.08	278.15	180.56	33.0	86.37	16.0	...	...
578.75	293.65	185.97	32.1	99.13	17.1	8.2	—
812.82	418.96	281.89	34.6	111.97	13.7	...	...
1223.75	666.93	398.12	32.5	158.70	12.9	8.6	—
			72-hour cultures				
65.46	43.21	22.21	33.9	0.00	0.0	8.4	+++
118.90	71.54	45.15	37.9	2.21	1.8	8.5	+++
494.32	293.92	157.58	31.8	42.82	8.6	8.6	+++
1196.52	648.22	455.04	38.0	93.26	7.7	8.6	—*

* Spores did not form until the fourth day of aeration.

Key: — No spores
\+ Few spores
++ Many spores
+++ Nearly all spores

mation did not occur in the latter culture until the fourth day of aeration. Figure 2 shows spore formation in a culture with a total nitrogen content of approximately 120 milligrams per liter.

FIG. 1. COMPACT, RAPIDLY SETTLING, VEGETATIVE GROWTH.

FIG. 2. OLDER FLOC, FEATHERY, **WITH** MANY SPORES.

Bulking.—In these experiments we have reproduced the condition of "bulking" which is so serious a difficulty in the operation of activated-sludge plants. The young vegetative filaments of *B. subtilis* formed compact rapidly settling flocs. As the cultures grew older and the food supply less abundant, spore formation set in; the filaments were thereby weakened at various points and began to break up. The result was feathery non-settling flocs, a typical "bulked" sludge. In this case over-ripeness was undoubtedly the cause of bulking.

In studying the metabolism of a large number of organisms, Kendall and Farmer (1912) used ammonia formation as a determining index for the rate and, to a degree, for the extent of protein catabolism in bacteria. The ammonia nitrogen, expressed in Figure 3 as a percentage of the total and in Figure 4 as milligrams per liter, has been plotted against the total nitrogen present in the culture.

As the original object of the experiment was to determine what percentage of the total nitrogen could be precipitated by *B. subtilis* from various concentrations of nutrient broth, the nitrogen precipitated has been plotted in Figures 5 and 6 against the total nitrogen of the various cultures. It is seen in Figure 5 that the maximum percentage of nitrogen was precipitated from a broth with a nitrogen content of 578 milligrams per liter after 48 hours of aeration.

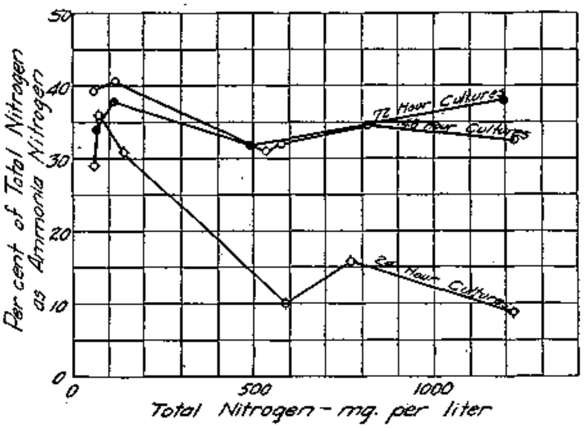

FIG. 3. GEAPHS SHOWING PERCENTAGES OF FREE AMMONIA NITROGEN IN *B. subtilis* CULTURES OF INCREASING TOTAL NITROGEN CONTENT.

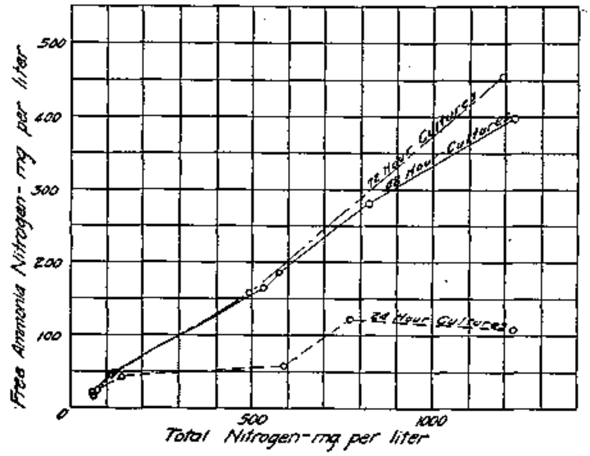

FIG. 4. GRAPHS SHOWING AMOUNTS OF FREE AMMONIA NITROGEN IN *B. subtilis* CULTURES OF INCREASING TOTAL NITROGEN CONTENT.

In connection with these experiments the sludge from a 48-hour, spore-free culture was filtered on a piece of canvas cloth and was dried at 103° C. A determination made on the dried material showed a nitrogen content of 12.8 per cent by weight. This value is more than twice that reported by Vaughan and Wheeler (1913), who found only 5.96 per cent nitrogen in a dried sample of *B. subtilis* grown on agar. It is possible, however, that their sample contained a large number of spores, which might account for their low nitrogen value.

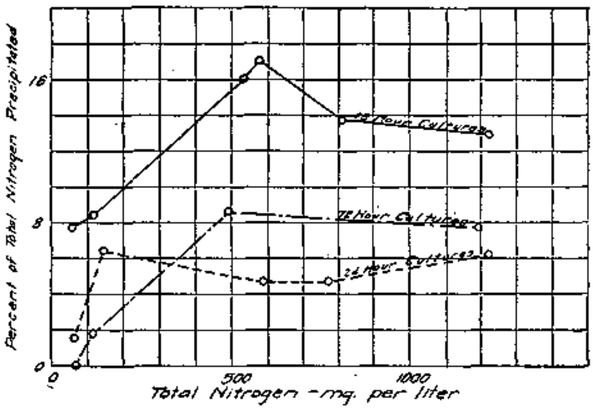

FIG. 5. GRAPHS SHOWING PERCENTAGES OF TOTAL NITROGEN PRECIPITATED IN *B. subtilis* CULTURES.

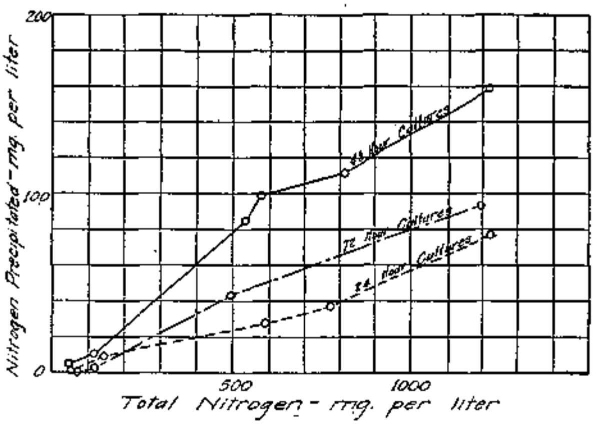

FIG. 6. GRAPHS SHOWING AMOUNTS OF TOTAL NITROGEN PRECIPITATED IN *B. subtilis* CULTURES.

An experiment was set up to determine whether the heavy growths of *B. subtilis* in aerated cultures were the result of mere agitation or whether the excess of oxygen played a part. A liter and a half of broth in a 2-liter Florence flask was inoculated with *B. subtilis* and placed in a revolving basket mounted on a motor-driven eccentric. The linear velocity of the basket was adjusted to about one-half foot per second, thus effectively stirring the broth in the flask without splashing. After 48 hours there was very little growth. During the next 24 hours the same culture was caused to splash in the flask, with the result that an extremely heavy growth was obtained as in previous aeration cultures. Another culture was set up in the basket and caused to splash from the start. At the end of 24 hours another luxuriant growth had developed. From this experiment it appears that plenty of oxygen is essential for the rapid growth of *B. subtilis.*

From the experiments carried out with *B. subtilis* there is reason to believe that in the activated-sludge process for sewage treatment, soluble nitrogenous bacterial foods such as amino acids, urea, creatinine, proteoses and peptones may increase the nitrogen content of the sludge by being ingested by the sludge organisms. The laboratory and experimental plant investigations described in this paper were prompted by this theory.

Construction of **Experimental Sewage Plant**

The construction of a continuous-flow treatment plant was begun in June, 1922. A wooden tank of 1500 gallons capacity was converted into a nidus tank, designed to treat from 5,000 to 30,000 gallons of domestic sewage daily. During 1923 and 1924, there were added a pump pit, a fine-screen chamber, an 1800-gallon flat-bottom settling tank, a 325-gallon concrete conical-bottom settling tank, an 8-foot trickling filter, a 212-gallon steel aerator, an air compressor, and pumping machinery.

A general view of the plant is shown in Figure 7. At the left in the foreground is the 8-foot trickling filter; adjacent to it are the two settling tanks; at the extreme right appears the top of the nidus tank with the framework built above it. The tower in the center supports a dosing tank used in connection with an experiment on sprinkling filter nozzles. The pump house is in the background. Figure 8 shows the plan of the general layout of the plant.

The sewage was drawn from the Champaign sewer. The dry-weather flow in the outfall sewer was from one to one and a half million gallons per day, and in wet weather the flow was greatly increased by surface water. The sewer connections included a manhole, three separate sewer lines, and a pump pit. Sewage flowed by gravity through either a 4-inch or a 6-inch vitrified tile from the Champaign sewer, through a bar screen to the pump pit, which was constructed large enough to act as a grit chamber. All excess sewage at the plant together with the effluent produced, was returned through an 8-inch vitrified tile to the Champaign sewer at a point some distance below the 4-inch and 6-inch intake lines.

Pumping Equipment.—Sewage was elevated from the pump pit through a 4-inch pipe line into the weir box by a Morris centrifugal pump having a capacity of 110 gallons per minute and belt-driven by a 2-horsepower electric motor. The sewage flow was regulated by a hand-operated valve at the pump. The influent weir box, containing a fine screen of ¼-inch mesh, was equipped with a 60-degree V-notch weir and an overflow for controlling the head and flushing out the screen chamber. A portion of the raw sewage could be by-passed before entering the fine-screen chamber when less than 20,000 gallons per day was to be treated. After passing over the weir, the sewage flowed by gravity into the top of the nidus tank.

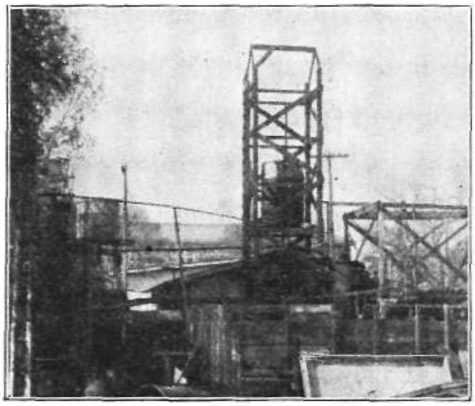

FIG. 7. GENERAL VIEW OF EXPERIMENTAL PLANT, 1924.

Nidus Tank.—Preliminary laboratory experiments* had indicated the advisability of having some mechanical means for maintaining the sludge in suspension, thus making it possible to balance

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* Described in the appendix to Part I of this bulletin.

the relative importance of stirring and oxygen requirement and to obtain data on critical stirring velocities and minimum oxygen necessary for biological growth. Accordingly, a tank was designed to afford a large amount of surface to support the growths of organisms ordinarily forming activated sludge, and to furnish mechanical means whereby these growths could be shaken from the racks and removed from the tank by the operator at will. A 1500-gallon circular wooden tank 5 feet 4 inches deep was used for this

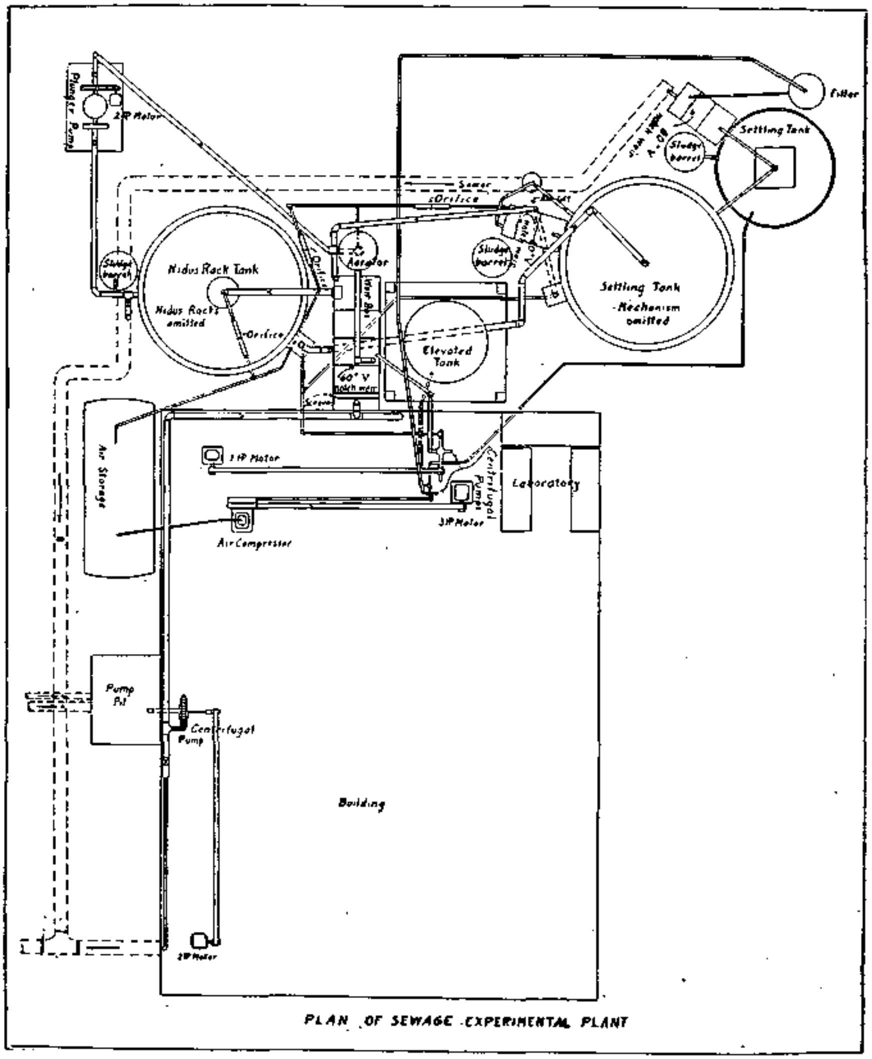


FIG. 8. LAYOUT OF EXPERIMENTAL SEWAGE-TREATMENT PLANT, 1924.

purpose. A concrete bottom was put in, having a slope of 20 degrees from the horizontal. The tank was equipped with eight nidus racks constructed of ordinary building laths and 1/16-inch-mesh galvanized-wire screen. Each rack stood 4 feet in height and was built wedge-shaped, so that the completed rack would set in a sector one-eighth the area of the tank and leave a clear space of 18 inches in diameter at the center of the tank. In building the racks, the wire screen was tacked to lath leaves, and the leaves were then assembled and properly braced as shown in Figure 9, leaving a clear space of ½-inch between the wire screens for circulation of the liquor in the tank. In the construction of the eight racks, 2200 square feet of wire screen was used, thus affording 4400 square feet of effective surface for the growth of organisms. A heavy wire was looped around each rack and twisted into a ring at the top, so that a hook could be attached for raising the rack and shaking off the sludge. On account of the light construction each rack easily could be shaken by hand, and this method was used throughout the experiments.

A section and top view of the tank is shown in Figure 10. The entire weight of all the nidus racks was supported by a web of sixteen ¾-inch pipes. The outside ends of the pipes rested on the concrete tank bottom, and the inside ends rested on a wooden frame hung from the superstructure of the tank by means of four ¾-inch extra-heavy pipe supports.

In the center of the tank, a cylindrical galvanized-iron well, 4 feet long and 18 inches in diameter, was introduced. Figure 10 shows a filtros plate 6 inches square resting on the wood frame within the central well. During those experiments in which compressed air was used, circulation of the liquor through the racks was effected by using the central well as an air-lift. In other experiments without compressed air circulation was effected by means of a 9-inch propeller, carrying 6 blades of 1-inch pitch, placed in the top of the central well and geared to a ¼-horsepower electric motor with a reversing attachment, so that the flow through the well could be made to pass upward or downward as desired. .

An annular trough, 4 inches wide, of laminated strips of wood nailed around the top of the tank, served to collect the overflow as it passed over a leveling board placed around the periphery. In order to prevent short-circuiting through open spaces at the rear of the racks, a snug-fitting baffle board was fastened on the top at the rear of each rack.

The sludge alter being shaken from the racks was either carried by the sewage over the leveling board to a tank where it settled out and was drawn off, or allowed to settle to the bottom of the nidus tank and then drawn off through a 3-inch sludge pipe.

The operating capacity of the nidus tank, determined by calibration against an 1800-gallon flat-bottom settling tank, was 1300 gallons. Before the racks were installed the tank had a capacity of

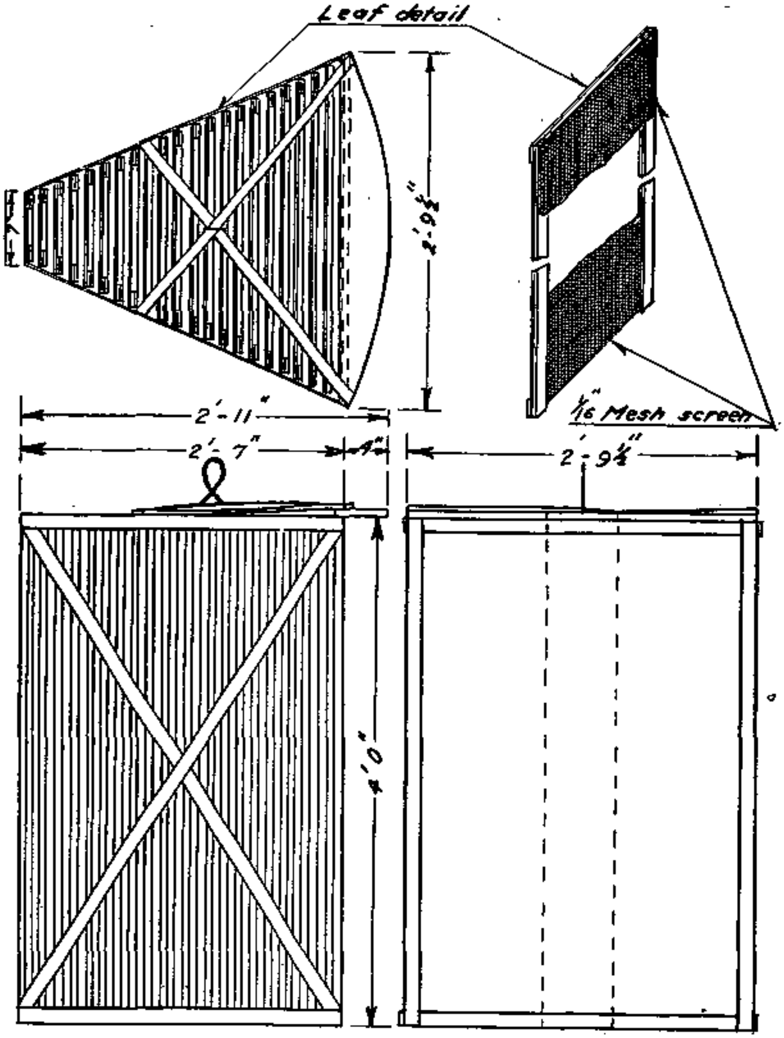


FIG. 9. DIAGRAMS SHOWING CONSTRUCTION OF NIDUS RACKS.

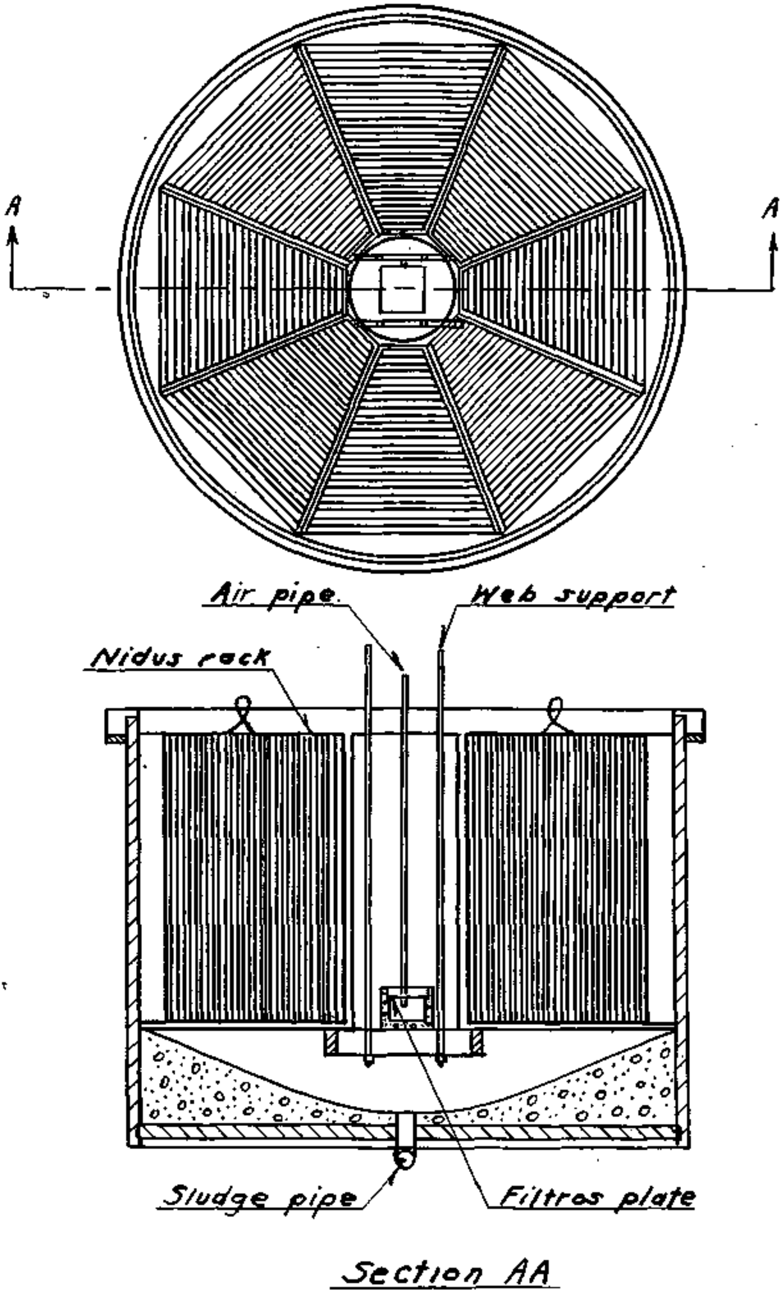


FIG. 10. DIAGRAMS SHOWING INSTALLATION OF NIDUS RACKS.

1500 gallons; whence the volume occupied by the nidus rack was 13.3 per cent of the original volume of the tank.

Sewage entered the top of the central well and was circulated through the racks by means of the propeller or air lift. The effluent flowed over the leveling board and passed by gravity to one of the settling tanks in the system.-

Auxiliary Aerator.—To permit the addition of definite small quantities of oxygen to the nidus tank, an auxiliary aerator was set up in such a manner that a portion of the nidus-tank liquor could be by-passed through it and then returned to give up its dissolved oxygen to the main body of liquor. This aerator consisted of a 212-gallon closed steel tank, 10 feet high and 2 feet in diameter, with 4-inch pipe connections, and one square foot of filtros plate, incased in a concrete box, supported on wooden blocks on the tank bottom and connected by a 1-inch line to the compressed-air system.

Air Compressor and Air-Measuring Apparatus.—A Union air compressor, with a rated capacity of 25 cubic feet of free air per minute at maximum speed, was belt-driven by a 3-horsepower, 2-phase, 440-volt electric motor. The compressed air was stored in a large steel tank from which 1-inch lines distributed it to various parts of the system. Orifices, ⅜- and 3/16-inch, standardized against a tested gas meter, were used to measure the flow, a constant pressure being maintained on them by a waste air valve on the tank.

Settling Tanks.—One settling tank, an 1800-gallon flat-bottom wooden tank, had an area of 44.1 square feet and a depth of 5 feet 5 inches; the other was formed in the shape of an inverted cone by an inside concrete filling, its area at the surface being 23.7 square feet, its depth 5 feet 6 inches, and its capacity 325 gallons. Both tanks were the Dortmund type, the liquor being directed downward at the center and allowed to flow slowly upward at a rate which permitted the sludge to settle out. The effluent from the flat-bottom tank passed over a leveling board built around its periphery and then into a launder similar to that on the nidus tank. The effluent from the conical-bottom tank flowed into the end of a 4-inch pipe terminating at the surface in the center of the tank. This pipe could be raised or lowered so as to change the detention period in the tank to suit the sewage flow.

The flat-bottom tank was equipped with a hand-operated thickener mechanism, consisting of a squeegee scraper, 2 feet wide and 3 feet 9 inches long, fastened in a vertical position at the bottom of the tank to a vertical central shaft, terminating above the surface in a large hand wheel. By means of this hand wheel the scraper could be revolved almost 180 degrees to push the sludge ahead of it to a stop plank, 18 inches high, fastened radially to the bottom of the tank and extending from the circumference to within 2 inches of the center. The stop plank and squeegee thus entrapped the sludge in a sector of the tank which could be closed by lowering a hinged cover actuated by means of a ¼-inch steel shaft from the surface of the tank. A 2-inch sludge pipe was located under the center of each compartment, or sector; and, by means of a 2-inch square opening at the central end of the compartment, liquor from the tank was permitted to rush in and flush out the sector when the sludge valve was opened. After the removal of the sludge, the scraper was revolved back to its original position, and the hinged cover was pulled up to prevent the deposition of sludge on its flat surface. This tank also contained two vertical baffles, 21 inches wide, running across the diameter of the tank at right angles to each other, to prevent the sludge from being stirred up in the top liquor. On account of the large amount of space occupied by the sludge-removal device, the effective capacity of the tank was only 1200 gallons.

The sides of the 325-gallon conical tank had a slope of 60 degrees from the horizontal, causing the sludge to settle to the apex of the cone from which it was drawn off in a 2-inch sludge pipe.

To each settling tank was attached a 6-inch 60-degree V-notch weir in a box, from which the effluent discharged into a 4-inch vitrified pipe and thence back into the main sewer, except when part of the effluent was pumped to a small dosing tank for the trickling filter described below.

Trickling Filters.—In June, 1924, a trickling filter was constructed from a steel tube, 10 feet long and 16 inches in diameter, placed in a vertical position. A false bottom was installed, and the tube then filled with gravel and crushed coke, in sizes ranging from ¼ inch to 3 inches in diameter, to a depth of 8 feet. A small dosing tank with an automatic siphon for intermittent dosing, was supported above the filter, and splash boards were placed so as to distribute the liquor from the dosing tank over the surface of the filter.

After a 2-week trial it was found that the area of the filter, .000032 acres, was not large enough to permit intermittent dosing at rates less than 10,000,000 gallons per acre per day. Another steel tube, 10 feet long with a diameter of 24 inches and an area of .000072 acres, was set up in place of the old 16-inch one and was filled to a depth of 8 feet with 2-inch limestone. The dosing device consisted of an automatic siphon and a metal box, 1 foot square and 6 inches deep, with a perforated bottom, from which the liquor had to fall through a distance of 16 inches before striking the filter surface. (See Figure 11.)

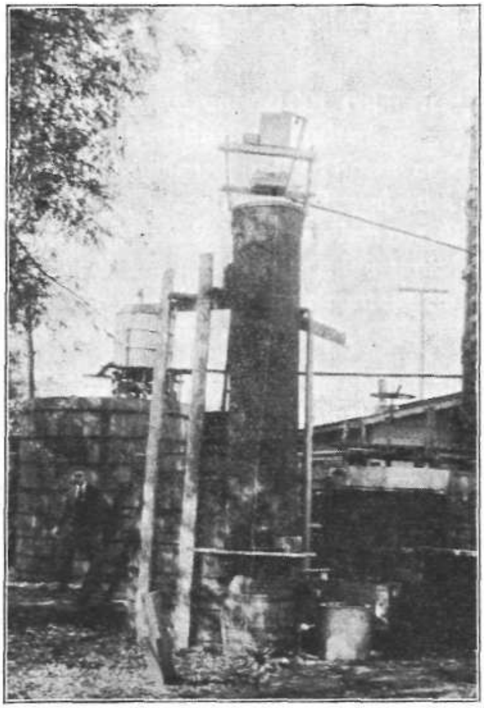


FIG. 11. SETTLING TANKS AND TRICKLING FILTER USED IN EXPERIMENTS, 1923-1925.

The effluent from the filter was caught by a funnel and run into the bottom of a 40-gallon barrel, which acted as a secondary settling tank as well as a base for the filter. The barrel was baffled to provide settling periods varying from ½ to 1 hour as desired.

Operation and Control of Plant

Operation of the experimental plant was begun on November 8, 1923, but had to be suspended after a 2-week run, on account of frost. Operation commenced again on April 21, 1924, and, except for a few shut-downs for repairs or additional equipment, continued until October 7, 1924, covering in all 124 working days.

Operating Records.—With the exception of an initial 7-day trial, July 23-29, the plant operation was divided into three 8-hour shifts. An attendant on each shift recorded the routine measurements every hour. The operating day began arbitrarily at 8:30 a.m. and ended at 8:30 a.m. the following day.

Rate of Flow.—The volume of sewage treated daily varied from 5,000 to 22,000 gallons. Both constant and varied rates of flow were used during the period of operation.

The flow in a city sewer is much greater by day than by night, and the day sewage is also much more concentrated (stronger). Variation in the flow in the Champaign sewer is shown in Figure 12. If an experimental sewage treatment device is fed at a constant rate day and night, the total amount of organic matter in the sewage treated per day will be considerably less than would be found in the same number of gallons of sewage collected at a rate per hour proportional to the flow in the sewer, so that the results would tend to show too high a quality of effluent and too little removal of organic matter. The ideal arrangement would be to vary the flow to an experimental apparatus continuously with the

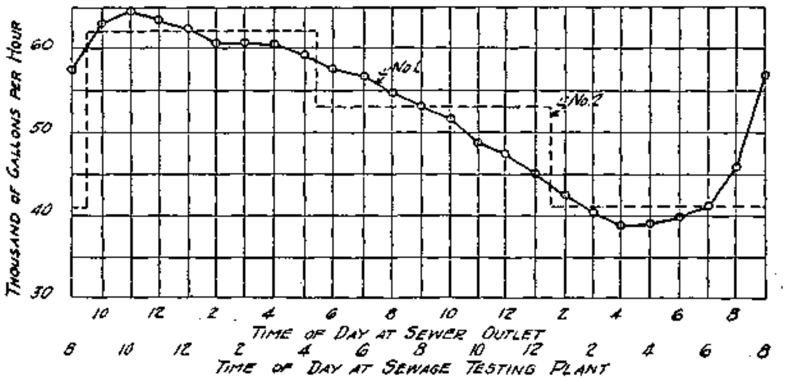


FIG. 12. CURVES SHOWING HOURLY VARIATIONS IN FLOW OF SEWAGE.
(Data from Illinois State Water Survey Bulletin 18.)

No. 1. *Curve showing average flow in Champaign sewer* (1921).
No. 2. *Curve showing proportionate rates of flow at different times of day through sewage testing plant.*

flow in the sewer from which it is fed. Automatic devices for proportioning flow give considerable difficulty with raw sewage, especially when handled in relatively small amounts. Manual adjustment of weirs and orifices as often as once an hour requires an undue proportion of the attendant's time. We solved the problem by arranging to adjust the flow three times a day. The proportionate amount of flow and the time of day are shown by curve 2 in Figure 12, so that the experimental plant was fed with a quantity and quality of liquor closely approximating the actual flow in the city sewer as shown by curve 1.

Collection of Samples.—At intervals of 1 hour during each shift. samples (250 c.c.) of the screened sewage and of the settled effluents from both the nidus tank and the trickling filter were collected, and these samples were composited in 1-gallon bottles containing chloroform. At the end of 24 hours the composites from the three shifts were recomposited according to the relative flow and sent to the laboratory for analysis. Sludge samples, likewise, were composited for analysis according to the volume of sludge drawn during the 24 hours. In warm weather the chloroformed samples were kept on ice.

Methods of Analysis.—The analytical procedures given in the 1923 edition of "Standard Methods of Water Analysis" of the American Public Health Association were followed in analyzing all samples taken at the experimental plant, with the exception that dissolved oxygen was determined by the Hale and Melia (1913) method. All results are expressed in parts per million unless otherwise indicated.

Data on Operation of Nidus Tank

A study of the various factors involved in the treatment of sewage by bioprecipitation required corresponding changes in methods of operation. For convenience, therefore, the entire experiment has been divided into periods, as follows:

First period, July 23-29, 1923.—Screened sewage was pumped through the nidus tank at a constant rate of 8,640 gallons per day, circulation through the racks being created by the propeller imparting an upward velocity of 1 foot per second to the liquor in the central well. The only oxygen received by the sewage was from surface absorption. The mean velocity of flow through the racks was 2.4 feet per minute, so that the tank contents were turned oVer once in 2.2 minutes. All the racks were shaken at 8:00 a.m. and

5:00 p.m. Sludge was drawn from the bottom of the tank at 8:30 a.m. and 5:30 p.m. Hourly samples of the screened influent were taken from 9:00 a.m. to 2:00 p.m., and of the effluent from 3:00 p.m. to 8:00 p.m. Since a settling tank had not yet been installed, the effluent samples were settled one hour and determinations made on the supernatant liquor. Turbidity and biochemical oxygen demand were determined on these samples as criteria of purification.

This run demonstrated that shaking the racks and drawing sludge twice a day was not sufficient to prevent septicity, especially in the afternoons. For example, the sludge removal at 5:00 p.m. always improved the general condition of the tank. At the end of 7 days it was decided to shut down the plant to install a steel aerator (described on page 53) and await the arrival of a settling tank. The operating results for the 7-day period are given in Table III. The treatment produced improvement as follows:

	Per cent improvement
Turbidity	41.2
B. O. D. (2½ days)	16.7
B. O. D. (5 days)	26.8

Second period, November 8-21, 1923.—During this period, it was decided to shake the racks more often than twice a day and to provide for the removal of the sludge as fast as it was shaken from the racks. Accordingly, one of the 8 racks was shaken each hour, so that all the racks were shaken once in 8 hours or 3 times a day. During this period the sewage was passed through 1/16-inch instead of ¼-inch screens. In order to carry the sludge out of the nidus tank, a heavy flow of liquor was passed through the tank by pumping 25 gallons a minute of the clear liquor from the settling tank into the screened sewage weir box, where it was mixed with sewage. This resulted in an average flow of about 32 gallons a minute over the leveling board and was found sufficient to carry the sludge out very quickly after a rack was shaken. Sludge in the settling tank was drawn off every 3 hours.

To insure aerobic conditions in the nidus tank, 25 gallons of liquor from the settling tank was by-passed by means of an air lift into the aerator and then returned to the nidus tank. From hourly measurements of flow and from dissolved-oxygen determinations every 3 hours on the influent and effluent of the aerator, it was possible to calculate the approximate volume of oxygen that was used up in the nidus tank in the form of dissolved oxygen per gallon

TABLE III

DATA ON EXPERIMENTAL PLANT OPERATION, FIRST PERIOD (JULY, 1923)

Date July 1923	Feed g.p.d.			Turbidity								
							2.5 days			5 days		
		Infl. ° C.	Effl. ° C.	Infl. p.p.m.	Effl. p.p.m.	removed	Infl. p.p.m.	Effl. p.p.m.	Per cent removed	Infl. p.p.m.	Effl. p.p.m.	Per cent removed
23	8640	23	23	210	140	33.3	105	*76*	27.6	230	168	26.9
24	8640	23	23	270	135	50.0	115	84	26.9	230	160	30.4
25	8640	22	22	270	140	48.1	145	112	22.7	220.	160	27.2
26	8640	23	23	230	135	41.3	120	104	13.3	260	192	26.1
27	8700	21	21	200	125	37.5	80	80	0.0	115	94	9.5
28	8640	21	21	220	140	36.8	110	104	5.4	210	156	27.4
29	8700	21	21	205	120	41.4	120	112	6.6	220	160	27.2
Av.	865)	22	22	228	133	41.2	113	96	16.7	212	155	26.8

of sewage treated. This calculation, however, did not include the oxygen that was used up by the liquor during its 10-minute detention in the aerator, and no meter was available to determine the amount of compressed air used in the air lift and aerator. Enough air was used in the aerator, however, to nearly saturate the liquor as it passed through.

The detention periods averaged about 3 hours in the nidus tank and 3 hours in the settling tank. Circulation in the nidus tank was brought about by forcing the liquor down through the central well by means of the propeller, thereby causing the liquor to flow upward through the racks at a velocity of about 3.6 feet per minute.

A varied flow of sewage was passed through the plant, the maximum being from 8:30 a. m. to 4:30 p. m., the mean from 4:30 p. m. to 12:30 a. m., and the minimum from 12:30 a. m. to 8:30 a. m.; but the flow was kept constant during each 8-hour period, so that the daily flow could be determined with accuracy. During the last three days of the test the flow was decreased from 10,000 gallons per day to about 6,000 gallons per day, in order to observe the effect of the increased detention period.

Grab samples of influent and effluent were taken at 10:00 a. m. and 4:00 p. m. for B. O. D. determinations. The heaviest flow and the strongest sewage entered the plant at 10:00 a.m.; the weakest day sewage entered the plant at 4:00 p. m., and at this time the poorest effluent was being discharged from the plant.

The results of this period of operation are given in Table IV. These show an average removal of 45 per cent of the turbidity, 34 per cent of the oxygen consumed from $KMnO_4$, 55 per cent of the suspended solids, and 55 per cent of the biochemical oxygen demand. Since the greater part of the suspended solids had been strained out of the sewage by the 1/16-inch-mesh screens, nearly all of the organic matter in the sewage was in colloidal or true solution. From these data it appears that a very reasonable amount of purification was obtained by a 3-hour detention period in the nidus tank when using only .0015 cubic feet of oxygen or .007 cubic feet of free air per gallon of sewage treated.

The racks collected a heavy growth of light-brown sludge, which settled readily and which had no offensive odor when drawn from the bottom of the settling tank.

In order to determine whether or not nitrogen was lost under the conditions of this experiment, daily samples of influent, effluent, and sludge were analyzed for free ammonia, nitrites, nitrates, and total organic nitrogen by the Kjeldahl method; and the data thus obtained, all expressed as nitrogen, were added together and converted into pounds of nitrogen for the total flow of the period. (For a discussion of the method of calculation see Bull. 18, pp. 73-75.) During the 14-day run, there was a net loss of 0.9 per cent of the nitrogen. Since this amount is within the limits of experimental error, we can conclude that there was no loss of nitrogen when the sludge was removed from the racks once in 8 hours to prevent liquefaction.

Calculations from total solids of influent, effluent, and sludge for the period showed 964.1 pounds of solids in the influent, 808.9 pounds in the effluent, and 140.0 pounds in the sludge. Adding the sludge to the solids of the effluent and subtracting from the total solids in the influent, we see that there was a loss of 15.2 pounds; that is the loss by "wet-burning" was only 1.5 per cent of the total solids of the influent.

The nitrogen of the dry sludge calculated from the analysis of 14 wet samples amounted to 4.9 per cent. Of the total nitrogen of the sewage 13.8 per cent was removed by the sludge. The sludge yield amounted to 872 pounds per million gallons.

Third period, April 21-May 11, 1924.—The 325-gallon conical-bottom settling tank was set up and connected to the system, and operation was resumed on April 21. Throughout this period, the racks were shaken only when there were indications of septic conditions arising in the nidus tank. The time of shaking each rack varied from once a day to once in 4 days. The influent flow alone, passing over the leveling board of the nidus tank, was not sufficient to carry all the sludge over to the settling tank; therefore, sludge was drawn from the bottom of the nidus tank as well as from the bottom of the settling tank.

Compressed air was introduced into the central well at the rate of 0.18 cubic feet per gallon, causing the liquor in the nidus tank to circulate downward through the racks' with a mean velocity of 2.5 feet per minute.

The sewage flow was decreased from 10,000 gallons to about 6,000 gallons per day, but was maintained constant throughout the entire period. The detention period in the nidus tank was 5 hours, and in the settling tank 1 hour.

B.O.D. samples of influent and effluent were taken at 10:00 a.m. and 4:00 p.m. as during the previous period.

The results of the test are shown in Table V. The nitrates in the influent were unusually high. During the first 10 days, 3 gold fish remained alive in the effluent but with some discomfort; but on the eleventh day, when purification was less effective on account of accumulated sludge on the bottom of the nidu.s tank, the fish died. Complete sludge removal was impossible because a velocity of 2.5 feet per minute was not sufficient to flush out pockets at the base of the racks.

As in the previous period, total-nitrogen determinations were made on the influent, effluent, and sludge, in order to determine nitrogen losses. Since a large volume of the sludge remained in the nidus tank at the end of the run, the racks were shaken vigorously and the contents of the tank were pumped to the large settling tank, where the volume was measured and a uniform sample obtained. The results do not indicate in wihat form the nitrogen was lost, but only that there was a net loss of 36.2 per cent of the total nitrogen of the influent when sludge liquefaction was allowed to take place. During the period there were 1032.5 pounds of solids in the influent, 914.4 pounds in the effluent, and 87.6 pounds in the sludge. Adding the solids of the sludge to those of the effluent and subtracting from the total solids in the influent, we find that there was a loss of 69.7 pounds, or "wet-burning" to the extent of *6.7* per cent.

The nitrogen of the sludge (calculated from the analyses of the wet samples) was only 3.6 per cent. The total nitrogen removed by the sludge was only 3.4 per cent. The sludge was very black in appearance and averaged 99.75 per cent moisture.

Fourth period, June 9-22, 1924.—The sludge was allowed to accumulate on the racks during this entire period, instead of being shaken off at intervals as in previous periods. Circulation was created by blowing 0.18 cubic feet of air per gallon through the central well, so that the liquor moved downward through the racks with a mean velocity of 2.5 feet per minute. The influent was varied hourly so as to represent an approximately proportional part of the flow of Champaign sewage. The average detention period in the nidus tank was 5 hours. As in the previous period, the effluent from the nidus tank was settled in the conical bottom settling tank, with an average detention period of 1 hour. A white opalescent effluent was obtained throughout the entire run. Sludge was drawn from both tanks every 6 hours. Since the sludge was allowed to accumulate on the racks there was very little to be drawn, but that little was black in color and had an offensive odor. For the determination of biochemical oxygen demand, samples of the influent were taken at 10:00 a.m., and of the effluent at 4:00 p.m. Results of operation are shown in Table VI. High nitrates in the influent probably kept the nidus tank from becoming septic during the test.

Part of the effluent from the settling tank was used to dose a trickling filter, with results which will be discussed later under trickling-filter operation.

Fifth period, July 16-Aug. 4, 1924.—This run was conducted under the same conditions as in the fourth period with the exception that the sludge was removed by shaking each rack every 8. hours, instead of allowing the sludge to accumulate. A chain drag was placed on the bottom of the nidus tank and was revolved every hour by hand to prevent stagnation of the sludge. Sludge, drawn from both tanks every 3 hours, was light-brown in color and was not offensive. Results are shown in Table VII. It is interesting to note that while the fourth period showed an average removal of only 4.3 per cent of the oxygen consumed from $KMnO_4$, this period, when the sludge was removed frequently from the racks, showed a removal of 24.8 per cent.

Sixth period, Aug. 5-18, 1924.—In order to obtain more data on surface absorption as the only source of oxygen, the propeller was used as in the first period of operation. The chain drag was used every hour to facilitate sludge removal. The influent flow was varied, but the detention period of the sewage in the nidus tank averaged 5 hours. The average settling period was 1 hour. One rack was shaken every hour; hence, each rack in the tank was shaken once in 8 hours. It was found that the contents of the nidus tank could be prevented from going septic by the aeration effected by gentle stirring. As in the small nidus tanks, it was found that activated sludge would grow at extremely low dissolved-oxygen concentrations. The results (Table VIII) were practically the same as those obtained when 0.16 cubic feet of air per gallon was blown into the tank, except that the effluent was more turbid.

Seventh period, Sept. 5-18, 1924.—Although the second period of operation (with a 3-hour detention period in the nidus tank and with removal of the sludge from each rack once in 8 hours) gave the highest degree of purification, the data also showed that low air activated sludge could not be used for final treatment where a high-grade effluent was desired. It was decided, therefore to study the effect of short detention periods (1 to 2 hours) in the nidus tank using 0.2 cubic feet of air per gallon. If enough purification could be accomplished by a short period of retention, a nidus tank might serve as an effective preliminary process, to be followed by treatment in a trickling filter dosed at a very high rate.

A varied flow of screened sewage, proportional to the flow of Champaign sewage, was pumped into the nidus tank at the rate ot about 21,500 gallons per day. The detention period in the nidus tank averaged 1½ hours (1 hour at maximum; flow and 2 hours at minimum flow). The settling period in the large settling tank averaged about 1.5 hours.

A rate of 0.2 cubic feet of air per gallon required an average volume of 3 cubic feet per minute. Of this, 0.5 cubic feet was introduced into the central well of the nidus tank thereby imparting a velocity of 2.5 feet per minute to the liquor circulating through the racks. The remaining 2.5 cubic feet of air was applied in the aerator to nidus-tank liquor circulated through it, by means of a plunger pump, at a rate of 25 gallons per minute. The plunger type of pump, rather than the centrifugal, was used because it had less tendency to break up the sludge.

Before the test the chain drag was removed from the bottom of the nidus tank because of mechanical trouble. Drawing 25 gallons of liquor per minute from; the bottom of the tank for the aerator, was expected to keep the bottom free from sludge. One rack was shaken every hour, so that each rack was shaken once in 8 hours. Sludge was drawn every 3 hours. Excellent results were obtained during the first 4 days. After the fourth day of operation the continual removal of 25 gallons a minute from the bottom of the nidus tank did not prevent sludge stagnation around the walls, and the stability of the filter effluent began to drop rapidly. (Table IX.)

Eighth period, Sept. 19-Oct. 7, 1924.—This run was made under the same conditions as the seventh period with the following three exceptions:

(1) All the air was blown through the central well, thus increasing the average mean downward velocity through the racks from 2.5 feet per minute to 4.0 feet per minute; this velocity prevented sludge stagnation and the flow over the leveling board was sufficient to carry out the sludge as long as it was kept off the bottom.

(2) Instead of introducing a constant volume of air, the volume was regulated according to the flow. At maximum flow, when the sewage was strongest, 0.3 cubic fleet of air per gallon was used; but at minimum flow the rate was decreased to 0.1 cubic feet, making the average rate for the daily flow about 0.2 cubic feet.

(3) The type of sludge obtained in the previous period indicated that shaking each rack once in 8 hours was not often enough; therefore, during this run, the rate was doubled by shaking 2 opposite racks every hour, each rack now being shaken once in 4 hours. This schedule produced a light-brown sludge which was not offensive and which settled readily. At the end of the run all the racks were shaken vigorously, and a mixed sample of liquor was found to contain 2 per cent of sludge byvolume.

In order to determine the percentage removal of suspended matter by the stationary ¼-inch-mesh screens during these experiments, samples of raw sewage were taken before the sewage was pumped to the screen chamber. From Table X, in which are expressed the results of this period, it is seen that the screens reduced the average suspended solids from 397 to 186 parts per million, or 53.1 per cent. According to curves submitted by Metcalf and Eddy (1922), this is equivalent to a detention period of 1 hour in a settling chamber. The high efficiency of these screens was due to the accumulation of solid matter on the screen faces; and their large area made cleaning necessary only about once every 2 hours!

In this period there was an average removal from the screened sewage of 56.2 per cent of the turbidity, 69.5 per cent of the suspended solids, and 28.7 per cent of the oxygen consumed from $KMnO_4$. In other words, just as much purification was obtained with an average detention period of 1½ hours in the nidus tank using 0.22 cubic feet of air per gallon as was obtained in any of the previous experiments using 0.2 cubic feet of air per gallon with a detention period of 5 hours in the nidus tank. Sludge was formed at the rate of 625 pounds per million gallons.

TABLE IV

DATA ON EXPERIMENTAL PLANT OPERATION, SECOND PERIOD (NOVEMBER, 1923)

Results not otherwise designated are in parts per million.

Date Nov.	Feed g.p.d.	Oxygen cu. ft. per gal at 20°C. 760 mm.	Temp. °C.		Turbidity			Oxygen Consumed from $KMnO_4$			Biochemical Oxygen Demand (20°C.)							
											10 a.m. samples				4 pm. samples			
											Infl.		Effl.		Infl.		Effl.	
			Infl.	Effl.	Infl.	Inffl.	Per cent removed	Infl.	Effl.	Per cent removed	2 da.	5 da.	2 da.	5 da.	2 da.	5 da.	2 da.	5 da.
8 T.	10586	.0021	18	14	190	48	74.7	42	28	33.3	188	197	26	39	134	161	58	85
9 F.	10824	.0020	18	15	110	55	50.0	40	36	10.0	134	197	39	58	88	116	67	85
10 S.	10314	.0015	18	16	120	65	45.8	49	33	32.6	170	304	35	62	58	206	67	120
11 S.	10369	.0016	17	16	110	75	31.8	50	25	50.0	...	...	..	..	..	...	..	...
12 M.	10368	.0018	18	16	240	90	62.6	52	32	38 4	143	286	35	67	125	170	89	147
13 T.	10345	.0016	18	16	160	95	40.6	52	36	30.7	188	268	35	67	143	179	72	112
14 W	10368	.0015	18	16	180	90	50.0	70	51	24.2	197	311	17	69	125	237	80	143
15 T.	10580	.0014	18	16	160	85	46.8	51	48	5.8	...	...	..	..	...	...	..	....
16 F.	10588	.0014	18	15	150	95	36.6	50	30	40.0	...	...	..	..	...	...	..	....
17 S.	10368	.0016	18	15	180	95	46.5	50	22	56.0	...	...	..	..	...	...	..	....
18 S.	10513	.0015	18	15	110	80	27.2	42	30	28.5	...	...	..	..	...	...	..	....
19 M.	6493	.0015	18	14	150	80	46.6	42	30	28.5	179	241	35	62	197	259	76	107
20 T.	6156	.0010	18	15	140	85	39.2	52	22	57.6	...	...	..	..	...	...	..	....
21 W.	6544	.0016	18	14	115	70	39.1	72	40	44.4	170	250	26	44	88	161	72	116
Av.	9601	.0015	18	15	151	79	45.5	51	33	34 2	171	257	31	58	119	186	72	114

TABLE IV *(Concluded)*

Date Nov.	Suspended Solids			Free NH$_s$ Nitrogen		Nitrite Nitrogen		Nitrate Nitrogen		Alb. NH$_a$ Nitrogen		Total Org. Nitrogen		Residue on evaporation			Sludge		
	Infl.	Eftl.	% re-moved	Infl.	Eftl.	Infl.	Eftl.	Infl.	Eftl.	Infl.	Eftl.	Infl.	Eftl.	Infl.	Eftl.	Per cent removed	Gals. drawn	p.p.m	Nitrogen p.p.m.
8 T.	91	22	75.8	24.0	24.0	.070	.065	.88	1.00	2.4	3.6	18.0	2.7	889	754	15.1	259	3466	188
9 F.	53	24	54.7	24.0	20.0	.300	.050	.96	.68	4.4	4.0	8.3	3.5	770	658	14.5	268	3968	201
10 S.	92	50	45.6	28.0	28.0	.120	.005	1.00	.36	7.2	0.00	9.8	2.9	787	697	11.4	297	7008	345
11 S.	54	45	16.5	28.0	26.0	.140	.005	1.24	.48	5.6	4.0	9.8	10.4	777	745	4.1	273	4750	277
12 M.	114	24	87.6	28.0	30.0	.240	.030	.96	.56	5.6	5.2	14.0	10.0	944	782	17.1	325	5100	240
13 T.	99	45	54.5	28.0	36.0	.175	.015	1.20	.40	5.6	4.4	14,0	9.2	803	781	9.5	315	4597	217
14 W.	128	55	57.0	26.0	26.0	.150	.010	.84	.32	5.6	3.6	24.0	10.0	806	760	5.7	278	5753	270
15 T.	55	35	36.3	40.0	38.0	.200	.010	.84	.36	5.6	6.4	13.0	10.0	828	786	5.0	256	5204	231
16 F.	49	41	16.3	26.0	34.0	.120	.015	.76	.32	7.2	4.0	10.8	9.2	868	812	6.4	214	5142	233
17 S.	1 01	42	58.4	30.0	30.0	.010	.010	.92	.20	4.8	5 6	25.2	9.2	1150	752	34.6	232	4257	189
18 S.	41	18	56.0	32.0	30.0	.280	.015	1.04	.40	3.6	4.4	9.8	8.8	914	805	11.9	187	4647	228
19 M.	82	36	56.0	28.0	30.0	.070	.020	.88	.36	5.6	4.4	5.0	3.0	794	724	8.8	235	3533	175
20 T.	64	39	39.0	28.0	38.0	2.40	.010	.80	.28	4.4	4.0	14.0	9.2	864	759	12.2	242	4010	187
21 W.	51	25	50.9	26.0	20.0	.120	.000	.88	.16	5.6	3 2	12.0	9.2	753	613	18.5	252	3048	141
Av.	81	36	55.5	28.2	29.7	.159	.017	.97	.42	5.2	4.0	13.4	7.6	857	739	13.7	259	4606	223

TABLE V

DATA ON EXPERIMENTAL PLANT OPERATION, THIRD PERIOD (APRIL-MAY, 1924)

Results not otherwise designated are in parts per million.

Date April-May	Feed g.p.d.	**Air** cu. ft. per gal. at 16° C. 760 mm.	Temp. ° C.		Turbidity			Oxygen Consumed from KMnO$_4$			Biochemical Oxygen Demand (20° C.) 10 a.m. samples				4 p.m. samples			
			Infl.	Effl.	Infl.	Effl.	Per cent removed	Infl	Effl.	j Per cent removed	Infl.		Effl.		Infl		Effl.	
											2 da.	5 da.	2 da.	5 da.	2 da.	j da.	2 da.	5 da.
21 M.	6120.0	.15	15	13	165	55	66.6	38	32	15.7	255.0	346	30	41	92	197	39	114
22 T.	6236 0	.15	14	12	172	53	69.1	42	25	40.4	251	346	36	45	170	275	102	140
23 W.	6364.8	.18	15	14	185	42	77.3	53	28	47.1	200	356	6	34	161	183	96	131
24 T.	6364.8	.15	16	16	195	41	78.9	43	40	6.9	155	237	39	58	138	197	81	114
25 F.	6364.8	.18	17	17	200	43	78.5	42	34	19.0	109	237	43	65	170	174	81	110
26 S.	6480.0	.17	15	14	165	38	76.9	45	22	51.1	191	264	**3**	3	65	129	62	75
27 S.	6364.8	.15	14	13	105	15	85.2	18	12	33.3	200	246	17	36	22	110	8	28
28 M.	6393.6	.18	14	13	270	25	90.0	39	18	53.9	73	209	2	3	28	101	40	69
29 T.	6393.6	.18	14	14	185	35	81.0	14	20	-4.2	...	...	..	..	..	...	...	...
30 W.	6422.4	.18	14	13	150	30	80.0	30	24	20.0	45	73	5	10	19	60	22	54
1 T.	6393.6	.18	14	14	125	38	69.6	33	12	66.6	27	54	2	3	47	57	51	67
2 F.	6278.4	.15	14	15	140	48	65.1	37	26	29.7	136	182	8	8	60	129	47	78
3 S.	6422.4	.19	15	14	135	55	59.2	31	19	38.7	...	...	..	..	..	...	...	...
4 S.	6393.6	.16	14	14	125	55	56.0	23	15	34 7	246	410	29	40	33	61	56	93
5 M.	6192.0	.15	16	16	175	70	60.0	38	25	34.2	155	237	.58	89	77	136	77	136
6 T.	6393.6	.15	16	16	. 170	80	52.9	25	25	0.0	155	228	23	38	136	251	91	133
7 W.	6333.0	.18	15	15	165	75	54.4	23	20	13.0	127	182	38	58	132	209	86	**127**
8 T.	6278.4	.17	15	14	143	85	40.5	30	25	16.6	73	100	20	31	54	91	59	104
9 F.	6307.2	.19	15	14	159	83	47.8	42	40	4.7	73	100	18	43	54	100	83	114
10 S.	6364.8	.36	15	14	125	90	28.0	50	36	28.0	...	...	..	..	..	...	...	...
11 S.	6364.8	.40	14	14	108	60	44.4	45	30	33.3	...	...	..	..	..	...	...	...
Av.	**6344.1**	**.18**	14	14	160	53	**66.7**	35	25	29.2	141	224	14	35	84	**144**	63	99

TABLE V *(Concluded)*

Date April-May	Suspended Solids			Free NH_3 Nitrogen		Nitrite Nitrogen		Nitrate Nitrogen		Alb. NH_3 Nitrogen		Total Org. Nitrogen		Residue on evaporation			Sludge		
	Infl.	Effl.	Per cent removed	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Per cent removed	Gal. drawn	Solids p.p.m.	Nitrogen p.p.m.
21 M.	79.2	27.3	65.2	40.0	44.0	.500	.100	2.20	.80	8.8	4.8	24	16	868	656	24.4	0.0		
22 T.	96.0	14.6	84.7	40.0	14	.350	.100	2.20	.80	7.2	4.0	32	22	902	783	24.2	17.0	1673	111.6
23 W.	98.4	15.6	84.1	70.0	50	.300	.050	1.72	.64	7.2	6.8	43	10	925	785	15.1	13.0	2841	99.6
24 T.	113.6	16.8	85.1	60.0	50	.250	.050	1.92	.40	10.0	10.0	39	9.0	913	772	15.4	44.25	3685	178.2
25 F.	165.6	27.2	83.5	40	50	.250	.050	2.80	.65	8.0	6.8	48	22	846	703	16.9	51.0	4640	206.5
26 S.	102.8	21.2	79.3	34	28	.500	.128	1.00	.68	8.0	5.6	44	14	857	756	11.7	51.5	1666	63.2
27 S.	57.6	10.9	81.0	40	44	.540	.25b	3.60	.92	6.8	4.8	15	10	861	751	12.7	53.75	1904	75.6
28 M.	192.8	19.2	90.0	40	60	.560	.230	6.80	1.52	14.0	6.8	58	9.0	1070	844	21.1	56.0	1669	75.7
29 T.	124.8	17.0	86.4	40	34	1.000	.140	8.00	.72	0.8	6.8	35	16	884	743	15.9	107.0	2576	198.8
30 W.	92.8	12.8	86.2	28	28	1.120	.140	11.20	.80	6.8	2.8	23	12	962	788	18.0	56.2	2496	90.8
1 T.	57.6	12.0	79.1	66	24	1.200	.200	6.8	.80	16.0	6.8	23	14	866	828	4.3	57.0	2763	106.1
2 F.	76.0	21.0	72.3	40	24	.880	.125	12.00	.64	8.8	3.2	28	9.0	1069	'906	15.2	66.5	4015	152.4
3 S.	60.8	24.8	59.2	50	36	.600	.100	9.60	.60	8.8	4.0	30	8.0	959	880	8.2	74.5	3700	157.9
4 S.	67.6>	19.2	71.5	48	34	.850	.200	13.20	.92	9.6	5.7	40	10	1074	903	15.9	72.5	4408	172.2
5 M.	93.2	28.0	69.9	46	34	1.500	.060	4.00	.52	10.0	4.0	40	12	1020	903	11.4	75.5	5327	213.7
6 T.	102.4	30.0	70.7	34	40	.500	.050	6.80	.64	14.5	9.6	50	16	922	856	7.1	64.5	4519	183.9
7 W.	104.0	29.6	71.5	40	38	.375	.080	1.72	.48	16.8	8.0	23	12	892	809	9.3	61.5	3660	184.8
8 T.	84.0	26.8	68.0	24	34	.625	.040	1.72	.36	6.8	3.2	23	13	887	819	7.6	53.5	2106	94.5
9 F.	94.4	26.6	71.9	34	34	.500	.035	2.20	.40	10.0	6.0	35	14	939	837	10.8	53.0	2950	126.1
10 S.	53.2!	28.6	46.2	64	40	.250	.025	2.32	.40	16.0	8.8	30	20	847	817	5.9	67.5	6528	300.3
11 S.	47.3	14.0	70.5	40	36	.500	.050	2.48	.32	9.6	4.8	42	15	884	757	14.3	64.0	2898	103.4
Av.	93.E	21.1	77.4	43	37	.626	.105	4.67	.66	10.0	5.5	34	13	926	804	13.5	57.9	3301	142.2

TABLE VI

DATA ON EXPERIMENTAL PLANT OPERATION, FOURTH PERIOD (June, 1924)

Results not otherwise designated are in parts per million.

Date June	Feed g.p.d.	Air cu. ft. per gal.	Temp. ° C.		Turbidity			Oxygen Consumed from $KMnO_4$			Suspended Solids		
			Infl.	Effl.	Infl.	Effl.	Per cent removed	Infl.	Effl.	Per cent removed	Infl.	Effl.	Per cent removed
9 M.	5034	.13	16	18	120	68	43.3	56.0	40.0	28.5	65.2	23.4	64.1
10 T.	5000	.13	16	16	140	85	39.2	34.0	42.0	-23.8	77.6	29.6	61.8
11 W.	5034	.18	16	17	155	85	45.1	52.0	40.0	23.0	90.0	24.0	73.3
12 T.	5010	1.00	16	17	155	85	45.1	48.0	46.0	4.1	99.6	34.7	65.6
13 F.	5034	1.00	16	19	145	72	50.3	35.0	30.0	14.2	78.4	17.4	70.1
14 S.	5034	.20	17	18	140	75	46.4	44.0	34.0	22.7	62.0	34.6	44.1
15 S.	5020	.20	16	18	125	78	46.2	52.0	45.0	13.4	86.0	17.0	80.2
16 M.	5100	.18	16	18	200	110	45.0	50.0	50.0	0.0	134.8	36.0	73.2
17 T.	5034	.18	17	19	195	110	43.5	58.0	54.0	6.9	120.0	31.6	73.7
18 W.	6200	.18	18	20	165	85	48.4	55.0	52.0	5.4	84.8	24.2	71.4
19 T.	5000	.18	19	21	170	90	47.0	73.0	73.0	0.0	98.0	23.6	75.9
20 F.	5034	.17	18	20	200	100	50.0	64.0	60.0	6.2	213.6	25.0	88.2
21 S.	5034	.17	18	20	150	110	26.6	57.0	54.0	5.2	99.2	24.2	75.6
22 S.	5034	.17	17	19	130	100	23.0	44.0	64.0	-45.4	69.6	19.6	71.8
Av.	5114	.29	17	18	158,	88	44.3	51.5	48.8	4.3	98.4	26.0	70.6

TABLE VI *(Concluded)*

Date June	Free NH_3 Nitrogen		Alb. NH_3 Nitrogen		Nitrite Nitrogen		Nitrate Nitrogen		Residue on evaporation			Sludge Gals drawn
	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Per cent removed	
9 M.	4.0	24.0	12.8	6.8	1.50	.20	1.80	1.12	1013	914	9.7	35
10 T.	28.0	16.0	12.0	6.8	1.15	.10	6.80	.48	1051	893	15.0	16
11 W.	4.0	22.0	10.8	4.0	1.00	.08	2.56	.64	1059	935	11.7	15
12 T.	16.0	8.0	10.0	6.4	.40	.06	2.20	.52	1022	934	8.6	21
13 F.	32.0	32;o	12.0	8.0	.65	.04	5.60	.48	950	897	5.5	21
14 S.	22.0	22.0	9.2	9.2	.45	.03	10.00	.36	898	867	3.4	20
15 S.	28.0	26.0	12.0	10.0	.65	.06	10.80	.48	1021	901	11.7	17
16 M.	38.0	44.0	8.4	9.2	.70	.04	1.88	.48	1007	846	15.9	21
17 T.	32.0	44.0	9.2	10.0	.30	.08	7.20	.80	1020	862	15.4	16
18 W.	28.0	39.0	8.8	9.6	.27	.02	1.76	.40	1026	825	19.5	18
19 T.	32.0	40.0	10.0	6.8	.15	.01	1.04	.28	855	800	6.4	19
20 F.	24.0	36.0	13.2	6.0	.15	.01	8.00	.08	975	782	19.8	15
21 S.	28.0	33.0	12.0	10.0	.75	.02	7.00	.28	977	790	19.1	15
22 S.	32.0	44.0	10.0	12.0	.70	.02	7.20	.56	926	783	15.4	17
Av.	24.8	307	10.7	8.2	.59	.05	5.27	.49	985	858	12.6	19

TABLE VII

DATA ON EXPERIMENTAL PLANT OPERATION, FIFTH PERIOD (JULY & AUGUST, 1924)

Results not otherwise designated are in parts per million.

Date July-Aug.	Feed g.p.a.	Air cu. ft. per gal.	Temp. ° C.		Turbidity			Oxygen Cons from $KMnO_4$		
			Infl.	Effl.	Infl.	Effl..	% Remov.	Infl.	Effl.	% Remov.
16 W.	5328	.17	21	21	230	88	61.7	61.0	60.0	1.6
17 T.	4856	.19	20	20	210	95	54.7	61.0	43.0	29.5
18 F.	5001	.18	20	20	230	100	56.9	57.0	40.0	29.8
19 S.	5159	.16	19	20	280	97	65.3	56.0	43.0	23.2
20 S.	5032	.18	20	21	160	90	43.7	60.0	40.0	33.3
21 M.	5032	.16	22	22	220	85	61.3	60.0	50.0	16.6
22 T.	5159	.16	21	21	240	90	62.5	54.0	54.0	0.0
23 W.	4929	.16	22	22	220	90	59.0	52.0	45.0	13.4
24 T.	4856	.16	20	21	200	90	55.0	67.0	50.0	25.3
25 F.	5032	.16	21	21	230	88	61.7	50.0	38.0	24.0
26 S.	5093	.16	20	21	190	90	52.6	68.0	54.0	20.5
27 S.	5098	.16	20	21	225	90	60.0	82.0	51.0	37.8
28 M.	5093	.15	21	22	250	108	56.8	75.0	55.0	26.6
29 T.	4892	.16	21	22	260	100	61.5	64.0	41.0	35.9
30 W.	5220	.17	22	22	250	85	66.0	62.0	42.0	32.2
31 T.	5159	.17	21	22	230	105	54.3	38.0	30.0	21.0
1 F.	5032	.18	21	22	250	95	62.0	44.0	30.0	31.8
2 S.	5060	.17	21	22	200	90	55.0	50.0	38.0	24.0
3 S.	5032	.17	21	22	200	80	60.0	50.0	34.0	32.0
4 M.	5082	.17	22	23.	270	110	59.2	67.0	40.0	40.2
Av.	5057	.16	20	21	227	93	58.4	58.9	44.0	24.8

TABLE VII *(Concluded)*

Date July-Aug.	Free NH$_3$ Nitrogen		Alb. NH$_3$ Nitrogen		Nitrite Nitrogen		Nitrate Nitrogen		Residue on Evaporation			Sludge	
	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	% Remov.	Gal. drawn	Solids
16 W	1.6	40.0	.40	7.2	.075	.000	.84	1.36	1026	876	14.6	27.5	....
17 T.					.075	.010	.84	.40	1026	789	22.1	38.5	....
18 F.	48.6	52.6	20.6	9.6	.075	.010	.88	.80	994	856	13.8	57.0	....
19 S.	67.0	48.0	4.0	13.2	.050	.010	.88	.40	995	782	21.4	126.5	....
20 S.	64.0	64.0	20.0	10.4	.050	.010	1.12	1.12	995	809	18.6	128.5	....
21 M.	48.0	56.0	12.8	6.4	.050	.010	.72	1.68	952	840	11.7	125.0	....
22 T.	44.0	66.0	13.2	6.0	.025	.010	.40	.28	993	782	22.2	130.5	....
23 W.	80.0	64.0	15.2	8.8	.060	.010	.88	.68	1022	861	15.7	124.0	3314
24 T.	70.0	68.0	12.8	8.8	.050	.005	.80	.80	965	899	6.8	123.0	4177
25 F.	70.0	110.0	10.0	9.2	.090	.005	.76	.48	1054	885	16.0	121.0	4486
26 S.	32.0	78.0	6.4	5.2	.010	.000	.96	.80	965	858	11.0	124.5	4620
27 S.	90.0	66.0	3.6	2.4	.070	.010	.76	.88	984	826	16.0	121.0	4724
28 M.	56.0	70.0	10.8	6.0	.080	.000	.84	.40	1021	886	13.2	119.5	4940
29 T.	46.0	50.0	7.2	4.4	.050	.000	.68	.28	1126	950	15.6	126.0	4925
30 W.	60.0	58.0	6.4	8.0	.050	.000	.24	.28	1006	880	12.5	131.5	8783
31 T.	32.0	48.0	7.6	3.2	.040	.000	.48	.36	959	875	8.7	128.5	4382
1 F.	76.0	56.0	22.0	8.0	.050	.010	1.00	.32	1120	863	22.9	130.0	4799
2 S.	52.0	60.0	17.2	12.8	.014	.016	.40	.32	821	796	3.0	137.0	3831
3 S.	64.0	84.0	16.0	12.8	.020	.004	16.00	.16	932	809	13.1	135.0	4569
4 M.	20.0	60.0	10.0	6.8	.025	.015	.80	.56	1108	878	20.7	138.0	5271
Av.	53.7	63.0	11.3	7.8	.050	.006	1.51	.61	1003	850	14.9	114.6	4832

TABLE VIII

DATA ON EXPERIMENTAL PLANT OPERATION, SIXTH PERIOD (AUGUST, 1924)

Results not otherwise designated are in parts per million.

Date Aug.	Feed g.p.d.	Temp. °C.		Turbidity			Oxygen Cons. from $KMnO_4$		
		Infl.	Effl.	Infl.	Effl.	% Remov.	Infl.	Effl.	% Remov.
5 T;	4995	20	22	250	130	48.0	50.0	40.0	20.0
6 W.	5193	21	23	270	135	50.0	78.0	44.0	42.3
7 T.	5032	21	23	200	120	40.0	70.0	54.0	22.8
8 F.	5192	21	22	300	155	48.3	85.0	56.0	34.1
9 S.	4900	21	22	210	140	33.3	83.0	55.0	33.7
10 S.	4863	20	20	175	125	28.5	77.0	53.0	31.1
11 M.	5032	20	21	220	130	40.9	73.0	57.0	21.9
12 T.	5032	22	22	230	120	47.8	90.0	47.0	47.7
13 W.	5192	21	20	200	115	42.5	61.0	60.0	1.6
14 T.	5166	21	21	205	140	31.7	83.0	58.0	30.1
15 F.	5027	21	21	240	120	50.0	70.0	63.0	10.0
16 S.	5032	21	21	250	110	56.0	65.0	60.0	7.6
17 S.	5000	20	20	290	130	55.5	74.0	52.0	29.8
18 M.	4929	21	21	290	125	56.8	72.0	66.0	8.3
Av.	5041	20	21	230	128	44.9	73.6	54.6	25.0

TABLE VIII. *(Concluded)*

Date Aug.	Free NH Nitrogen		Alb. NH Nitrogen		Nitrite Nitrogen.		Nitrate Nitrogen ,		Residue on Evaporation			Sludge	
	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	% Remov.	Gals, drawn	Solids
5 T.	44.0	56.0	12.8	7.2	.040	.005	.56	.40	1003	916	8.6	142.5	5515
6 W.	76.0	80.0	12.8	12.0	.075	.000	.72	.28	1106	912	17.5	139.2	5662
7 T.	66.0	76.0	10.0	1.6	.040	.000	.60	.48	1109	922	16.8	134.0	5474
8 F.	50.0	50.0	7.6	4.0	.125	.040	1.52	.40	990	871	12.0	133.0	4919
9 S.	60.0	60.0	14.0	9.6	.180	.000	2.40	.40	1005	819	18.5	128.0	4581
10 S.	80.0	80.0	12.8	6.8	.170	.000	.96	.36	1054	800	24.0	140.5	3402
11 M.	56.0	50.0	7.6	4.8	.050	.000	.96	.40	1107	946	14.5	123.0	4124
12 T.	60.0	56.0	16.0	10.0	.010	.000	1.60	1.04	1133	933	17.6	127.5	3628
13 W.	20.0	46.0	4.0	4.0	.050	.000	.60	.40	920	850	7.6	126.0	3320
14 T.	44.0	44.0	7.2	6.0	.020	.000	1.00	.40	1048	899	14.2	130.0	4054
15 F.	40.0	30.0	8.8	4.0	.010	.000	.68	.60	1033	883	14.5	132.0	3092
16 S.	34.0	30.0	8.8	5.6	.000	.000	.96	.36	1045	949	9.1	121.5	2248
17 S.	34.0	28.0	6.8	6.0	.030	.000	.60	.48	1098	930	15.3	113.5	2578
18 M.	36.0	30.0	9.6	4.8-	.025	.000	.68	.56	1061	914	13.8	115.5	....
Av.	50.0	51.1	9.9	6.1	.051	.003	.98	.46	1050	896	14.5	129.0	4044

TABLE IX

DATA ON EXPERIMENTAL PLANT OPERATION, SEVENTH PERIOD (SEPTEMBER, 1924)

Results not otherwise designated are in parts per million.

Date Sept.	Feed p.p.d.	Air cu, ft. per gal.	Temp. ° C.		Turbidity			Oxygen Cons. from $KMnO_4$			Suspended Solids		
			Infl.	Effl.	Infl.	Effl.	% Remov.	Infl.	Effl.	% Remov.	Infl.	Effl.	% Remov.
5 F.	21,840	.21	21	20	210	110	47.6	65	48	26.1	112.0	41.6	62.8
6 S.	21,840	.18	20	20	250	110	56.0	55	47	14.5	186.0	53.2	71.3
7 S.	21,840	.20	20	20	190	85	55.2	62	45	27.4	141.0	39.6	71.2
8 M.	21,720	.20	20	20	270	110	59.2	72	52	27.7	203.0	56.4	72.2
9 T.	21,552	.21	20	19	250	125	50.0	74	50	32.4	180.0	52.4	70.8
10 W.	21,312	.21	20	20	275	130	52.7	78	58	25.6	160.0	57.0	64.3
11 T.	21,600	.22	20	20	250	120	52.0	69	53	23.1	145.0	54.0	62.7
12 F.	21,840	.20	20	20	250	125	50.0	70	65	7.1	145.0	24.5	83.1
13 S.	21,600	.22	20	20	255	115	54.9	85	58	31.7	149.0	49.5	66.7
14 S.	21,210	.22	20	19	250	110	56.0	82	60	26.8	136.0	49.5	63.6
15 M.	21,160	.22	21	20	310	160	48.3	85	63	25.8	....	...	...
16 T.	21,680	.33	20	20	310	135	56.4	73	58	20.5	....	...	...
17 W.	21,600	.33	21	20	280	135	51.7	86	60	30.2	....	...	...
18 T.	20,780	.30	20	20	260	130	50.0	70	50	28.5	204.	58.5	71.3
Av.	21,541	.23	20	19	257	121	52.9	73	54	26.0	160.0	48.7	69.5

TABLE IX *(Concluded)*

Date Sept.	Free NH$_3$ Nitrogen		Alb. NH$_3$ Nitrogen		Nitrite Nitrogen		Nitrate Nitrogen		Residue on Evaporation			Sludge	
	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl	Effl.	% Remov.	drawn	Solids
5 F.	48	22	8.4	4.0	.100	.025	1.00	.28	1,017	875	13.9	277	4,842
6 S.	42	44	4.8	8.4	.060	.000	.96	.28	1,033	874	15.3	270	6,186
7 S.	48	60	12.8	14.0	.090	.000	2.00	.28	955	846	11.4	267	5,430
8 M.	64	60	8.4	12.0	.080	.000	1.28	.32	1,031	901	12.7	293	5,204
9 T.	54	58	22.0	9.6	.080	.000	1.20	.28	1,149	894	22.1	319	5,578
10 W.	48	30	8.0	5.2	.060	.000	.64	.40	1,022	871	14.7	352	4,779
11 T.	50	58	16.0	6.0	.080	.000	.44	.16	1,006	874	13.1	323	4,800
12 F.	60	44	8.8	9.2	.060	.000	.60	.40	842	830	1.4	312	5,193
13 S.	34	40	6.8	6.8	.020	.000	1.00	1.80	921	845	8.2	282	4,812
14 S.	60	44	*9.6*	14.8	.030	.000	3.40	.28	897	818	8.8	263	3,263
15 M.	40	74	9.2	9.2	.050	.020	.60	.60	1,172	945	19.3	338	3,977
16 T.	66	44	9.2	9.6	.020	.005	.60	.16	1,165	909	21.9	279	5,200
17 W.	50	46	9.2	7.2	.040	.005	.40	.48	1,124	964	14.2	340	6,818
18 T.	44	44	6.4	6.0	.025	.005	.60	.32	1,074	971	9.5	314	6,196
Av.	50	47	9.9	8.7	.056	.004	1.05	43	1,029	986	13.8	302	5,162

TABLE X

DATA ON EXPERIMENTAL PLANT OPERATION, EIGHTH PERIOD (SEPTEMBER & OCTOBER, 1924)

Results not otherwise designated are in parts per million.

Date Sept.-Oct.	Feed g.p.d.	Air cu. ft. per gal.	Temp. °C.		Turbidity			Suspended Solids				Oxygen Cons, from $KMnO_4$		
			Infl.	Effl.	Infl.	Effl.	% Remov.	Raw Sew.	Inn.	Effl.	% Remov.	Inn.	Effl.	% Remov.
19 F.	21,840	.18	22	21	350	125	64.2	564	210	36.5	82.6	70	42	40.0
20 S.	21,600	.18	22	21	220	100	54.5	392	133	42.5	68.0	75	53	29.3
21 S.	21,840	.19	21	20	200	90	55.0	298	137	42.0	69.3	70	56	20.0
22 M.	21,840	.26	21	20	280	135	51.7	410	190	59.0	64.2	72	46	36.1
23 T.	21,360	.23	21	20	260	130	50.0	312	184	52.0	71.7	64	50	21.8
24 W.	21,360	.23	21	20	260	120	53.7	282	186	61.5	61.5	64	50	21.8
25 T.	21,360	.21	22	21	270	110	59.2	382	148	56.0	62.1	58	45	22.5
26 F.	21,960	.22	21	20	280	100	64.2	...	171	70.5	58.7	70	50	28.5
27 S.	21,600	.25	20	18	310	125	59.6	336	193	48.5	74.8	80	56	30.0
28 S.	21,120	.24	21	18	270	110	29.2	...	178	51.0	71.3	70	56	20.0
29 M.	21,840	.23	21	19	340	135	60.2	420	257	77.5	69.8	70	50	28.5
30 T.	21,840	.26	21	18	260	130	50.0	372	169	65.5	61.2	58	44	24.1
1 W.	21,120	.22	21	18	310	120	61.2	338	250	45.5	81.8	72	44	38.8
2 T.	21,240	.22	21	19	350	140	60.0	314	218	73.0	66.5	78	42	46.1
3 F.	20,640	.23	22	21	250	130	48.0	636	156	66.0	57.6	48	44	8.3
4 S.	21,720	.22	20	19	310	140	55.2	660	240	69.0	71.2	70	48	31.4
5 S.	21,120	.23	21	20	230	110	52.1	330	170	58.0	65.8	47	37	21.2
6 M.	22,080	.25	21	20	240	120	50.0	312	150	45.0	70.0	67	52	22.3
7 T.	21,840	.22	22	21	230	115	50.0	400	194	58.0	70.1	65	40	38.4
Av.	21,543	.22	21	19	274	120	56.2	397	186	56.6	69.5	66	47	28.7

TABLE X (*Concluded*)

Date Sept.-Oct.	Free NH_3 Nitrogen		Alb. NH_3 Nitrogen		Nitrite Nitrogen		Nitrate Nitrogen		Residue on Evaporation			Sludge	
	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	% Remov.	Gals.	Solids
19 F.	32	32	5.6	5.2	.020	.010	.56	.12	1052	845	19.6	345	4,770
20 S.	26	24	5.6	5.2	.010	.000	.56	.84	988	840	14.9	344	5,578
21 S.	26	26	3.2	3.2	.090	.000	.64	.28	951	788	17.1	319	5,812
22 M.	44	30	8.0	4.8	.010	.000	.56	.16	1025	883	13.8	400	5,545
23 T.	58	48	10.0	1.6	.050	.000	.72	.28.	1000	905	9.5	342	6,120
24 W.	66	64	10.0	10.0	.050	.000	.40	.36	959	854	10.9	366	6,705
25 T.	56	60	10.0	9.2	.050	.000	.44	.32	975	839	13.9	359	5,920
26 F.	14	40	8.8	6.4	.010	.000	.64	.12	971	851	12.3	326	5,426
27 S.	34	*76*	9.2	12.0	.020	.010	.80	.28	960	*796*	17.0	339	5,044
28 S.	56	44	8:0	7.2	.010	.000	.24	.16	913	751	17.7	363	2,637
29 M.	24	. 24	8.0	4.0	.050	.000	.56	.32	.1095	975	10.9	345	6,675
30 T.	32	32	4.0	4.8	.060	.000	.44	.36	997	928	6.9	359	3,825
1 W.	66	36	6.0	6.0	.020	.000	1.32	.40	1067	890	16.5	301	4,895
2 T.	28.	24	8.8	4.8	.010	.000	1.04	.56	1063	880	17.2	338	6,281
3 F.	32	30	6.0	4.0	.005	.000	.64	.32	921	878	4.6	303	4,721
4 S.	30	32	8.8	5.6	.040	.020	.88	.64	936			330	6,668
5 S.	30	32	6.0	6.8	.080	.000	.36	.12	988	810	17.1	339	5,830
6 M.	32	36	9.2	4.8	.005	.000	.88	.48	1110	872	21.4	377	8,297
7 T.	24	24	3.6	*3.6*	.050	.000	.92	.20	943	802	14.9	413	3,534
Av.	37	37	7.3	5.7	.033	.002	.66	.33	995	854	15.1	347	5,485

Removal of suspended solids effected by screening and a short detention period in a nidus tank is much more efficient than removal of suspended solids by an Imhoff tank. The curve used by Metcalf and Eddy to estimate the removal of suspended solids during various detention periods in a settling chamber with a sewage containing 400 parts per million of suspended solids shows that in 3 hours there is a removal of only 70 per cent. Similarly, Fuller found that only 70 per cent of the suspended matter in the sewage of Columbus, Ohio, could be removed by plain sedimentation; and Dr. W. D. Hatfield (in a private communication) states that Imhoff tanks at Decatur, Illinois, remove only 70 per cent of the suspended solids. In our experiment, however, using a sewage containing 397 parts per million of suspended solids, there was a removal of 85 per cent. Removal of this additional 15 per cent of suspended matter in a nidus tank permits trickling filters to be dosed at very high rates with good nitrification.

Sludge-Filtering Experiments.—During the third period, April 21-May 11, there were times when the sludge drawn from the settling tank was fresh and light-brown in color, but at other times it was black in color and slightly septic. By concentrating the two types of sludge to about 98.5 to 99 per cent moisture and then adding alum as recommended by Mohlman (1924) to the extent of 10 pounds per thousand gallons of sludge, it was found that the fresh sludge filtered through a 12-inch Buchner funnel to give ⅛-inch cake in 10 to 15 minutes, and this cake could be removed easily from the filter cloth; the slightly septic sludge, on the other hand, required from 4 to 6 hours for the production of a ⅛-inch cake, and even then the cake was very slimy and difficult to remove from the cloth.

Trickling Filter Experiments.—In an attempt to determine whether a trickling filter could be dosed with nidus tank effluent at higher rates than with settling tank effluent, experiments extending over a period of 81 days were carried out with the trickling filter described above (p. 54) ; but it was not found possible to regulate the flow of so small a volume of sewage as would be required to dose a filter of 2 feet diameter at the desired rates. These experiments, therefore, were discontinued, and the results are not reported.

Summary of Results of Nidus-Tank Operation

Bacterial growths similar to those in activated sludge removed appreciable amounts of organic matter from sewage in a nidus tank 5 feet deep without the introduction of air other than by gentle stirring.

The introduction of compressed air at a rate calculated to supply 0.0015 cubic feet of oxygen per gallon of sewage, in addition to the oxygen absorbed during gentle stirring, accelerated the growth of activated-sludge organisms.

For highest efficiency it was found necessary to shake the growths from the nidus racks at intervals depending upon the detention period in the nidus tank and upon the strength of the sewage. When strong sewage was being treated at very high rates (22,000 gallons a day), it was necessary to shake each rack once in 4 hours. With 10,000 gallons of strong sewage or less per day, it was necessary to shake the growths from the racks only once in 8 hours. In the spring of the year, however, the growth did not have to be removed more than once in 24 hours when treating less than 10,000 gallons of weak sewage per day.

The foregoing experiments have shown no evidence of denitrification in the nidus tank when the sludge was removed from the racks frequently enough to prevent liquefaction, but there was an apparent loss of nitrogen when the sludge was allowed to liquefy on the racks.

Straining through ¼-inch-mesh screens and subsequent treatment in the nidus tank for a period of 1½ hours removed 85 per cent of the suspended solids. This is 15 per cent more than Imhoff tanks remove when treating about the same strength sewage with a detention period of 3 hours.

PART III

RECENT EXPERIMENTS WITH NIDUS TANK

By A. M. BUSWELL

In the summer of 1925, Professor H. E. Babbitt, of the University of Illinois, Department of Municipal and Sanitary Engineering, constructed two experimental Imhoff tanks for investigations reported by him elsewhere. We were thus provided with a source of settled sewage with which to feed our nidus tank.

Shive's tank (Fig. 10) was repaired and arrangements made to pass the Imhoff tank effluent through it, the operating routine being essentially the same as that employed by Shive. Aeration was effected by means of compressed air introduced through a filtros plate set in the central well.

Experiments with various amounts of air indicated that 0.18 cubic feet per gallon was required to bring about purification. It was also found necessary to shut off the air during the night to prevent the growth of free-swimming bacteria which increased the turbidity. The appearance of these organisms had previously been noted by Mr. Shive. The air was actually fed at the rate of 0.25 cubic feet per gallon during the two day shifts and none during the night shift, averaging 0.18 cubic feet per gallon. During a 23-day run under these conditions the following results were obtained.

	Turbidity	*Residue*	*Gooch solids*	*Oxygen consumed*
	Average results	(parts per	million)	
Imhoff Effluent	231	904	83	63
Nidus Effluent	184	848	50	54

As noted by Shive, the nidus tank was not constructed to provide prompt and effective removal of the sludge which formed on the rack. This difficulty could not but interfere with the purification. The tank was, therefore, reconstructed for subsequent experiments.

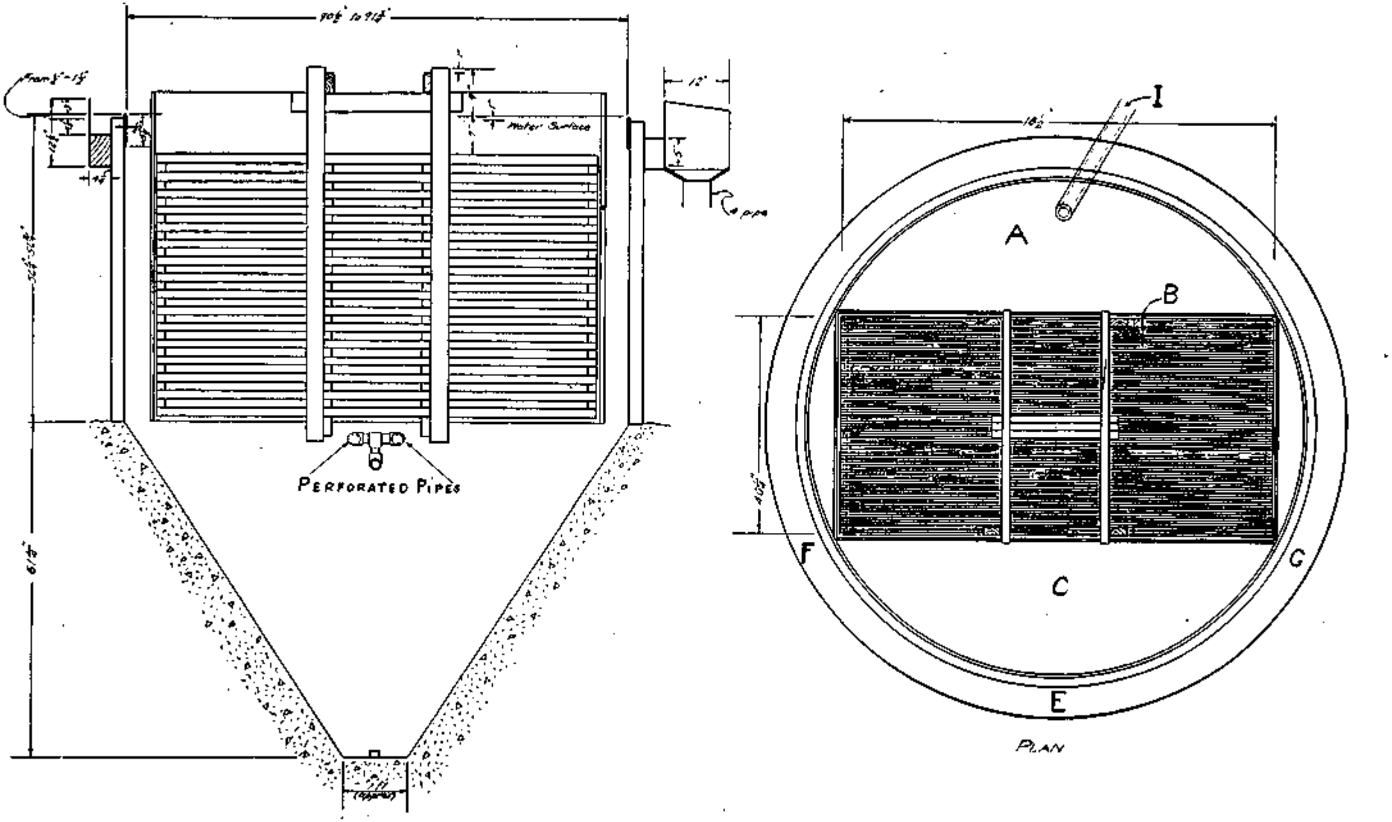
Nidus Rack Operating in a Sedimentation Tank

The most promising practical application of contact surfaces is that for which they were originally put by Travis and later by Imhoff, that is, as a means of increasing the efficiency of a sedimentation tank.

Our experiments had led us to the belief that if the central portion of any given sedimentation chamber is filled with proper contact surfaces and aerobic conditions maintained, the removal of colloids by bioprecipitation would be much greater than by sedimentation alone in the same tank, always provided that the precipitated colloids are removed promptly before liquefaction can set in. Imhoff had amply demonstrated the correctness of this belief on a relatively large-scale installation at Essen. The sewage at Essen is so much stronger than the average American sewage that it seemed advisable to run experiments under local conditions. This was done using a tank constructed as shown in Figure 1.

As seen in the figure, the tank is circular in shape with a conical bottom, for sludge storage. A box without top or bottom was built into the central portion, thus dividing the tank into three chambers: *A,* a preliminary sedimentation chamber; *B,* a space for the nidus rack; and *C,* a chamber for subsequent sedimentation. The walls of the box extended 5 inches above the flow line. The spaces at the ends of the central chamber were simply dead spaces. The sewage entered through pipe *I,* was settled in the preliminary chamber *A,* passed beneath the first wall of the box, was picked up by the upward current caused by the aeration, circulated through the nidus rack, and then passed on through the secondary sedimentation chamber *C,* in which particles of bacterial growth from the nidus rack, especially those dislodged at the time the rack was shaken, were allowed to settle. The liquor was discharged over the weir *FEG* into a circular channel from which it was returned to the sewer.

This tank provided 0.42 hours for preliminary sedimentation, 1.08 hours for aeration and contact (counting the total volume of the central chamber *B,)* or 0.73 hours (subtracting the volume of the lath rack), and 0.42 hours for subsequent sedimentation (figured on the average detention period). The steep conical bottom was kept free from accumulations of sludge by a hand-operated chain drag, which provided for much more effective sludge removal than had been possible in previous experiments.



Section

FIG. 1. DIAGRAMS SHOWING CONSTRUCTION AND INSTALLATION OF LATH NIDUS RACK.

The tank was fed with raw sewage at the following rates:

957 gallons per hour from 6 a.m. to 2 p.m.
814 gallons per hour from 2 p.m. to 10 p.m.
562 gallons per hour from 10 p.m. to 6 a.m.

Aeration was accomplished by means of perforated pipes placed beneath the nidus rack. The amount of air used was 0.10 cubic feet per gallon. The air-lift effect caused a circulation upward through the center of the rack and downward through the end portions. It was roughly estimated that the liquor circulated ten times before passing to the sedimentation chamber.

The rack was constructed of lath as shown in Figure 1. It had a total surface of 1620 square feet, or 19.3 square feet per cubic foot of the volume which it occupied. The rack was shaken daily at 6 a.m.

The tank was operated continuously on the above schedule from January 14 to April 19, 1927. During this period the temperature ranged as much as 3 or 4° C. from 2 p.m. to 6 a.m., usually from 15° to 11°. The maximum temperature was 16° and the minimum 10°. The effluent temperature varied only occasionally from the influent. It was a half-degree colder at 2 p.m. on the colder days and a half-degree warmer on one or two warmer days.

The analytical data (Table IV, p. 21) show 41 per cent decrease in the B. O. D. and 45 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.

Surface Material

As far as our experience goes, any type or kind of surface may be used for supporting the biological growths, with the possible exception of very smooth glassy surfaces. Strings of cotton or hemp, copper gauze, galvanized iron gauze, as well as lath and brushwood, have been used with success. Strings have not proved durable in small-scale experiments; metal cloth which will not corrode (copper or monel metal) is expensive; brushwood is not a common article of commerce in this country as it is in Europe; lath is satisfactory but more bulky (smaller ratio of surface to volume) than the other materials.

Veneer or basket wood may be had in strips of almost any desired length, width, and thickness. Veneer strips may be woven into mats, these mats fastened into a frame with any desired spacing, and a rack thus constructed which has a large surface area and a relatively small displacement in water.

Such racks have been in use in our experiments for nearly a year. The results from the standpoint of purification are equal to or a little better than those obtained with lath racks. The veneer racks are lighter and more easily handled. They become water-soaked more quickly than lath racks so that they do not have to be weighted down.

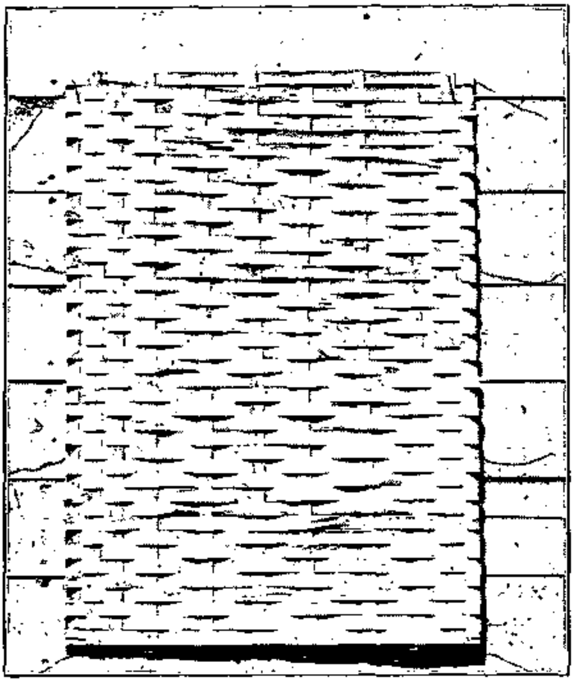


FIG. 2. PHOTOGRAPH OF VENEER MAT FOR NIDUS RACK.

Strips l"xil/16"x72" have been used in our experiments. This size was chosen arbitrarily and found satisfactory. The construction of the mats is shown in Figure 2.

To date, no deterioration of the veneer has been observed. Iron wires used to fasten the mats in the frame rusted out in about nine months. Copper wire is now used for this purpose. No data on the life of copper wire is available, but experience with the use of copper under sewage leads us to hope that it will be satisfactory for this purpose.

Mechanisms for Operating Wooden Racks in Settling Tanks

In our small experimental plant the racks have been agitated or shaken by hand. In a large installation it would be necessary to do this mechanically.

Professor Rudolph Michel, of the University of Illinois, College of Engineering, was asked to report on the design of a mechanism to accomplish the necessary agitation of the racks. After several conferences with Mr. G. C. Habermeyer, Engineer of the State Water Survey, Professor Michel has submitted the following report:

> In arriving at a suitable design of a mechanism for raising and lowering a series of wooden racks immersed in the sewage, five different schemes were considered.
>
> 1. For cylindrical settling tanks, a scheme was considered to revolve a wooden rack, more or less cylindrical in shape about its vertical axis. The mechanism for accomplishing this would consist of a motor to drive a shaft through a worm reduction gear. The shaft would carry an eccentric to operate a ratchet, thus giving the rack an intermittent rotation. This scheme has the disadvantage, (a) of being rather complicated, and (b) of agitating unequally the sewage with which the racks come in contact. The sewage in contact with the outer portions of the racks receives a greater amount of agitation than that which comes into contact with the racks pear the axis of revolution.
> 2. A mechanism for revolving prism-shaped racks about a horizontal axis through their center of gravity was considered. It has the disadvantage mentioned under (b) in the preceding paragraph, and in addition is not very efficient in operation because of the fact that the racks must be made considerably smaller than the settling tanks, thus allowing considerable sewage to pass without coming into contact with the racks.
> 3. A mechanism for tilting racks of prismoidal shape about either end was devised. This has the disadvantage of leaving one end of the rack exposed, or very near the top surface of the sewage after the tilting operation has taken place. The racks would also have to be considerably smaller than the settling tank in which they operate, thus losing efficiency in operation.
> 4. A design for rotating prismoidal racks through a small arc about a horizontal axis in the plane of their top surface was considered. This scheme has the same disadvantages as were enumerated in the discussion of scheme No. 2.
>
> 5. The fifth type of scheme considered was to raise and lower the racks a distance of about four inches vertically. This

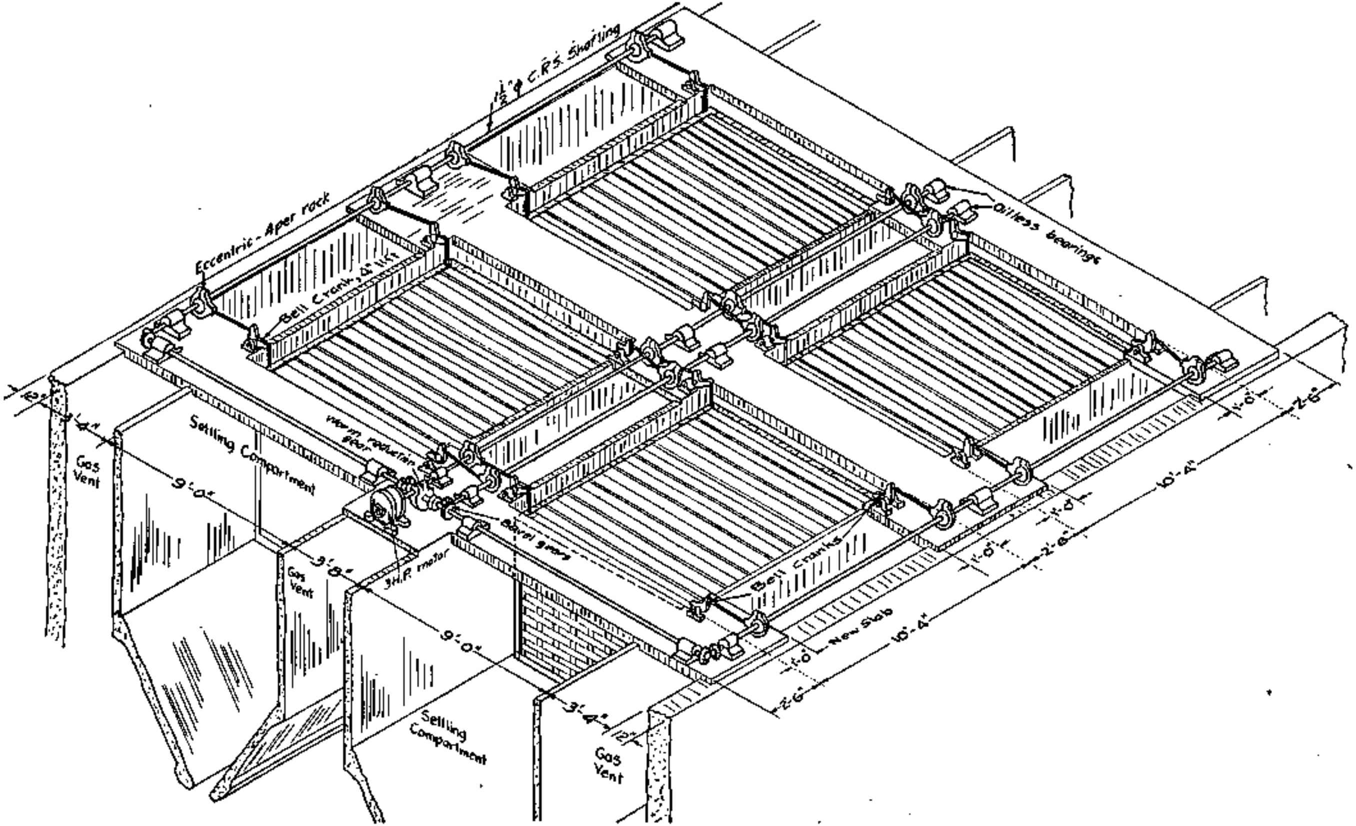


FIG. 3. DIAGRAM SHOWING PROPOSED GENERAL ARRANGEMENT OF MECHANISM FOR OPERATING RACKS IN SETTLING TANKS.

mechanism would consist of a motor operating through a worm reduction gear revolving a shaft carrying the eccentrics. The eccentric rods would be hooked at the end and engage plates, thus raising the racks. Due to their buoyance, however, the racks must be weighted in order to sink. To obviate this, scheme No. 6 was adopted.

6. This scheme is in general similar to 5, but a bell crank (see Figure 3) takes the place of the oscillating plate and a rod, attached to the bell crank, raises and lowers the racks. The latter are made to almost completely fill the volume within the settling tanks, thus giving maximum efficiency by this method. Every part of the rack receives the same displacement as every other part, and thus uniform treatment of the sewage is assured.

The following estimates of cost were prepared by' Professor Michel and Mr. H. L. White, assistant engineer, of the State Water Survey Staff:

ESTIMATE OF COST OF VENEER RACKS PER 1,000,000 GALLONS

Veneer strips for 480 mats size 4 feet by 8½ feet ($3.00 per thousand pieces 1/16"xl"x72")	$162.00
Freight for veneer	35.00
Labor for weaving ... ?	960.00
Wire 18 gauge copper wire, 5 wires to the mat (20c per 100 feet)	30.00
Wood for frame ($40.00 per thousand board feet)	30.00
Pipes for air distributor	
128 feet of 1½-inch galvanized pipe at 20c per foot	26.00
100 feet of 3-inch pipe at SOc per foot	50.00
Pipe fittings	17.00
Labor for assembling—30 days, §5.00 a day	150.00
TOTAL	$1,460.00

ESTIMATE OF COST OF BLOWER

Equipment to deliver 110 cubic feet of free air per minute at 4 pounds per square inch pressure.

Blower	$200.00
5-horsepower motor	60.00
Freight, drayage, and installation	140.00
TOTAL	$400.00

Equipment to deliver 367 cubic feet of free air per minute at 4 pounds per square inch pressure.

Blower	$460.00
10-horsepower motor	100.00
Freight, drayage, and installation	190.00
TOTAL	$750.00

ESTIMATE OF COST FOR RACK SHAKER

Motor, 3 H. P., 1200 R.P.M., 60 cycles, 220 volt, 3 phase	$ 100.00
Worm gear reducer (ratio 40:1)	85.00
Shafting, 136 feet of 1½-inch cold-rolled shaft	40.00
16 Eccentrics and eccentric straps *(2″* throw)	160.00
16 Eccentric rods	10.00
4 sets of mitre gears C. I	80.00
16 oilless bearings for 1½-inch shaft	150.00
32 small cast-iron bearings for bell cranks	50.00
16 bell cranks	20.00
Switch for starting motor	30.00
Concrete foundation mechanism	50.00
Bolts, nuts, keys, and vertical rods to mats	25.00
Labor of installing	150.00
Freight	50.00
TOTAL	$1,000.00

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