

square inch or more could be measured, and, for the type of soil tested at Singapore, that was considered a distinct advantage.

Mr. Hunter hoped that the Authors would publish the results of further tests made with their apparatus, and he suggested that the results should be expressed as constants for use in the Bell formula.

* * No reply had been received from the Authors at the time of going to press.—
SEC. INST. C.E.

CORRESPONDENCE

ON PAPERS PUBLISHED IN

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Paper No. 5235.

“The Design of Sewage-Purification Works.” †

By HERBERT CECIL WHITEHEAD, M. Inst. C.E.

Correspondence.

Mr. L. B. Escritt observed that the Author had indicated the disadvantages of badly-designed hopper-bottomed tanks. In the design of the pyramidal tank there were many pitfalls, and whilst that form of construction had been found to be highly efficient and most suitable in those cases where low detention-periods were essential, for example, in the final separation tanks of an activated-sludge plant, unsatisfactory design had, in many cases, caused it to be unpopular with sewage-works managers. In the case of the earlier rectangular continuous-flow tank, with which long detention-periods were possible, adequate sedimentation could be effected by giving large capacity to a tank of simple form; with the pyramidal tank in a modern works, there were many controlling factors.

As had been pointed out in the Paper, it was necessary to avoid stream flow or jet formation, eddy currents and patches of dead water, the possibility of holding up sludge on the sides of the tank, and long periods of detention in one part of the tank only. The Author had referred rather vaguely to the capacities of sedimentation-tanks suitable for different strengths of sewage.

† Journal Inst. C.E., vol. 16 (1940-41), p. 3 (March 1941).

Generally, the detention-period of sedimentation-tanks, the over-all dimensions of such tanks, and their number, were based upon practical experience. Theory, of necessity, lagged behind practice, because until practical results had been obtained no data were available upon which to base theory; but whilst practice required experience, theory could be communicated, and for that reason it was particularly valuable to those engaged in design. There was already much theoretical matter on which a principle of design could be based, the general heads being as follows:—

(a) It had long been known that, in the absence of all disturbing factors, and assuming perfect flow and perfect arrangement of inlet and outlet, the efficiency of a sedimentation-tank depended, not upon the capacity, but upon the surface-area, and that that rule applied to upward flow, horizontal flow, and the common arrangement which combined upward and horizontal flow. In the case of the upward-flow tank, the rate of upward flow should not be greater than the subsiding velocity of the smallest particle to be settled; whilst in the cross-flow tank, the smallest particle to be settled should be able to fall to the bottom of the tank before the water containing it at the time of entry passed over the outlet-weir. Simple calculation would show that, in both cases, an equal surface-area was required, and that, if a falling velocity of 4 feet per hour were assumed when the flow was three times dry-weather flow, a surface area of 1 square foot per 200 gallons per day dry-weather flow was required. That figure gave a higher standard than that suggested by the Author and was always possible in practice. As the maximum quantity of solid material was transported at the peak daily flow, the tank should be designed on the assumption of a peak flow; and it would be assumed that three times dry-weather flow was the basis of design. Thus the surface-area of the tank could be calculated.

(b) Irregularities of flow in a tank could arise from several causes, including convection due to differences of temperature, convection due to differences of specific gravity of settled and unsettled sewage, flow due to wind action, and streaming due to arrangement of inlet and outlet. Whilst the first three items were the least easy to control, the last two were the most liable to cause inefficiency—particularly the arrangement of the inlet. The peripheral weir had generally been found to be the most satisfactory form of outlet. Any form of inlet which was liable to form a jet (and among such inlets might be included the weir inlet) would disturb flow throughout the tank. However, satisfactory central inlets had been devised; for example, the Clifford inlet, the only requirements for which were a central position equidistant, so far as possible, from all parts of peripheral weirs, placed so as not to interfere with sludge settlement, and giving a velocity into the tank which was low and equally distributed.

(c) In positioning the inlet it should be remembered that in a tank not continuously de-sludged, the proportion of the depth of the pyramid

containing stored sludge was very high. If all possibilities were allowed for and it was assumed that tanks were not de-sludged more often than twice a week, storage of, say, 4 days' sludge would have to be allowed. Assuming that the moisture-content was $97\frac{1}{2}$ per cent. (a safe figure) that quantity of sludge would, in the case of a tank of 6 hours' dry-weather-flow capacity, be found to occupy about two-thirds of the depth of the tank. Thus, it was advisable for the inlet of the tank to be arranged comfortably within the top third of any tank which was completely pyramidal or conical. As had been pointed out by Dr. Karl Imhoff, the capacity of the vertical-sided portion of the hopper-bottomed tank was theoretically waste capacity, as regards sedimentation. More deeply-placed inlets had been known to prevent settlement entirely.

(d) A long outlet-weir was advantageous; but if the weir was too long the depth of flow would, during a great part of the day, be less than $\frac{1}{10}$ inch over the weir. At that figure surface-tension prevented further flow, and flow occurred in patches (a not uncommon sight), causing streaming. Therefore, the length of weir should be determined by the flow. The smaller the tank, the longer could be the weir in proportion to capacity, with the result that in the case of a tank with the capacity referred to above, there was no advantage in making the tank smaller than 27 feet square, unless castellated weirs were provided.

Assuming tanks which were completely pyramidal, a method of design calculation could be formulated, on the above principles, which could be compared with the more usual methods.

For example, assuming the data for the sedimentation tanks for a percolating-filter scheme to be as follows:—

Population: 27,000 persons.

Dry-weather flow: 30 gallons per head.

Maximum rate to be treated: three times dry-weather flow.

Quantity of sludge: $\frac{1}{2}$ gallon per head per day at $97\frac{1}{2}$ per cent. moisture-content.

Tanks to be complete pyramids with sides sloping at 60 degrees.

One commonly-used method might be as follows:—

Capacity, say, 8 hours' dry-weather flow = 270,000 gallons = 43,200 cubic feet.

Assuming four tanks, each of 10,800 cubic feet capacity; then $10,800 = 0.289x^3$ where x denoted the length, in feet, of the sides of the tank; therefore the tanks should be 33 feet 6 inches square.

In that method, the detention period was taken as "moderate" for a medium sewage, and the number of tanks was guessed. Four errors were possible: (1) the total capacity might be too large, with unnecessary expenditure on materials and an unnecessarily long detention period; (2) the individual size of tanks might be too large, with consequent low efficiency in proportion to capacity (both of those conditions obtained in the figures chosen above); (3) the total capacity might be too small,

with insufficient storage and the possibility of an excessive rate of upward flow, resulting in low efficiency; (4) the individual size of the tanks might be unnecessarily small, adding to the cost and complication of the works.

An alternative method would be as follows:—

$$4 \text{ days' quantity of sludge} = \frac{27,000 \times 4}{2 \times 6\frac{1}{4}} = 8,640 \text{ cubic feet.}$$

If that was to be stored in the lower two-thirds of the depth of the pyramidal tanks (a generally satisfactory arrangement) the capacity of the tanks would be $8,640 \times \left(\frac{3}{2}\right)^3 = 29,160$ cubic feet = 5.4 hours dry-weather flow, say 6 hours.

Then the required capacity of tanks = 6 hours dry-weather flow = 202,500 gallons = 32,400 cubic feet, and the required surface area $\frac{810,000}{200} = 4,050$ square feet.

That area divided by $27^2 = 5.5$, so that six tanks would be required.

The capacity of one tank = $\frac{32,400}{6} = 5,400$ cubic feet = $0.289x^3$;
 $x = 26.6$ feet.

Therefore the tanks should be, say, 26 feet 9 inches square.

In the latter method, a constant standard of efficiency was aimed at, together with a minimum capacity, and therefore the least possibility of septic conditions. It would be found that the capacity of the tank, by that method, increased with the quantity of sludge to be dealt with, which would often mean that the capacity was greatest for the strongest sewage. The method was also intended to overcome some of the pitfalls of hopper-bottomed tank design. In the calculation rectangular tanks had been chosen, but conical tanks could have been substituted.

The only remaining detail would be the arrangement of the sludge-pipe (usually a simple matter) and the inlet. The latter should preferably be placed so as to discharge either on to a baffle-plate or below a central baffle-box, all of which was comfortably housed in the upper third of the depth of the tank.

A revision of the same method was applicable to mechanically-raked tanks, humus tanks, and those which involved floating weirs, castellated weirs, etc.

Mr. Paul Hansen, of Chicago, observed that the Paper was a well-balanced resumé of current British sewage-treatment practice, and constituted interesting and instructive reading for an American sanitary engineer. Whilst certain differences existed between current British and United States practice in the design of sewage-treatment works, he was

struck principally by the similarities in practice as well as thought. The use of the oxygen-consumed determination in conjunction with the 5-day B.O.D. determination as a means of detecting substances inhibitive to bacterial life was interesting. In the United States the oxygen-consumed determination had been almost abandoned, although its use continued as a routine determination in a few laboratories. Erratic results with the oxygen-consumed determination were principally responsible for its abandonment, especially since the advent of a reasonably reliable and simple standard procedure for the B.O.D. determination. That, combined with suspended solids and occasional bacterial counts, seemed to yield all the routine information needed for plant-control. In Great Britain much more consideration appeared to be devoted to the partial treatment of storm-water overflow from combined sewers. In a few instances, the collection, storage, and sedimentation of storm overflows in excess of three times dry-weather flow, had been applied effectively in America, notably at North Toronto, Ontario, at Columbus, Ohio, and at Decatur, Illinois. Generally speaking, however, streams in the United States were of a more flashy type than those of Great Britain, and increased in volume rapidly with rainfall. Many, of course, were much larger than any streams in the British Isles. The small degree of temporary pollution that occurred following a rain was, as a rule, of little consequence. Roughly speaking, those overflows occurred during only 1.5 per cent. of the time in the region of Chicago.

Practice in screening and removal of grit (detritus) differed but little in Great Britain and the United States. *Figs. 3* in the Paper showed adjustable wings or vanes on either side of a grit-channel for maintaining the requisite high velocity. The customary practice in the United States was to install "proportional" weirs, at the ends of the grit-channels, which maintained the velocity of flow within the channel more or less uniform—usually at the rate of about 1 foot per second.

The Author had emphasized the variation in the strength of sewage during the hours of the day. A similar phenomenon, of course, was evident in the sewages of the United States. In some instances industrial wastes created such wide fluctuations in strength that some means of equalization were deemed necessary. That occurred particularly in moderately small towns containing large meat-packing establishments, such as Cedar Rapids, Iowa, Austin, Minnesota, and Sioux Falls, South Dakota, in each of which the packing-house wastes constituted the predominant element in the sewage-flow. At both Austin and Sioux Falls the population equivalents of the packing-house wastes were greater than the population of the town. The wastes were received in an equalizing-tank which had an outlet through a rate controller similar to those used for controlling the rate of flow through water filters, thus creating a relatively uniform flow of the strong wastes and also a relatively uniform strength by virtue of the mixing that was effected in the equalizing tank. Such equalizing tanks were warranted only where the industrial waste was relatively considerable and strong as measured by B.O.D.

The general acceptance of the standard for sewage effluents recommended by the Royal Commission on Sewage Disposal was interesting as reflecting the general similarity of streams in the British Isles, in contrast with the wide variations in those in the United States. That standard, namely, not more than 30 parts per million of suspended solids, and 20 parts per million of five-day B.O.D., was in accord with United States practice where small streams were concerned. On the other hand, when relatively large streams were the receiving bodies of water, the removal of readily settleable solids was considered sufficient treatment. When water-supplies were affected such treatment might be supplemented by sterilization with chlorine, which was obtainable very cheaply in the United States. Such conditions were exemplified by recently completed treatment plants at Detroit, on the Detroit river and at Buffalo and Niagara Falls, on the Niagara river. (Niagara Falls used fine screening and chlorination.)

For cities located on the Great Lakes sewage-disposal presented problems peculiar to the United States and Canada. Whilst considerable dilution was available, effective dilution that would protect water-supplies and bathing beaches was difficult because of the erratic character of wind-induced currents. Generally speaking, for such cases, a rather high degree of purification, including chlorination, had been found necessary, as at Milwaukee and Cleveland, and as now proposed for Toronto.

One striking difference between British and United States practice was reflected in the displacement-period used in sedimentation tanks. The Author had indicated a displacement period of about 4 hours, based on average dry-weather flow, and regarded periods of from 6 to 8 hours as appropriate for some sewages. In the United States displacement periods of about 2 hours were usual and were considered adequate to remove 90–95 per cent. of the settleable solids. Even shorter displacement periods—about $1\frac{1}{2}$ hour, based upon average dry-weather flow—were considered sufficient, as at Buffalo and Detroit. In that connexion it had to be borne in mind that the per capita dry-weather flows in the United States and Canada were considerably higher than in the British Isles.

When sewage was fresh and primarily of domestic character, a longer displacement-period in preliminary sedimentation tanks was considered desirable. Thus, in connexion with army cantonments, a period of 3 hours was recommended by the consulting engineering firms of Messrs. Greeley and Hansen, Chicago, and Messrs. Metcalf and Eddy, New York, assuming an average flow from sanitary sewers of 70 (U.S.) gallons per capita per day. Both circular radial-flow and rectangular straight-flow sedimentation tanks were in common use in the United States; but as a number of manufacturers made mechanical sludge-removal devices for rectangular tanks, there was a growing preference for that type. At Buffalo bids were received for alternative designs for circular and rectangular tanks,

and price was permitted to control the selection, which, in this case, was in favour of circular tanks.

During the past 2 or 3 years, considerable interest had developed in trickling filters operated at high rates and with recirculation of the effluent. It had become evident that conventional methods of dosing had not developed the maximum capacity of that type of filter. A further influence had been the acceptance of B.O.D.-removal, rather than induced nitrification, as a measure of performance. High rates of application of sewage had been found to prevent clogging, and that had been another effective stimulus to high-rate operation. Sufficient reliable operating data were not yet available to provide complete assurance as to the performance that might be expected, but, roughly speaking, a population loading of 30,000 per acre-foot of filtering material followed by sedimentation, would result in a B.O.D. reduction of about 50 per cent. Higher removals had been claimed. Double filtration at high rates through trickling filters with various arrangements was increasing in favour. Double filtration appeared to be adaptable to strong wastes such as those from packing houses, whereas activated sludge alone had proved unsuitable.

High-rate trickling filters had been favoured by consulting engineers for a number of more or less temporary army cantonments. In each case provision had been made for the recirculation of sewage through the filter, to maintain a desirable rate of application and to prevent clogging. Sedimentation following the filters was provided to give a displacement period of $2\frac{1}{4}$ hours: chlorination was also provided. Such an installation was relatively inexpensive, and yielded an effluent substantially better than that from sedimentation alone and sufficiently stable to avoid odour nuisance. Chlorination afforded protection against danger to health, and could, if necessary, be applied in quantities sufficient to produce direct oxidation or to retard decomposition sufficiently to permit re-aeration in the receiving body of water to keep pace with decomposition, thus ensuring odourless decomposition when dilution was limited.

Activated sludge had retained its popularity, especially for larger plants wherein a high degree of purification was required and the sewage was not very strong. It had not proved satisfactory as a preliminary treatment when strong industrial wastes were involved, but it had performed acceptably as a finishing treatment for strong wastes following pre-treatment on trickling filters, as at Sioux Falls. Various modifications of the activated sludge process, including so-called step aeration and aeration combined with chemical precipitants, were being examined with interest.

Mechanical de-watering and incineration of sludge had become popular in the United States. It had proved economical at such large installations as the Southwest Side and Calumet plants of the Chicago Sanitary District, at Buffalo, Detroit, and Cleveland, and in the Minneapolis-Saint Paul Sanitary District. It had also been found advantageous in dealing with

raw sludge containing a preponderance of paper-mill wastes which did not digest readily. Probably economy for the mechanical de-watering and incineration of sludge could not be demonstrated at some of the smaller installations. Two general types of furnaces were used, one of which was an adaptation of practice with pulverized fuel, as at Buffalo and Chicago, whilst the other was an adaptation from ore roasting and calcining practices, as at Detroit, Cleveland, and Minneapolis-Saint Paul.

Another marked tendency in the United States was towards the use of mechanical equipment in connection with sewage treatment. For that credit was due to the enterprise of manufacturers who had developed such equipment. Typical equipment included self-cleansing screens, grinders for screenings, automatic devices for removing and washing grit, sludge- and grease-removal mechanisms in sedimentation tanks, and stirring devices for sludge digestion tanks. Perhaps some plants were overloaded with such mechanical equipment, but in large plants where good maintenance and operating supervision were exercised, mechanical equipment was useful and economical.

The use of gas from digesting sludge had been an outstanding development during recent years in the United States. The gas was used (a) to accelerate digestion by heating digestion tanks; (b) to heat buildings; (c) to operate internal-combustion engines, which, in turn, operated air-compressors and pumps and generated electricity. Generally speaking, gas-production amounted to about 1 cubic foot per capita per day, but some industrial wastes produced greater volumes of gas, as at Peoria, Illinois, where almost enough power was generated with sludge gas to meet all of the power requirements of the treatment works, including pumping and compressing air for bio-aeration.

The disposal of garbage with sewage was being increasingly tried, although sufficient operating data were not yet available to demonstrate fully the economy, or even the entire practicability, of that arrangement. Garbage-disposal in conjunction with sewage-disposal was practised at Lansing, Michigan, and at Gary, Indiana. In the former case the ground garbage was introduced into the digestion tanks, whilst in the latter, it was discharged into the main sewer near the treatment-plant. There was also an increasing utilization of household garbage-grinders arranged to discharge finely-ground garbage into the soil-pipes.

During the past 6 years many sewage-treatment works had been installed as "made work" enterprises, principally under the Federal Government agency known as the Public Works Administration, which had made grants in aid of up to 45 per cent. of the costs of the project. To be effective in promptly increasing the employment of labour, those plants had to be designed quickly. That fact had induced a bolder attitude in trying new methods and devices, which had resulted in much good by way of experimentation on a large working scale. On the other hand, there had probably been some financial waste.

The larger and more recent sewage-treatment plants in the United States had been constructed with creditable architecture and landscaping, and compared favourably in general appearance with British plants.

Mr. H. V. Lawrance considered that it was doubtful whether odour-control methods had reduced operation costs. Perhaps the Author would care to exemplify methods in which that had been achieved.

Detritus pits had always been found very beneficial and, in fact, almost essential in South Africa, where separate systems were installed. Mr. Lawrance believed that it was beneficial to eliminate as much as possible of the mineral matter from the flow to the sedimentation tanks, especially when they had conical bottoms, for if the tank had "silted up", desludging under hydrostatic head became wellnigh impossible. When the sludge had to be pumped, it would be found advantageous for the avoidance of wear on pump parts and reduction of the pumping head to have the sludge as free as possible from mineral matter.

The design of a simple efficient sedimentation tank afforded considerable scope for research. Could the Author indicate the methods by which short-circuiting and streamlining in the hopper-bottomed tank might definitely be obviated?

The Author's requisites of a good percolating filter medium were rarely completely satisfied in South Africa, where igneous rocks and quartzites were most commonly used for the purpose. The size usually found most useful was $1\frac{1}{2}$ -2 inches, with perhaps a bias towards the larger material. In providing the medium for some recent percolating filters Mr. Lawrance had observed a tendency towards an upper layer, usually 18-24 inches in thickness, of large stone (say 4-6 inches), a middle layer of smaller stone (say $1\frac{1}{2}$ -2 inches), and a bottom coarse layer 12 inches thick above the filter tiles. Apparently the object of that arrangement was to reduce the accumulation of growths which promoted ponding. It would be interesting to know whether the Author anticipated that that would have the desired effect when treating a settled sewage which had not been given flocculation treatment. Was it not probable that fungal growths would be promoted at the top surface of the middle layer, thus transferring the ponding to a region where it could not be seen?

Despite the Author's commendation of stage and alternate filtration, Mr. Lawrance considered that, owing to pumping costs, a very good case could still be made out for single-stage purification. When the contours of the site permitted of gravitational feed to the lower unit, stage treatment might be carried out very cheaply, but in established works it would often prove difficult to adapt the units and supply system to a stage purification system.

He would have been pleased if the Author could also have discussed the question of materials, especially metals, found to be most resistant to attack at purification works. He realized, however, that to discuss fully all aspects of the design of sewage-purification works would be beyond

the scope of the Paper, in which the Author had furnished a valuable summary of present-day practice.

Mr. F. G. Penny considered that the statement that, "Since the Author and Mr. O'Shaughnessy presented their joint Paper in 1931, there has been little progress to record in sludge-treatment, other than the more general adoption of bacterial digestion", was misleading in view of the fact that a more modern and efficient system had been in use in England for more than 2 years and had proved highly successful. That system had been adopted at Horsham for a small population, and at Halifax for secondary sludge for a large population; whilst another large plant was under construction at Luton. Those plants were under the supervision of distinguished consulting engineers and sewage department managers and had demonstrated the following advantages in comparison with the use of bacterial digestion and drying beds:—

- (1) Elimination of drying beds completely.
- (2) Sterilization of sludge and liquors removed from it.
- (3) Operation independent of weather conditions.
- (4) Elimination of the danger of foul liquor poisoning subterranean water-supplies.
- (5) Very small area of ground required for plant, with a consequent saving of land and "rateable values" in or near large cities.
- (6) No chemicals or fuel necessary.
- (7) Reliability of operation and rapidity of the process, needing only a few hours instead of the months required by the "digestion and drying bed" method. The sludge could be treated while fresh and need never go septic in the works.
- (8) In addition to fertilizers, many useful materials could be produced from the sludge and the valuable extracts from greases were not destroyed, as in fermentation processes.

The process consisted of mechanical de-watering in any good type of machine filter after "conditioning" the sludge by means of heat treatment. That method of conditioning had proved many more times effective than any other conditioning treatment at present known, whilst the resultant settlement of the solids was rapid and their separation from the liquid was very easy by decantation and filtration methods. Any form of filter could be used, but so far filter presses had produced a much dryer cake than had vacuum filtration methods.

That system, which was being developed by Messrs. W. K. Porteous, Ltd., was well known in England, and in comparison with the incineration method stated by the Author to be practised in Chicago considerable savings would be made because (a) the high cost of ferric chloride used for conditioning the sludge would be saved; (b) the sludge-cake produced in the Chicago plant had a much higher water-content than that produced by the Porteous plant and the further drying of the filter-cake from the latter would therefore be much cheaper.

The following extract had been made from a published speech by the widely-experienced Chairman of the Halifax Sewage Committee :—

“ The adoption of the Porteous process was taken with a certain amount of hazard, but at the end of the first twelve months the plant had exceeded, not only the expectations of the makers, but far exceeded the guaranteed performance and also the expectations of the Sewage Manager and Committee. The great thing was that the sludge was dealt with and finished within a few hours. There is no other system in the world which will deal with humus sludge in this way.”

Mr. Penny considered that, in view of the high standing of the Author, it would be a gracious act and beneficial to the whole community if he would modify his observations so that they would be less misleading to the uninitiated.

Mr. C. B. Townend observed that the Author had rendered a service in drawing attention to the shades of meaning which should be attached to the various analytical tests applied to sewage for the purpose of deciding upon the method of treatment to be adopted. That was not understood : even to-day it was all too common to find that the strength of sewage was assessed solely by an analysis of the crude sample without any consideration of its behaviour during different stages of the purification processes.

It was of great importance to have a means of assessing the difference between the effect of two trade wastes, apparently of equal strength, one of which had an impurity load capable of being easily and cheaply removed by plain sedimentation, whilst in the case of the other the oxygen-demand had to be dealt with almost entirely by the more difficult and costly biological process.

With regard to the treatment of stormwater, he agreed with the Author that the results which it was generally desired to achieve in the prevention of river pollution would not be attained until purification were given to larger volumes than at present. The existing practice of giving full treatment to three times the average dry-weather flow and partial treatment to a further three times the dry-weather flow had served quite well in the past as a rough and ready guide, but such a basis of calculation appeared to be illogical and unsound. Two similar towns might have very different water-consumptions and sewage strengths, but in times of storm when a given flow of, say, 120 gallons per head had been reached in both cases, the strengths of the two sewages should be about the same. Yet in the one case, 120 gallons per head might represent only three times dry-weather flow whilst in the other it might be as much as six times dry-weather flow.

What could be calculated to produce greater lack of uniformity than recommendations based in terms of dry-weather flow ? Mr. Townend would suggest that for ordinary inland towns full treatment should be given to, say, 100–120 gallons per head irrespective of dry-weather flow,

and partial treatment to the whole of the remainder of the sewage arriving at the works, or at least to another 100-120 gallons per head. Other standards would, of course, be necessary where conditions varied, for example, if considerable trade wastes were present or tidal water were available for discharge. Logically, the degree of treatment should be based upon the quality of effluent produced in relation to the river receiving the discharge; but it was, perhaps, premature to expect such idealistic standards to be accepted in the early future.

The Author's comments on sedimentation were very sound. With regard to the balancing of the pollution load arriving at the biological purification plant, one helpful factor not mentioned in the Paper might come into play on works where special balancing arrangements were not possible. The velocity of travel through a treatment plant at any moment was dependent upon the rate of flow then being received from the incoming sewers. When sedimentation tanks were of several hours' capacity, the weak night sewage would arrive at the biological plant during the morning, and would be pushed through that part of the process at a relatively high rate. The strong day sewage, on the other hand, would arrive at the biological plant in the late evening, when the rate of flow was much lower, and so automatically would receive a longer detention-period. That factor did materially assist in smoothing out the rate of pollution-load arriving at the biological plant.

The Author had shown that the disability of the activated sludge process due to the low rate at which a mass of sewage could take up oxygen could be overcome, in dealing with strong sewages, by increasing the volume of well-oxygenated effluent returned with the activated sludge. That was a very important point which was becoming widely recognized. It was already quite common to use volumes of return liquor to the extent of 50 per cent. of the sewage flow, and provision should generally be made for an increase up to 100 per cent.

The Author had stated that an alternative way of ensuring a good oxygen-balance was to avoid coupling aeration-channels or tanks in series, and that when sewage entered four short aeration-channels, working in parallel, it received an initial dilution with oxygenated water four times greater than when the same channels were worked in series. That could be true only if it were assumed that the channels were designed definitely to produce short-circuiting: otherwise the incoming sewage could not mix with water which had arrived some time earlier: but with short-circuiting, other troubles were likely to occur, such as "rising sludge" in the final separating tanks, due to de-nitrification taking place in the presence of matter reacting there in a partially purified condition, and that might lead to still other remedies having to be adopted. A better way would appear to be to avoid short-circuiting altogether by working the channels in series, and to obtain oxygen-balance by proper control of dilution with returned effluent.

The Author in reply, reminded Mr. Escritt that in the Paper stress had been laid upon the four-fold function of sedimentation tanks for the treatment of crude sewage, namely (1) the separation of settleable solids; (2) averaging variations in strength of sewage; (3) balancing inequalities in the daily flow; and (4) the provision of sufficient time for some degree of self-purification. Only in dealing with the weakest sewages was the time required for the first function sufficient to cover the desirable period for the fourth function. Further, the varying nature and condition of the sewage itself often provided factors interfering with the perfect flow of the liquid and causing disturbance to the settled sludge. For those reasons the most important dimension in the design of all sewage sedimentation tanks was the detention-period, which provided for the fourth function. That detention-period could be satisfactorily established only by laboratory experiments, followed, whenever possible, by a working scale experiment.

Additional emphasis to the need for the determination of that detention period had been furnished by Mr. Townend. With sewage of a readily fermentable character it might not be desirable to provide capacity for more than one week's detention of sludge in a horizontal-flow sedimentation tank, or for perhaps 48 hours in an upward or radial-flow tank; but with sewages containing considerable trade-waste of an antiseptic character, or where the sewage was subjected to an acid treatment, as at Bradford, Yorks., it was of considerable advantage, in the subsequent treatment of the sludge, to have ample sludge storage capacity within the sedimentation tanks. As a result of a sludge detention period of 3 months in the Bradford sedimentation tanks, it was possible to discharge to the presses sludge containing only 80 per cent. of water, in comparison with the more usual water-contents of from 92 to 96 per cent.

The surface-area theory mentioned by Mr. Escritt could be applied to the design of tanks for the separation of humus, and of activated sludge from which the sediment was removed continuously, or at very short intervals, and which unlike tanks for sewage sedimentation, could be regarded as single-purpose tanks. Even in those tanks perfect flow and settlement was occasionally interfered with by the formation of minute bubbles of nitrogen within the deposited sludge, causing flotation of particles of sludge. That was one reason why a tank designed to give continuous removal of activated sludge or humus was preferable to one where the discharge was intermittent.

The Author had read with keen interest Mr. Hansen's comparison of American sewage treatment practice with British practice. The three principal differences in American as compared with British conditions, were much larger rivers, more copious use of water for domestic and trade purposes, and greater extremes in climatic conditions. After due allowance had been made for those differences, it was gratifying to find much similarity in the trend of development and thought in both countries.

The oxygen-consumed determination showed no sign of losing its popularity in Great Britain, owing to its standardization in recent years and the speed with which its results could be obtained.

In experimental work required to check the course of purification at different stages of treatment, that test had proved to be valuable at Birmingham and elsewhere.

It was particularly interesting to read of the outstanding development in the use of gas from digesting sludge in the United States within recent years, as it was from a small experiment carried out by the Author at Yardley, Birmingham, in 1921, under the direction of Mr. J. D. Watson, Past-President, that the use of this source of power began in Great Britain. The Author believed that the works at Coleshill, Birmingham, designed by him and opened in 1934, was the first sewage purification plant in which all power for activated sludge treatment, sludge and top water pumping, lighting, and heat for sludge digestion was provided for by gas from the digesting sludge. The Coleshill works now treated sewage from a population of 150,000.

The acceptance of B.O.D.-removal as a measure of performance was general, but it was recognized in Great Britain that a nitrified effluent was indicative of a higher degree of purification than one which was not nitrified. There was no generally-accepted method of expressing the superiority of nitrified effluents in quantitative terms.

The Author was not aware of any wide use of chlorine in Great Britain to oxidize the putrescible matter in sewage or sewage effluents; although chlorine acted mainly as an oxidizing agent in attacking organic substances, its common use was as a partial sterilizing agent. Chlorine had been added to easily decomposable factory effluents to delay decomposition, but the result had usually been to shift evidence of pollution from the point of discharge to a lower portion of the stream receiving such discharge. Activated sludge had proved to be highly satisfactory at a number of plants as a medium for eliminating part of the sludge-forming matter and reducing the strength of strong sewages containing trade wastes. Mr. Hansen's comments as to the unsuitability of the process as a preliminary treatment possibly referred to strong factory wastes, or sewages containing a preponderating quantity of such wastes in which the initial oxygen demand was very high. The Author suggested that, even in those cases, partial purification could be satisfactorily effected by maintaining the sludge employed in a condition of activity in a separate conditioning tank of ample size.

The Author assured Mr. Lawrance that in Great Britain odour-control methods had, in almost every instance within the Author's knowledge, reduced operation costs at the various treatment works at which they were in force. The outstanding example was the Mogden works of the Middlesex County Council, where the pre-war value of diesel oil displaced by gas in the power-station amounted to £21,000 annually. As the full

operating expenses, including sludge pumping, drying, and tipping amounted to only £13,000, an annual margin of £8,000 partly counter-balanced the loan charges of £17,000 on the whole of the plant devoted to sludge treatment and disposal. Those figures took no account of unused gas which might yet be utilized for other purposes, and which, on the same basis, was valued at £3,000 annually.

At Birmingham, where a smaller proportion of the total yield of gas was required for power and heat, the cost of sludge disposal had been reduced to a fraction of the cost of disposal of crude sludge which was in operation before the inauguration of sludge digestion in 1911. It was, however, unlikely that equal success would result in countries where climatic conditions favoured the rapid drying of crude sludge, because it was in promoting better water-separation and sludge-drying that the chief economy of the sludge-digestion process lay.

Similarly at Minworth and Yardley, Birmingham, where the treatment capacity of existing percolating filters had been doubled by interposing a partial treatment of the settled sewage with activated sludge, reductions had occurred in both operation costs and odour from the liquid distributed on to the percolating filters.

The Author agreed with Mr. Lawrance that much room remained for research in sedimentation-tank design, more especially where single-purpose tanks, such as those required for the separation of humus and activated sludge, were concerned. Two of the most important points in hopper-bottom tank design were the symmetrical placing of the inlet-box in relation to the weirs, the inlet-box being free of internal obstructions, and a centrally-placed inlet pipe, such as might be seen in the final separating tanks at Mogden. Another form of tank which appeared to have possibilities for the separation of humus and activated sludge, and with which the Author was experimenting, was the circular tank with a tangential inlet port described by Messrs. Robert Walton and Thomas Dow Key, M. Inst. C.E.*

The Author had no doubt the alternating double filtration method would prove economically attractive at many new and existing works of moderate and large sizes. For small installations, where the filters were often left to take care of themselves for periods of two or three days, pumping would be regarded as an added complication, and single-stage purification, despite its lower efficiency, would undoubtedly continue to be used.

The question of materials used in the construction of sewage purification works seemed to require a Paper to itself. Generally speaking, portland cement concrete could be safely used in works which received sewage containing trade wastes of an acid character, provided that the alkalinity

* "Application of Experimental Methods to the Design of Clarifiers for Water-works," *Journal Inst. C.E.*, vol. 13 (1939-40), p. 21 (Nov. 1939).

of the sewage was a sufficient buffer to maintain an alkaline condition in the sedimentation tanks. Where the risk of occasional discharge of an acid sewage was present, it was advisable to construct all sedimentation-tank inlet and outlet weirs of concrete made with Ciment fondu, or of brickwork set in Ciment-fondu mortar. For the same reason inlet baffles and scum-plates should be made of Ciment-fondu concrete, and cast-iron should be used wherever possible in preference to steel or wrought iron. The Author had found copper-bearing steel a useful material for sludge-gas collectors, tank inlet boxes, and for other purposes where a light metal plate construction was called for. Particular attention should be given to the use of corrosion-resisting materials in travelling sewage distributor installations, for it was there that the use of cast-iron supply troughs and distributors of non-ferrous metals and copper-bearing steel was most frequently worth the higher initial cost in comparison with all-steel construction.

He saw no reason to modify his statement regarding the trend of progress in sludge treatment, to which Mr. Penny had taken exception. Even three swallows did not make a summer, and the process to which Mr. Penny referred would have to show independent records of efficient and economical work before receiving more general acceptance of the claims made by its sponsors.

The Author welcomed the views expressed by Mr. Townend regarding the volume of sewage and storm water which should be subjected to full and partial treatment, and agreed with him that a given rate of flow of, say, 100 gallons per head per 24 hours would be a fairer way of fixing the rate of full treatment for domestic sewage from inland towns, than the present practice of giving full treatment to three times the average dry-weather flow. The volume of trade waste to be given full treatment should continue to be a separate determination. There were so many pitfalls in the adoption of idealistic treatment standards based upon the river receiving the effluent discharge, that the Author was content, with Mr. Townend, to leave the discussion to some future occasion. It was true in theory, as mentioned by Mr. Townend, that in a sewage works not provided with flow-balancing arrangements, the varying velocity of travel of the sewage through the works effected a compensating action by delivering the stronger portion of the liquid to the percolating filters or activated-sludge plant during a period of the day when the rate of flow was lower, thus providing longer time for treatment.

In actual practice the benefit was not so real as, by diffusion and unequal flow through sedimentation tanks of, say 9.2 hours capacity, much averaging of the strength of the sewage occurred, and the impurity load transmitted to the filters or activated-sludge plant became more nearly proportionate to the rate of flow, as was illustrated in *Fig. 5* of the Paper.

The Author considered that, in discussing activated-sludge treatment difficulties, too many major evils had been ascribed to "short-circuiting",

when the real cause had been a bad oxygen-balance at the commencement of the aeration channels. "Short circuiting", properly regarded, was an unavoidable minor evil in the activated-sludge process, which could be counterbalanced in a variety of ways, all of which should be designed to keep a close balance between the demand and supply of oxygen in all portions of the aeration tank.

Paper No. 5255.

"Some Corrosion Tests in a Railway Tunnel." †

By SYDNEY CHARLES BRITTON, M.A.

Correspondence.

Mr. T. H. Turner observed that steel rails in tunnels and alongside water troughs had a noticeably shorter life than the normal.

The Paper and the Author's companion Paper to the Institute of Metals, which dealt in greater metallurgical detail with the corrosion of non-ferrous metals, covered a field of practical importance to railway engineers.

The outstanding successes in the tests were those with rubber and bakelite.

The London and North Eastern Railway had found in tunnel tests that almost any paint coating was of some value, red lead and tar being of more value than most others. To give a datum line for the comparison of painted specimens, small panels of unpainted mild steel, stainless steel, copper and zinc had been exposed.

Figs. 8 showed one series of those, inspected in July 1941 after 287 days' exposure and subsequent wire brushing, which had been placed in Potters Bar tunnel, on the Great Northern main line. This tunnel had a single ventilating shaft in its 1,240 yards length, and had one up and one down road, both carrying much traffic drawn by coal-burning locomotives.

The panels were fixed to the wall at about rail level and, as would be seen, the stainless steel had pitted to a greater depth than the mild steel, copper, or zinc, all three of which had corroded fairly uniformly over the surface, without special pitting.

Observations were made of the temperature of the tunnel, of the composition of the atmosphere, and of the soot from the walls and the ballast from the track. The temperature was warmer in winter and

† Journal Inst. C.E., vol. 16 (1940-41), p. 65, (March 1941).