

Paper No. 6497

Some developments in the activated-sludge process†

by

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Discussion

Mr C. B. Townend (formerly Chief Engineer, Middlesex County Main Drainage Department) referred to the Author's remark in § 1 concerning the high cost of treatment by activated sludge. This might mislead the public and the authorities concerned.

51. The figures given in Table 7 worked out at about £4-£5 per million gallons, or only 1d. per thousand gallons, which was really extraordinarily cheap. He wondered what industry could show comparable economy in treating 5 tons of polluted liquid for a penny. Per head of population, this worked out at a cost of only one-twentieth of a penny per day. He realized that the Author had not included capital costs, the addition of which would probably double his figures, but even so they would still be quite insignificant. Having said that, however, it was equally true that total costs could run into many thousands of pounds, and they should always be striving still further to increase efficiency wherever possible and to reduce costs in the way described.

52. With regard to the depth of tanks, a great deal of work had been done on this in the early days of 30-40 years ago. In 1914 the original Manchester plant was about 4 ft deep, but for compressed air, deeper tanks were more economical and occupied far less area; this had always been a most important consideration. Manchester's final decision was 15 ft, and this depth had also been used in nearly all American plants. The limit was reached at Reading in the middle 1920s at 23 ft, but this proved to be a big failure and the pendulum quickly swung back to 10 ft at Birmingham for Bio No. 2 plant in 1928, and again for their Coleshill plant in about 1933. For Mogden, the choice was 12 ft, which had proved very successful.

53. In those days there had been much controversy as to how much oxygen was absorbed from the bubble in rising to the surface and how much was taken in at the surface by the breaking of the bubble at that point. Recent work by the Water Pollution Research Board had confirmed the earlier view that in a compressed-air plant very little was taken in at the surface, and that in this case the relation of surface area to depth or tank volume was not so important. With surface-aeration plants, on the other hand, such as the Simplex, the Kessener brush, and the Sheffield system, where a predominating proportion of oxygen was taken in at the surface, the effect of the surface area in relation to volume should be far more pronounced, and the advantage of shallower tanks, as shown by recent Manchester work, had proved to be considerable. On the other hand, shallower tanks were more expensive in relation to volume and lost the advantage of economy in space which was always so important in modern plants.

54. So far as capital costs were concerned, it had always been possible to operate a compressed-air plant vigorously with more power and less capacity, as advocated by Lockett right from the start, or to economize in power with a longer detention period. For example, at Mogden, where ample cheap power was available from methane gas, a fully nitrified effluent had been obtained in 8 hours, whereas at Coleshill, Birmingham, power had been reduced by 30%, but with a detention period increased to 14 hours. The choice always depended on the relative costs of power and construction, and still did.

55. The early surface-aeration plants were comparatively less able to provide

† Proc. Instn civ. Engrs, vol. 20 (Sept. 1961), pp. 19-38.

vigorous operating conditions. They functioned reasonably economically in power consumption, but with detention periods rarely less than 14 hours, and often up to 24 hours as he understood to have been the case at Sheffield and at Manchester. It was therefore good to learn of the considerable progress which had been made in recent years in the efficiency of surface-aeration process, particularly of the Simplex plant which was now giving what could be described as a competitively vigorous performance. Coupled with the technical advantage of the shallow tank, the advance was very striking, but ultimate progress must always be subject to the question of capital cost. Not very much could be said on this because the Author had not supplied any figures for construction expenditure. In earlier days the provision of deep conical pockets for the Simplex plant would certainly have increased the cost considerably, and it was interesting to hear that the requirements were now much more simple, and the prospects appeared promising.

56. Similar advances in efficiency were equally being made in compressed-air operation, and in assessing the relative position of these various processes it was most important that a comparison should be made on a proper basis; he did not think that had been the case in this Paper. All the Manchester results on surface aeration were viewed alongside compressed-air tanks using the least efficient medium of the 4-in. dome. This type of diffuser had been introduced after the 1939-45 war to cheapen the cost of maintenance as compared with that of the earlier flat plate. The 4-in. domes, however, had not been successful from the angle of aeration efficiency and had been superseded by the 7-in. domes which had proved to be reasonably comparable with the earlier plates. More recently, work had been carried out at Mogden to increase the performance of aeration tanks still further by a change in the distribution of the diffusers on the floor; these alternative arrangements had given very promising results and a considerable increase in performance capacities was confidently expected.

57. In comparing performances the Author had stated in § 21 that the Simplex plant had achieved a removal of oxidizable matter equivalent to 54·7 lb. of B.O.D. per 1,000 cu. ft. of aeration tank capacity; this he had compared with the figure of 37·5 B.O.D. for an air-diffusion plant given in Mr Townend's Paper.¹³ The reference made on that occasion, however, was stated to relate to the complete treatment of settled sewage to an advanced degree of nitrification—quite a different condition from those described in the present Paper.

58. This question of the basis of comparison was most important. In the earlier stages of treatment, the removal of impurity load was comparatively easy and cheap; as treatment progressed further the work became increasingly difficult in terms of so-called B.O.D. removal, particularly in the nitrification stage. By comparing, as the Author had done, on the basis of B.O.D. removal without any consideration of the quality of the effluent, a misleading result would be obtained. In any case, such a comparison had little meaning when framed on 5-day B.O.D. figures.

59. The Author's work was most valuable and should inspire others to seek further progress in this most important field.

Mr J. T. Calvert (Consulting Engineer, John Taylor and Sons) asked if the Author would give some figures on his nitrate results, because he was a little apprehensive under normal conditions of using such short times of aeration.

61. Another factor which might affect results when using the short aeration times was the possibility of shock-load on the works being passed through very quickly; therefore when the Author gave average values for B.O.D.s it would have been useful also to know some figures of the extreme values, because he imagined that with the short times of aeration there was a danger of having much bigger extremes, since the buffer action would be lost.

62. He had been impressed by the differences in the qualities of the final effluents from the different processes and this was a subject on which a lot more information was required. When figures were quoted of B.O.D.s around 20 and related to the horsepower consumption the small differences between, say, 17 and 22 (which was about the

range of the figures quoted in the Paper) could make quite a difference to power consumption because that ultimate removal at the lower end of the scale required much more horsepower per lb. of B.O.D. than the big drop from, say, 400 down to 20. It was obviously very difficult to get precise figures because one was working with such a variable liquid, but it was something which ought to be borne in mind.

Mr E. H. Vick (Divisional Engineer, Main Drainage, London County Council) agreed with the Author's statement that the biological treatment was the most expensive part of his works, but he also agreed with Mr Townend that it was regarded as expensive merely because the other parts of the process were so cheap. It spotlighted the comparatively high cost of the biological treatment only, but the plant had to be taken as a whole in looking at the economies of it. The Paper was really a plea for economy in the biological stage, but one had to make sure that it was really sound economy and not only economy in capital expenditure. To try to reduce the capital expenditure too much and bring up the operating cost might be a bit short-sighted.

64. In Britain most sewage purification works outlasted their loan repayment period by many years, and if they had been properly designed and were still efficient the later generation would gain very considerably by the low operating and maintenance costs. Although engineers were accustomed to looking well into the future, it was difficult nowadays for them to look so far as to forecast the cost of various forms of power. It was particularly difficult because power these days was being influenced largely by politics. Capital was paid off eventually but power went on and usually increased in cost with the coming years, and then one had to try to cut down power to make economies and got into trouble with the plant.

65. Mr Vick agreed with Mr Townend's remarks about the B.O.D. curve, but he criticized the B.O.D. test itself. He was not a chemist but he knew that it was a very "cagey" sort of test. Chemists would never be cured of the habit of quoting B.O.D.s to two places of decimals in parts per million. This was quite useless to the engineer, since he could not design to that degree of accuracy. Also, the sample on which the test had been done was not quite accurate. The B.O.D. test, especially in the lower range, was adversely affected by the presence of nitrates and minute portions of algae, both indications of good effluents, in fact one was dependent on the laboratory attendant thoroughly cleaning the vessels; they must not only be clean but thoroughly clean, which to a chemist was a different matter. In all those circumstances the B.O.D. figures could be misleading, especially when trying to give the difference between 17 and 20 p.p.m., and he did not think that one could relate horsepower figures to them at that range.

66. He had heard a distinguished chemist say at a well-known research establishment that the B.O.D. test was excellent for every experiment except the one being done today.

67. In § 4 the Author had referred to porous diffusers and stated that they had to be reconditioned every 2-3 years. He agreed that this was the case with the old plate diffuser with its 1-in. downpipe, which was subject to internal rusting, but the modern 7-in.-dia. dome diffuser did not suffer from this defect. In his opinion, if the air was cleaned to a reasonable degree, and particularly if it was not shut off for long periods, these domes would not clog. At the Northern Outfall Works 7-in.-dia. dome diffusers had been working in raw sewage in the pre-aeration channels for 5 years with no signs of clogging or undue increase in pressure, and he hoped that the 120,000 domes in the new diffused-air plant which had now been working for 2 years would last at least as long without reconditioning, although in this case the air was cleaned by electrostatic precipitators to a high degree of purity. One reason for the better performance of the 7-in.-dia. dome might be that the condensation of the moisture in the air at the bottom of the air main under the domes washed the dirt out of the air, and provided efficient operation was carried out, by opening the blow-out cocks regularly, the dirt was blown out with the water before reaching the dome.

68. The extent to which the air should be purified raised the question of design and economics. At the Northern Outfall Works electrostatic precipitators were used,

but this was mainly because the air for the gas turbines had to be exceptionally well purified to save maintenance costs on the turbines. Generally, precipitators could trap particles smaller than $\frac{1}{10}$ of a micron while filters of the dry type could only remove particles down to 5 microns. Precipitators had a constant pressure drop of not more than 0.2 in. W.G., whereas the dry filter started with a drop of about 0.15 in. and increased with the contamination taken out by the filter. Precipitators cost approximately ten times as much as dry filters but they removed considerably more dirt.

69. As engineers they had to weigh up all these factors, and particularly that of the atmosphere with which they had to deal, before making a decision on the type of plant, and he agreed with the Author that there was little basic research or information on which to work.

70. In § 9 some interesting facts were given about the Inka system of aeration. This system appealed to a lot of engineers because of the simplicity and flexibility of the layout. The Author had stated that four to five times the amount of air could be used as in conventional diffused-air plants for the same power, which would amount to about 6 cu. ft./gal. Whether it could be really usefully used in the time available was something on which he would have liked the Author's views. The Author appeared to be afraid of the small discharge holes in the pipes becoming choked by biological growths, but he could see no reason why this should occur if the air was not allowed to go off for long periods.

71. He agreed with the Author about costs, but he felt that when the Government asked for costs the returns would be so varied owing to the different methods of computing the costs that they would not be strictly comparable with each other.

72. He hoped that the Institution might sponsor some research in some way on the biological treatment of sewage. He agreed with the Author that this was a most important matter.

Mr W. Fillingham Brown (Consulting Engineer), thought that the Author had in general made out a good case for the virtues of surface aeration as against diffused-air systems. That, of course, applied to Manchester sewage, and he would like the Author's views on whether the same could be said of south country sewages with much smaller quantities of trade waste in them.

74. One point which he had missed in the Paper was the disposal of surplus activated sludge. Perhaps the Author was in a more fortunate position in that respect than some of them had been, in that all his sludge was barged out to sea. But those who had to try to dispose of sludge in more normal ways knew that surplus activated sludge was one of the most difficult substances to dry. In his experience this sludge was most easily dealt with in that way—drying—by whatever means, when it was in good condition and highly nitrified. Most of the Author's conclusions referred to a very low nitrification, or none at all. Did he consider that if his method of sludge disposal was more conventional it would prove so easy to dispose of his surplus activated sludge, and how would it compare with the sludge from diffused-air plants?

75. In § 32 the Author referred to the high rate of sludge return. One had, of course, to agree with this, and there were two advantages to it: it took care of the build-up of solids in the final tanks when high rates of flow, due to stormwater, arrived, and it reduced the time in which the sludge stayed in the tanks and therefore the duration of the gap in the aeration. That was a great advantage if the condition of the sludge was to be maintained.

76. The Author's experience in relation to total oxidation methods was interesting, and it was to be hoped that more experiments might be undertaken on this. If successful, it might possibly lead to a better and easier method of disposal of surplus activated sludge.

Mr H. R. Oakley (Partner, J. D. and D. M. Watson) remarked that the Paper gave a good example of how competition could stimulate development.

78. The Author had referred to the application of additional aeration to the Sheffield

unit, and it was relevant to add that at Chesterfield recently occasion had arisen to consider the remedy for an over-loaded Sheffield plant. Following the example given by Sheffield itself, the experiment had been conducted of adding a third line of paddles to one of the original units.

TABLE 10

System	Biochemical oxygen demand: p.p.m.		Suspended solids: p.p.m.		Aeration period: hours	Horsepower required per million gallons treated per day
	Feed	Effluent	Feed	Effluent		
Control unit (14 paddles)	267	23.6	—	15.9	13.4	33.3
Experimental unit (21 paddles)	267	17.3	—	14.0	9.8	35.7

79. The conditions were not dissimilar to those the Author had described, and Mr Oakley thought it of interest to add two lines to Table 6, using the yardstick of B.O.D. for want of a better; the figures (Table 10) were those of 5 months' operation of the experimental unit. The sewage was industrial in character, and the effluents contained little or no nitrate.

80. It was of interest to note that the horsepower per million gallons was not significantly increased by the addition of the third line of paddles, and the pounds of B.O.D. removed per paddle per day in the control unit were 129, and in the experimental unit 125. These figures had been supplied by Mr J. Hirst, the manager and chemist at Chesterfield, who had pointed out that the B.O.D. loading was unequal, and thought that for comparable conditions the experimental unit would remove more B.O.D. per paddle than the control unit. Perhaps the explanation was that due to the increase in flow per unit the channel velocity was increased from 1.1 ft/sec. to 1.4 ft/sec. The aeration period of the experimental unit did not approach the low values of the high-rate Simplex units at Manchester, but a fourth line of paddles was to be installed to see if the aeration period could be further reduced. He was not suggesting that this was in the present stage a serious competitor to other forms of mechanical aeration for a new works, but it appeared a useful means of relieving overload on an old works.

81. The general conclusion he drew was that if one used more vigorous aeration one could carry more sludge and consequently get more work done; that concept was introduced in 1926, and was developed more recently by Professor G. M. Fair. It would be of interest to make comparison between the various experiments in terms of the sludge solids carried. The only figures given in the Paper in that connexion were in Table 5, which showed that for the Simplex standard units, during the periods 1 to 5, as the aeration period decreased so the return sludge rate increased and presumably the sludge concentration in the mixed liquor increased also.

82. In § 2 the Author had stated that "the problem really falls into two parts inasmuch as means for the efficient mass transfer of oxygen to liquid, and of transfer from liquid to micro-organisms, are sought". Most of the rest of the Paper was concerned with the first part, the efficient mass transfer of oxygen to liquid, and the Author had had little to say about the transfer from liquid to micro-organisms. Would he say whether there was any significant difference between the sludge from a high rate aeration plant and that from a more normal plant?

Dr. S. G. Burgess (Scientific Adviser, London County Council) said that the Author had pointed out that in the diffused-air plant at Manchester, even if the air was filtered,

the problem existed of the gradual loss in efficiency due to the choking of the diffusers and the cost of replacement and cleaning; and as a chemist he agreed with him. Also, if moist air was put into iron pipelines corrosion of the metal would probably occur, and there would be conditions in which small rust particles were formed on the clean air side of the filter which would go to the diffusers and possibly reduce their efficiency.

84. It seemed that a stage had been reached when non-choking diffusers should be considered, so as to avoid altogether the expensive air-filtration plant, with its attendant difficulties. With regard to Table 7 would the Author give an estimate of how the figures could be modified if no air filtration plant were supplied and diffusers were unchokeable? The London County Council's work at the Northern Outfall Works had shown that rubber diffusers, developed by the Distillers Company for the manufacture of aureomycin and similar compounds, and patented by them did not choke and no filtration plant was required. The device consisted of a rubber diaphragm perforated suitably by a needle. At a flow rate of 0.5 cu. ft/min the efficiency of a 9-in. rubber diffuser was equal to that of a 7-in. dome, but as the flow rate increased the rubber diffuser showed a relative increase in efficiency. Its non-choking properties were demonstrated by placing the contents of a tin of scouring powder on the air side of the diaphragm, when the air rapidly cleared the expandable pores. These non-choking properties were proved by using the diffuser in a pilot plant producing sulphur from a mixture of sewage sludge and calcium sulphate. The diffuser was in use for 2 years and was left out of action covered in sludge for weeks at a time, and yet operated satisfactorily when the gas was turned on. This was indeed a far more severe test than in any diffused-air plant.

85. Mr Townend had mentioned the inefficient 4-in. diffusers that were dealt with in § 37. While the 4-in. dome had an efficiency of only 62% of the 7-in. dome at an air flow of 0.65 cu. ft/min, its efficiency increased to 85% when the air flow was 0.86 cu. ft/min, and there would not be much difference if the air flow were 1 cu. ft/min. Would the Author say what the air flow through the dome had been to enable them to decide whether these were more or less efficient than the 7-in. domes?

86. From Table 6 it appeared that the average B.O.D. values were slightly below 20 p.p.m. from which Dr Burgess expected that for part of the day the values exceeded 20. What had been the attitude of the River Board to a sample taken at such a time, and had any allowance been made for nitrate if nitrate was present?

87. On the question of plant flexibility he would be interested to hear the Author's experience on the comparison of the diffused-air plant and mechanical air plant in relation to the ease of plant operation.

Mr L. B. Escritt (Principal Assistant, Professional, London County Council) had examined the data of the experiments for the purpose of determining the comparative efficiency of the Simplex high-intensity cone and finding a basis of design. The first figures he had examined were those supplied by Ames Crosta Mills & Co. Ltd: these had been adjusted by that firm according to a logarithmic rule so as to show the horse-powers required to give final effluents of constant B.O.D. value.

89. When flow multiplied by B.O.D. was plotted to exponential ordinates and abscissae against aeration capacity multiplied by aeration horsepower, the data points roughly formed a straight line. This suggested that there was a straight line rule linking the above-mentioned factors but that some additional factor must be influencing the result, unless experimental error was the cause of irregularity.

90. On comparing the data of the points that fell above and below the line, it was found that greater B.O.D. reduction occurred in those instances where detention period of the final sedimentation tanks was high: in carrying out the experiments it had been impracticable to maintain constant final sedimentation detention period, but the variations had been very appreciable and enough to influence results, as shown by the figures in Table 11 which were the averages for four sets of experiments.

91. It was well known that increased detention period improved sedimentation efficiency, but little attention had been given in the past to the biological changes that

took place in the sedimentation tanks. One too easily accepted the doctrine that aeration was effected in the aeration tanks and settlement in the sedimentation tanks, but actually aeration of water took place in only part of the aeration tanks, the organisms continuing to grow and multiply, using the oxygen in the lower parts of the aeration tanks away from the actual aeration. It would therefore be reasonable to consider that the organisms in the activated sludge continued to develop and use the oxygen for as long as it was available during their journey through the final sedimentation tanks and back to the aeration tanks, and that therefore it would be reasonable to plot biological load against horse-power and aeration tank capacity plus a proportion of final sedimentation tank capacity.

TABLE 11.—AVERAGE DETENTION PERIOD: HOURS

Aeration	Final sedimentation	Total
8.65	4.63	13.28
8.36	5.03	13.39
6.02	6.44	12.46
2.57	8.92	11.49

92. Following this line of reasoning, the biological load had been plotted against horsepower multiplied by total capacity in aeration and final sedimentation tanks. This had produced the remarkable result that all the data points fell on a straight line so exactly that it had been hardly possible to see if any were above or below, and it was found that the biological load that could be reduced to a standard B.O.D. value in the final effluent varied as the square root of the aeration plus final sedimentation tank capacity multiplied by the square root of the aeration horsepower (Fig. 4).

93. Further figures of the original and additional experiments had been obtained from the Author. These, of course, had not been adjusted to a logarithmic rule. From these it was possible to derive the provisional formula:

$$M.G.D. \times B.O.D._1 = K \log_{10} B.O.D._2 \sqrt{C} \sqrt{H.P.}$$

where

M.G.D. = million gallons per day

*B.O.D.*₁ = 5-day biochemical oxygen demand of settled sewage in parts per million

*B.O.D.*₂ = 5-day biochemical oxygen demand of final effluent in parts per million

C = capacity of aeration plus final sedimentation tanks in million gallons

H.P. = aeration electric horsepower

K = a constant, varying with the efficiency of the process and amenability of the sewage to be treated.

Note: This provisional formula is applicable only between the values of 30 and 8 for *B.O.D.*₂

94. This formula had been applied to further figures obtained from time to time, and the same remarkable consistency of straight-line production on logarithmic paper had continued, showing that the form of the curve was not accidental. The investigation therefore appeared to prove that final sedimentation tank capacity must be considered in investigations and calculations relating to research or design. It also showed that, other factors remaining the same, aeration detention period could be reduced to such a small figure as 2½ hours provided only that final sedimentation tank detention periods were increased by the amount that the aeration tank detention period had been reduced.

95. The various other methods of aeration had been examined by the same procedure and it was found that the value of K denoted the efficiency of each process, being:

Type of plant	Performance index K
Simplex	46.8
Kessener	34.6
Diffused-air (units 1 and 2)	34.2
Pasveer	32.4
Sheffield, with Kessener mechanisms added	30.2
Sheffield	26.5

It could be seen that the diffused-air system gave a comparatively low value for K compared with what might have been expected. But in fairness to that system it should be pointed out that the diffused-air plant at Manchester was not of recent design: the

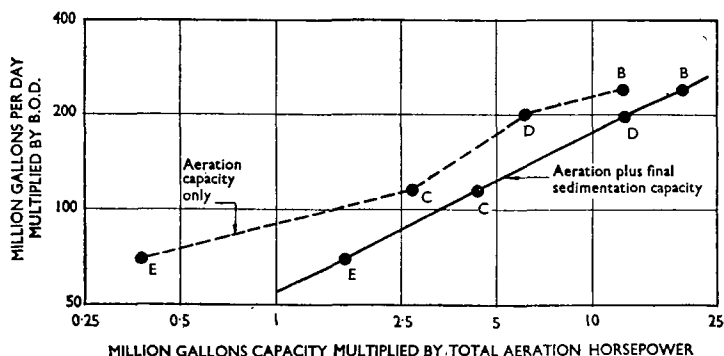


FIG. 4

tanks were 15 ft deep and were equipped with the not very successful 4-in. dia. diffusers—not the modern 7-in.-dia. diffusers required for the rate of air flow that was passed. Also the exceptionally high horsepower used as compared with plants elsewhere showed that the diffusers needed cleaning.

96. Of figures received relating to plants in various parts of Britain, those from Dalmarnock showed the reverse position (August to December, 1958).

Diffused-air	Simplex
53.4	49.6

At Dalmarnock the aeration tanks were of the modern shallow type (5 ft 6 in. deep) and the diffusers 7 in. dia.

97. At Manchester and Dalmarnock, while good B.O.D. figures for final effluent had been obtained, nitrification was negligibly low. When figures from works in various other parts of Britain had been examined and compared with those of Manchester, lower values for K were often found and it appeared that this was due to nitrification having the effect of increasing final B.O.D. value. Further investigation of this was desirable, for if the effect of nitrification could be expressed numerically, a very useful research and design formula could be evolved.

Mr R. W. Horner (Supervising Engineer, Outfall Works, London County Council) said that the cost of cleaning the air versus the cost of cleaning diffusers was a matter of economics. At the Northern Outfall Works there were two types of air cleaner in

operation. The first type, on the electrically driven blowers supplying the air to the pre-aeration channels, had expendable cotton-wool filters which lasted about 3 weeks. The pressure loss across a clean filter was about $\frac{1}{2}$ -in. water gauge and this rose to 2 in. by the time of replacement. The running cost worked out at about 7d. per million cu. ft of free air passed through the plant; therefore, in comparison with secondary treatment costs of £4 to £6 per million gallons of sewage treated quoted in the Paper, the cost of air filtration was negligible. The second type, the electrostatic precipitators, were more expensive to run, and the cost so far had been about 10d. per million cu. ft of free air passed through the plant—again not a high figure—and he felt that efficient filtration was well worth while.

99. Another problem in relation to keeping diffusers clean was that of corrosion of the air mains. In an acid industrial atmosphere the effect of the air itself on the mains was bad, and the question of pipe corrosion could be a serious matter. Most pipe materials were subject to attack of one form or another and some kind of coating had to be considered, which should be applied before installation. When once in service, it was difficult to stop the air supply to re-coat the pipes, and a permanent lining was required. For small pipes, polythene had been used; and polythene-lined pipes for the larger air mains were worth considering. He had had no experience of glass-fibre pipes, but they sounded attractive and it might be interesting to investigate their possibilities.

100. On the subject of efficiency of aeration, Mr Horner referred to Fig. 1 which showed the relation between the diffused-air co-efficient and the permeability of plate diffusers. The results were interesting and a convincing case was made out for the efficiency of the fine bubble.

101. In Downing's paper (Ref. 1 of the Paper) figures were quoted for the pore size of the plates used for the test which were coarser than the average figure quoted in the present Paper. Fig. 9 of Downing's paper showed the effect of the reduction of depth of liquid over the 7-in. domes, and from these results it was possible to calculate that the optimum depth for oxygenation for the 7-in. domes was just under 3 ft, which was quite different from the 12–15 ft mentioned by Mr Townend. As stressed by the Author, there was a wide gap between oxygenation capacity and actual B.O.D. removal, but there seemed a strong case for some research on quite shallow aeration plants using standard diffusers to see what results could be produced.

102. With regard to the B.O.D. test he was on rather dangerous ground, but it was a yardstick that had been imposed on them, so that they had to use it. He thought there was evidence that the removal of B.O.D. roughly followed a logarithmic law against time, and therefore against aeration energy. It followed that if one had a plant reducing the B.O.D. of a given volume of sewage from 200 p.p.m. down to 100, and one assumed that this required one unit of aeration energy, the next step, from 100 to 50 would take another unit of energy, but the pounds of B.O.D. removed per kWh in the step from 200 to 100 were double those for the step from 100 to 50. This probably accounted for the very high performance figures produced for the Inka plant. The Inka plant appeared to exploit the efficiency of shallow aeration but was handicapped by the use of the coarse bubble type of aeration.

103. He felt that the good results for Hamburg were due to the purification being carried out in the partial treatment range as mentioned in the Paper. It was interesting to note that if the treatment was in the range from 250 p.p.m. B.O.D. down to 100 p.p.m. the power consumption per lb of B.O.D. removed would be only about a third of the overall figure necessary to continue the treatment to produce a Royal Commission Standard effluent. On this basis the figure of 4.5 lb per kWh for the Inka plant would be reduced to 1.5 lb per kWh for full treatment, which was a more normal figure. The Simplex and Kessener experiments were most interesting from the aspect of this short aeration period, but he joined with earlier speakers in stressing the need for a stable plant with a good reserve of capacity; it would be unsound to cut the aeration period down to the bare minimum so that the plant was difficult to run. The old aeration plant at the Northern Outfall Works, which was a partial purification plant, was capable

of producing some surprisingly high figures for pounds of B.O.D. removed per kWh, but it could only be maintained at that level for a few weeks at a time. It had always proved very difficult to keep the sludge in good condition when the plant was heavily loaded.

Mr A. W. Shilston (J. D. and D. M. Watson) observed that the average results contained in the Paper suggested that the Manchester experiments had been conducted to yield effluents within the Royal Commission's standard, but not well within it. It further appeared that the Manchester settled sewage was not unduly difficult to purify in an activated-sludge plant to Royal Commission standards using a clarifying sludge. He had always understood that the Manchester sewage was difficult to nitrify, and perhaps that explained why no reference had been made to the possibilities of taking the purification process to a more advanced stage. In this context did the Author agree that there were positive advantages in purifying to the nitrification stage, should that be reasonably possible, as an aid to operational control?

105. Referring to Townend's paper (Ref. 13 of the Paper) the discussion on that paper had revealed a method by which a nitrifying diffused-air plant could be kept in a trim condition by using nitrate determinations. He was advised that a nitrate determination took 3 hours, so that rectification of a deteriorating effluent could be effected without undue delay by increasing the air supply, which was frequently possible by varying the speed of the compressor prime mover. The traditional method employed for varying intensity of oxygenation in a Simplex plant involved either the changing of the sprocket wheels on the gear case of the line shaft drive motors or varying the depth of immersion of the rotating cones. This latter involved an alteration in the level of the outlet weirs, and neither method was intrinsically flexible in actual practice.

106. If, as would appear, it was the intention at Manchester to operate the new plant at just within the Royal Commission's standards and under non-nitrifying conditions, would the Author say how in practice he considered the plant would be operated? How quickly in practice could a deteriorating effluent be detected and what criteria would he employ to facilitate such detection? Taking matters a stage further, what immediate operational steps would he take to remedy a falling off in standard? Would he regard the speed control of the rotating cone line shaft drive motors a desirable feature to achieve this end?

Mr M. A. Kershaw (General Manager, West Herts Main Drainage Authority), speaking as the operator of a sewage plant, said it was obvious that the main object of the Paper was to raise the question of the economy of sewage treatment. Recent work—particularly that carried out at Manchester—had been devoted to and aimed at reducing capacities and time, and at the same time of intensifying aeration.

108. He referred to the overall economy of sewage treatment. One particular section was the biological one, and it was important and necessary to assist its efficiency, not only from the scientific angle but from that of *£ s. d.* In fact they must assess the method by the complete treatment.

109. This brought him to the question of the disposal of the surplus sludge. Visitors to the Water Pollution Research Laboratories had that week seen two investigations going on side by side, which could be termed diametrically opposed. One gave details of scientific investigation into the intensification of aeration methods and another was an investigation into a serious practical problem, where on a comparatively new sewage works it was found increasingly difficult—in fact, virtually impossible, he understood, at one stage—to dewater the sludge. So far, investigations were tending to show that one of the basic causes of this problem had been due to the increased agitation of sludge during circulation in the digestion process. Had the Author any information as to the effect the increased agitation and aeration processes might have on the extremely difficult problem of de-watering by the conventional processes of air drying, etc.

Mr H. C. Parkman (Assistant Engineer, Sandford Fawcett and Partners, Consulting Engineers) stated that recently two senior members of his firm had visited six sewage treatment works operating on the Inka principle in Sweden and had brought back some interesting information concerning the operation of the diffusers. Evidently clogging did not appear to be a problem. Generally speaking they back-flushed their diffusers in order to clear them when there was any minor blockage, which seemed to occur very rarely. This was done simply by turning off the fans and allowing the diffusers to fill with liquid and then re-starting the fans to cause a flushing action. However, where there was a high proportion of industrial wastes they used larger holes in the diffusers and this eliminated the trouble completely. Only a small loss in efficiency occurred due to the larger holes. One works was seen to be under maintenance after 4 years of operation. Removal of the grids was easy and it was seen that there was no need to put the whole tank out of commission during maintenance. Foam control was much easier, since it all tended to be carried across to one side of the tank where it could be destroyed by jets of effluent. It was a very flexible form of treatment because the air could be varied over a wide range with time-clock control. From the results obtained at these works there was every reason to hope for about a 2-hour detention time in order to achieve a Royal Commission standard effluent from normal sewage.

111. With regard to the total oxidation process which the Author had described in his experiment, it appeared from all the American literature available that this total oxidation was not possible since there was always a certain amount of non-oxidizable material left, and that a minimum of this non-oxidizable material was only obtained with certain trade effluents if supplements were added, usually in the form of nitrogen. Could the influent at Manchester, which must contain a lot of mixed industrial waste, possibly have some effect on this 28% reduction in the sludge solids, and could there be more hope for a bigger reduction in an easier type of influent?

112. Even so, this process seemed to have certain possibilities for small flows; quite clearly for large flows it was uneconomic. For small flows in isolated places the maintenance could be reduced and it could be hoped that this reduction in maintenance would compensate for the increased cost of air blowing.

The Author, in reply, dealt first with points raised by Mr Townend. He said that § 1 meant to convey the fact that biological oxidation was the most costly part of waste treatment, since as a rule it accounted for 40–50% of the total expense of sewage purification. He was, however, in complete agreement that the cost of the service as a whole was invariably quite modest compared to that of other services, e.g. water supply.

114. On the question of the economy which the construction of deep aeration tanks showed over shallow types, it did not appear that this might always be so. For instance, where ground was difficult to excavate and the water-table was high, shallow tanks might prove to be cheaper to construct. It so happened that the new aeration tanks at Manchester were to be built on a site which formerly had been the bed of the River Irwell, and it was known that the water-table was very high and that excavation would be costly. Consequently, his civil engineering colleagues were delighted at the success of mechanical aeration in relatively shallow tanks.

115. The omission of construction costs was regretted. The Paper already contained nine Tables, and had had to be pruned in order to comply with the requirements of the Institution regarding length. The only figures which he had relating to construction costs were estimates prepared for the particular site conditions at Manchester, and it did not seem appropriate to quote these, but he could assure Mr Townend that the installation of a mechanical aeration system appeared to be decidedly cheaper than an air diffusion plant. No doubt Mr Townend would be able to work out figures for the general cases himself, once aeration periods were fixed.

116. It was agreed that the 7-in.-dia. domes were more efficient diffusers than the 4-in.-dia. type used in the Manchester plant, but this had not been generally known at the time when this intensive comparative work was initiated under the Author with a view

to a final decision being made on the type of aeration system to adopt for the new plant. Today he could equally be accused of not using the most efficient type of rotor in his Kessener plant because the new design installed at the Rochdale Works was proving more effective than the standard brush. He had reason also to think that there might be further developments in other mechanical aerators. One had to make a selection sometime from the range of equipment which one had tested.

117. It had been implied that the comparison in § 21 of the performance of the Simplex plant with that of an air-diffusion installation elsewhere was quite invalid because the latter had been producing a nitrified effluent whereas the Simplex plant had not. The comparison, however, was not as erroneous as had been suggested because it would be seen in Table 6 that the Manchester air-diffusion plant had been operated with an overall aeration period of 8.8 hours to produce an effluent of similar quality to the Simplex plant. Now, in a Paper by Lockett¹⁶ it was stated that a well-nitrified effluent could be obtained at Mogden in an aeration period of 8 hours. If this was regarded as a normal possibility, it would be evident that the aeration period of 8.8 hours given in the Manchester air-diffusion plant was quite comparable to the Mogden retention time. Therefore there was some justification for comparing the Simplex plant performance to that of the air-diffusion installation referred to by Mr Townend in his Paper.¹³

118. The answer to Mr Calvert's first question was that normally there was little or no nitrate in the effluents from the activated sludge plants, because the sewage treated contained about 40% of industrial effluents, in some of which were chemical substances which inhibited the activity of nitrifying organisms.

119. It was quite true that the more one shortened the aeration period the greater was likely to be the effect of shock-loads on the process. In a large drainage system such as that of Manchester, sudden variations in sewage composition had not occurred to anything like the extent of those found in smaller systems, but nevertheless there were some fluctuations. It had been found, however, that considerable smoothing out of these variations occurred in the primary settlement tanks, and in addition the dilution which occurred with return activated sludge and mixed liquor at the inlet of the aeration units gave a further damping effect. Consequently, the variation in final effluent B.O.D. over 24 hours was probably small. Dr Burgess had also drawn attention to this possibility, and it was one to which some consideration had been given. There seemed to be a case where a sewage works was treating a high proportion of industrial effluent—some of it because of pressure brought to bear by a River Board on the traders to seek admission of their wastes into the local sewers—to ask the River Board to judge effluent quality on average composite samples rather than on "snap" samples. This should certainly be considered in cases where sewage works were discharging into rivers or watercourses which contained no fish. However, in the design of the new plant, certain safeguards were being provided. These included pre-aeration for the whole of the flow receiving full treatment, and completely new primary sedimentation tanks. By such means it was known that there would be a greater deposition of sludge in the settlement tanks, and consequently less impurity in the sewage to be aerated. The aeration tanks were being designed to provide $3\frac{1}{4}$ hours' aeration at $1 \times \text{d.w.f.}$ as against about $2\frac{1}{4}$ hours in the experimental unit, and furthermore the new aeration plant was being laid down to cater for a daily d.w.f. of 45 m.g.d., whereas initially the volume to be treated would be about 38 m.g.d. It had been felt that these measures would enable an effluent of B.O.D. less than 20 p.p.m. to be produced continuously, but if by chance that standard were not to be attained the plant was being arranged in such a way that additional aeration tanks could readily be constructed and incorporated into the scheme.

120. Mr Vick had suggested that to reduce capital expenditure on an aeration plant and increase operating costs might be short-sighted, because most sewage purification works outlasted their loan repayment period and, if well-designed and built, future

generations would benefit considerably by the low operating and maintenance costs. The Author felt that there was another way of looking at this point. It could be argued that it was hardly fair that the present population should be saddled with higher capital costs for the benefit of future citizens. Might it not be more equitable for each generation to pay for the service as they used it, i.e. in operating costs? In addition, Mr Townend had pointed out (Ref. 13) that capital costs had risen far more than power costs over recent years, so there was a case for considering higher operating costs in preference to increased capital charges.

121. It was agreed that the five-day B.O.D. test was far from perfect as a measure of plant performance, but it was at the moment recognized in the Ministry of Housing and Local Government's booklet on the analysis of sewage and effluents as a test for the assessment of impurity and, until something better was devised, it would probably continue to be used throughout the world for that purpose.

122. The information about the cleaning of air at the Northern Outfall Works of the L.C.C. and its influence on the non-clogging of dome diffusers had been very interesting and appeared to bear out the comments made on American experience in § 5 of the Paper.

123. Although the Author had no practical experience in the operation of the Inka aeration system, he was inclined to agree with Mr Vick that it was questionable whether as much as 6 cu. ft./gall. could be used to advantage in the contact time. As regards chokage of the small air discharge holes in the pipes, Dr von der Emde of Hamburg had told the Author that this had occurred in the Hamburg plant and, in some experiments with jet aerators which the Author himself had carried out a few years ago, $\frac{1}{8}$ -in.-dia. tubes in a full-size aeration tank had become clogged by biological growth.

124. There was no apparent reason why mechanical aeration systems should not perform quite well on the sewages of southern England mentioned by Mr W. Fillingham Brown. It was reasonable to expect that, if they could deal with intractable trade wastes, they ought to have little difficulty in coping with domestic sewage, which did not present a great problem to any system of biological oxidation.

125. It appeared that, when Mr Fillingham Brown referred to the better drying properties of a nitrified activated sludge as compared with an un-nitrified sludge, he was assuming that the drying process was being operated on the activated sludge alone without prior digestion. Experimental work carried out at Manchester by the Author's predecessors had confirmed this opinion held by Mr Fillingham Brown. The drying characteristics of activated sludge from the intensive aeration process had been raised also by Mr Kershaw. The surplus activated sludge from the high-rate Simplex plant was very similar in general properties to the sludge from the diffused air and other systems; it contained the same sort of organisms and had a comparable density index and one could therefore expect it to be no more difficult—and certainly no easier—to de-water than other activated sludges.

126. The performance figures of the Sheffield-type plant, installed at Chesterfield and modified by the introduction of a third line of paddles, had been most interesting and, as Mr Oakley pointed out, more intensive treatment was being achieved without any reduction in the efficiency of power utilization. This experimental work was valuable and served to prove that there were various ways in which the rate of purification could be increased.

127. As Mr Oakley was probably well aware, it was most difficult to study the factors affecting the transfer of oxygen from liquid to micro-organisms, and hitherto the subject had been approached mainly through studies on dispersed growth aeration; Mr Oakley was referred to these for further information. As mentioned in § 125 above, there was no significant difference between the Manchester high-rate activated sludge and that from the conventional plants. This was probably because purification in both cases was taken to "Royal Commission Standard" but, in circumstances where a high-rate plant was operated to produce effluents of B.O.D. 50–100 p.p.m., the sludge would have different characteristics and would be less stable.

128. Consideration had been given to Dr Burgess's question about the probable cost (shown in Table 7) of operating the diffused air plant if no difficulty had been experienced with air filtration and diffuser chokage, and it was estimated that the treatment cost would be reduced to about £4 16s. 0d. per million gallons. The main reduction would be in electricity consumption and maintenance charges, but the compressor station would still have to be continuously manned.

129. The amount of air passed through a 4-in.-dia. dome diffuser during treatment was 0.71 cu. ft/min.

130. So far as flexibility was concerned, the Author found mechanical plants to be easier to operate than air diffusion units. It was a simple matter to vary intensity of aeration in a mechanical system by adjustment of outlet weir levels, which gave variable immersion of cones or rotors. A further, but less convenient, adjustment could be made by varying the speed of rotation of the aerator. A point on which these systems scored heavily over air diffusion was in their rapid return to normal performance after an accidental shut-down. In a matter of minutes, sludge which had settled out in aeration tanks could be brought back into circulation and, if the stoppage had been prolonged, a few hours' aeration would serve to revive the sludge. Indeed, it was the practice at some works to shut off some mechanical units during the night (in dry weather) when the load was insufficient to warrant running all of the plant. In the case of air diffusion it was a slow and difficult business to restore normal suspension of sludge after an interruption to the air supply and invariably the compressors had to work to a higher pressure for quite some time after such an occurrence. This meant the consumption of more power. Usually, too, compressors were few in number for an air diffusion plant, and consequently they were each of relatively large capacity, so that it was not often possible to increase or decrease air input by small amounts. Fog and humid conditions also had adverse effects on the performance of air compressors. Irregularities in pore size of diffusers caused uneven air distribution and, if diffusers were not all located at exactly the same level in an aeration tank, air distribution would be affected.

131. Mr Escritt's contribution was very interesting and showed that he had given careful consideration to the performance of aeration systems. The Author found it difficult to accept the contention that a significant amount of purification continued to take place in the final settlement tanks of an aeration system. The point in this theory which Mr Escritt did not explain was: where did the oxygen come from to enable the organisms to continue their work? Normally, mixed liquor entering final settlement tanks did not contain more than about 3 p.p.m. of oxygen in solution and, as the sludge particles fell to the bottom of the tanks, this was quickly respired by the living matter. Purification did not continue without oxygen, and it was hardly feasible to suggest that layers of surface liquid, containing oxygen, diffused to the lower levels of the tanks because, in the case of the Manchester installation, the final tanks were upward-flow Dortmund type; these would discharge over the outlet weirs any oxygen-bearing surface liquid.

132. Mr Horner had made out quite a good case for efficient filtration of air, and the Author agreed with him entirely; he agreed also that experiments on the use of standard diffusers in shallow aeration tanks would yield interesting results. It was quite true that the removal of B.O.D. in the activated sludge process followed a log-arithmetic law, which of course accounted for the high efficiency of aeration systems when carrying out partial purification. From personal observation, the Author could confirm that the activated sludge in the partial treatment plant at Hamburg was not in good condition.

133. Agreement had been expressed with Mr. Shilston that it was an advantage to operate an aeration plant to the nitrification stage where economically practicable but, as explained in § 118, Manchester sewage could hardly be nitrified. It was a fact too that most activated sludge plants in Britain were not producing nitrated effluents.

134. It was not the Author's experience that mechanical aeration plants were difficult

to control in practice, and the matter was dealt with in the reply to Dr. Burgess's question (§ 130). The new aeration plant at Manchester would be operated in a conventional manner, but with provision for a high rate of return of the activated sludge. The quickest tests for detecting a deteriorating activated sludge—for that was affected before effluent quality—were microscopical examination and sludge density determination. The steps to be taken in remedying a falling off in standard would depend on the reason for the deterioration—toxic matter or increased sewage strength were not the only factors which caused this—as no doubt Mr Shilston was aware. If increased air input were required, adjustment of cone immersion was easily made by manipulation of outlet weir level—quite a simple matter. Variation of cone speed was also a useful remedy, and in that connexion the use of d.c. motors was advantageous.

135. The reply to Mr Parkman's question about the possibility of other types of sewage producing activated sludge which was more amenable to *total oxidation* than the Manchester sludge was that this was quite possible. Sludge from domestic sewage alone was likely to undergo greater degradation, and American work had shown that sludges from milk wastes were very amenable to this type of oxidation. It would appear that the process was attractive where the regular removal of surplus sludge to a disposal point was likely to be troublesome and expensive.