Paper No. 6424

The economics of waste-water treatment†

by

Charles Bruce Townend, C.B.E., B.Sc.(Eng.), M.I.C.E.

Discussion

Mr J. T. Calvert (Consulting Engineer, John Taylor and Sons), asked for more information on some of the ranges of costs of which the Author's figures were averages. In some cases a range was given, but there was no indication of how many figures were used to obtain the averages. Could they be treated as true averages statistically?

126. The operating costs of sewage-treatment works were most interesting but his experience led him to question the Author's averages. Table 1 gave, for populations of 100,000 and 200,000, operation costs of 6·5 and 5·5s. respectively per head per annum. He had had occasion recently to look at the accounts of two authorities with modern works and populations very close to those figures, and in the case of the 100,000 population the cost was 15s. and in the case of the 200,000 population it was nearly 10s. Had the Author included some larger works where the operating costs were particularly low perhaps because land treatment was used? This process tended to cut down the operating cost but used a large area of expensive land.

127. Had the Author included rates, which could be a very large factor in Britain? In one of the cases to which he had just referred the rate represented 284% of the total annual operating cost. From the strict engineering point of view the incidence of rates could have misleading results.

128. It was stated in the Synopsis of the Paper that the joint drainage of adjoining towns could be effected with considerable overall saving. There were other factors to be taken into consideration which were not merely price factors. In particular, a series of towns down a valley would have the effect on the stream in the valley of reducing the flow by carrying it in sewers down to the lowest works. If the works were sizable enough to produce a satisfactory effluent, he wondered whether there was not something to be said for discharging a treated effluent at a number of points down the valley.

129. The statement in § 65 that the reduction in cost obtained by the lowering of standards was not as much as might be expected was interesting. Mr Calvert felt that that raised a very interesting point in reverse in view of the current demand in many cases for improved standards, and he thought that the Author would agree that if the standard was increased the cost was perhaps more than might be expected. Had the Author formulated any approximate figures for the cost of improving standards in relation to either the B.O.D. or the suspended solids?

Mr H. D. Manning said that the Paper dealt essentially with policy and broad generalizations and it was not easy to discuss it on precise matters of arithmetic or straight logic.

131. In § 12 it was stated that 240 g.h.d. had been adopted in some of the larger schemes over the past 20 years as the capacity of the sewers. In § 13 there was a reference to the fact that 240 g.h.d. had given excellent results in practice in the case of separate sewers. He thought that in most of the cases where that figure had been adopted

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† Proc. Instn civ. Engrs, vol. 15, p. 209 (Mar. 1960).

by statute or otherwise as the acknowledged basis of design the sewerage system was not strictly separate and that a number of combined systems were included. He thought that where there was a strictly separate system, as there might be over a large area in the case of a new town, a figure lower than 240 g.h.d. might be adopted for trunk sewers even if certain yard washings were connected.

132. In § 24 the Author said that the degree of treatment recommended by the 1908 Royal Commission was assumed in the Paper as the standard requirement. Mr Manning supposed that that standard was still very widely adopted in Britain, but there was a strong trend towards higher standards. Had the Author, in the course of his collection of figures for the purpose of his investigation, obtained any figures which would indicate the cost of raising standards of purity?

133. Mr Manning had been interested to learn that the cost of water supply was five times that of sewage disposal (§ 122). Did that figure embrace distribution as well as treatment? Its relevance to standards was that where higher standards were required at sewage works designers were now tending towards water-treatment practice, and if they carried it much further their costs might go up a great deal more than they or the river boards had imagined.

134. In §§ 72–74 the Author indicated that heated sludge digestion was an economic proposition and well worth while when compared with cold digestion. Mr Manning did not find that borne out by the actual figures in the case of smaller plants. Unheated tanks could be put in for as little as 3s. per head, whereas the Author quoted figures of 12s. to 16s. per head for full heated digestion plant from which there might be a return of perhaps 1s. 8d. as the value of the gas.

135. On the subject of whether it was advantageous to generate power, Mr Manning thought that to put the figure as low as 50,000 for the population was a little optimistic. His own experience was that it could seldom be shown to pay with less than about 100,000 population, from the point of view of the council concerned. Very big strides would have to be made in respect of the simplification of control, reliability, and automation of small power plants before it was economic to use gas at plants for populations under about 100,000. The cost of maintenance and of shift engineers in particular was very heavy.

Mr C. D. C. Braine (Consulting Engineer, Cardiff) said that for many years the Author had been advocating the use of strictly separate rather than partially separate or combined sewers, but now suggested (§ 13) that the strictly separate system had been found wanting and implied that he now preferred the partially separate system. However, the pollution from overflows on the partially separate system was probably worse than that of the overflow from combined systems. If the Author used a “storage” type of overflow, which Mr Braine believed would be used a great deal before many years had passed, he would find that overflowing from sewers of, say, 30 in. dia. or larger, occurred so seldom that pollution from them could almost be neglected. Nearly 2 years earlier Mr Braine had demonstrated the value of storage to the Storm-Water Overflow Committee. He felt that there was a lot to be said for this new type of overflow. If a major economy was considered—and economies were being discussed—a combined system, with proper storm-water overflows costing perhaps £2,000 each instead of a mere £200, saved thousands of pounds because it obviated a complete system of foul sewers. He knew a case where, on a housing estate of about 1,000 houses, the anticipated cost of sewerage was reduced by about 35% by this means. This example would be followed extensively elsewhere, before very long. He had been told that in Holland the pollution caused by overflowing from the other systems was so great and the cost of the system was so high that it had been decided to revert to the combined system.

137. In the case of large systems like the West Middlesex, the available storage capacity in the main sewers was so great that it hardly mattered whether the sewerage of local areas was separate, partially separate, or combined. The storage available in big sewers was huge and the times of concentration in local sewers were so different

from those of the main sewers that the main sewers could absorb the intake from local sewers without embarrassment.

138. Fig. 2 was of considerable interest to Mr Braine, because he was now working in Wales, dealing with a number of small schemes. In the British Isles few towns of 5,000 inhabitants remained unsewered, but there were scores of villages which had no sewers. When speaking in terms of sewerage for these small communities, the question of house connexions became a big item. It might sound a little mundane, but on a recent scheme with 580 connexions, the average cost of a connexion, including contributions from the local inhabitants, worked out at about £70 per house or, say, £23 per head. Looking again at Fig. 2 and considering the cost of sewerage for a town of 2,500 inhabitants, then, on the basis of £23 per head for connexions, the Author's cost of sewerage for a small town was precisely doubled. It might be said that house connexions should not be considered, but for small communities the cost of connexions was a material factor in the cost of sewerage.

139. The use of Figs 3 and 4 to support regionalization was very interesting. In 1952 at the annual conference of the Institute of Sewage Purification at Scarborough, Mr Braine had given a Paper on a similar subject, in which two of the diagrams, reproduced here as Figs 6 and 7, were in extraordinary agreement with the Author's Figs 3 and 4.

FIG. 6.—COST OF SEWAGE-PURIFICATION WORKS

140. In Fig. 7 the curve of costs for sewers showed that, economically, not much was to be gained by building a sewer of more than 10 ft dia. Fig. 3 showed that the economic limit for sewers was about 12 ft, which was little different from Mr Braine's conclusions.

141. Mr Braine's curve had been prepared in 1951 and although the costs given then were now out of date, it was interesting that, allowing for the cost of construction index, his curve, in fact, almost tallied with the Author's.

142. With regard to the economic size of disposal works, Mr Braine had considered only activated sludge plants, for which he had a fair number of costs. When plotted these naturally showed some scatter. Fig. 6 illustrated this and the best-fit curve adopted became asymptotic for plants with a dry-weather flow of about 40 m.g.d. He agreed with the Author that although on the operational side the staff needed for a plant of 40 m.g.d. dry-weather flow would probably almost suffice for a plant of, say, 60 million or 70 million g.p.d., constructionally a plant for 40 million g.p.d. was getting near the economic limit.

143. The comparison of costs in § 77 was interesting. Mr Braine now felt that at many small works, provided that sufficient land was available, the cheapest method of dealing with sludge was, as the Author had pointed out, to pump it into permanent lagoons for drying in situ. Mr Braine imagined that the Author was thinking in terms of big permanent lagoons such as those at the Birmingham Tame and Rea District Drainage Board, where at least one lagoon extended to 11 acres—there might now be some larger ones. Those lagoons had been there for so many years that they could properly be called permanent. Sludge could be pumped into lagoons of this type for year after year. It would be interesting to know how long the Author thought it had to stay there after sludge pumping had ceased before it would be dry enough to be taken out by a mechanical excavator.

FIG. 7.—COST OF SEWERAGE

144. The Author estimated the cost of sludge disposal by means of lagoons to be 10–15s. per ton of dry solids, but Mr Braine wondered if the combination of large lagoons with a few sludge-drying beds for handling separated liquor, etc., was not a more effective way of handling sludge. However, these sludge-drying beds might represent a cost of another 20–30s. per ton of dry solids, bringing the total cost of sludge disposal by this method up to 30 or 40s. per ton of dry solids.

145. It was noteworthy that the annual cost of a heated digestion plant plus the cost of the necessary drying beds seemed appreciably more than the cost of drying undigested sludge on open beds, but, of course, where gas from the digesters could be used for power, this would not be the case. It had lately been said that digested sludge was more difficult to dry today than it was 25 years ago. Whether it was detergent affecting the sludge he did not know, but sludge also seemed to him to be more difficult to dry than it used to be. In fact, crude sludges nowadays appeared to dry better and more easily than some of the digested sludges and this must reflect itself in the general economy and the choice of system for sludge disposal. Another factor was that quantities of sludge seemed still to be increasing.

Mr E. H. Vick (Divisional Engineer, Main Drainage, London County Council) said that he had been concerned about § 12 in which was quoted 240 g.h.d. as the figure for design of separate or combined sewers. Many engineers still had to deal with combined sewers only, or largely, and it was still necessary to design new ones. He did not think that 240 g.h.d. was the proper basis for the design of a combined sewer. He knew of no reliable method of estimating the total flow in combined sewers other than by calculation of rainfall and runoff.

147. He would rather design overflow weirs on combined sewers (§ 14) at four times the maximum dry-weather flow than at six times the average dry-weather flow. The

latter basis was suitable for an outfall sewer where all the connexions had come in already. It was better to base overflow design on the strongest sewage, which could be calculated from the time and the maximum dry-weather flow, than to base it on an average.

148. The figures relating to the cost of sewers were extremely accurate compared with his own facts. He assumed that the Author was taking generally undeveloped areas for his figures, for they would be very much higher in built-up areas.

149. In London it had been found that the older brick sewers, those built about 1860, were just reaching the end of their useful life, and there was now a quite considerable repair programme.

150. Did the Author consider that a sewer should be designed for a life of 100 years or more? There was no doubt that a modern sewer could last longer, but would it be preferable to design a cheaper sewer to last a shorter time?

151. Mr Vick did not think that there had been the development and progress on the design of sewers in tunnels that there had been in other fields of sewerage.

152. Three important factors influencing the cost of sewage treatment were given in § 12. The Author should add facilities for the disposal of sludge, which often affected the works very considerably.

153. In § 29 it was stated that the larger plants were tending to become more standardized. That followed naturally as knowledge and experience increased, but he felt that a contributing factor, which might not run side by side with advance of knowledge, might be that for economic reasons the use of manufacturers' standardized equipment, for example tank scrapers, might have an inhibiting effect on the design of treatment plant. Possibly the choice of dimensions of sedimentation or digestion tanks was governed by the size of the cheapest and most easily obtainable equipment from the manufacturers.

154. Both Birmingham and the London County Council had recently constructed digestion plants, without any conference between them. The tanks in question had turned out to be almost exactly the same design. He felt that they had been led to that position by the manufacturer's design more than anything else.

155. The methods of screening and grit removal probably showed more diversity in design and equipment than any other feature of a modern works, but during the past 25 years the whole aspect of that part of sewage treatment had changed very much for the better. In fact, that was not a part of any works where low initial cost, or indeed running cost, should be the deciding factor, but rather the provision of good working conditions for staff, since in modern works that was about the only part where the operators needed to come into contact with the sewage.

156. Much research had been and was being done on primary settling tanks, and papers had been written, on the size, depth, type, and distribution of flow. The Author made the point that that was the cheapest part of the sewage purification system. Mr Vick felt that the labour and research should go more into the secondary process than into the primary.

157. The economic effect of pre-aeration should not be overlooked, particularly where there was a long outfall sewer resulting in septic sewage arriving at the works, where there was much grease in the sewage, or where surplus sludge was returned upstream of the primary tanks. That sort of plant was cheap to install and run, and in some cases could be installed in existing supply channels to the primary tanks.

158. There seemed to be little information on pre-aeration in Britain, but he believed that it might, if properly applied, provide a great improvement in the efficiency of primary sedimentation tanks.

159. He felt that the Author had over-simplified the sludge disposal problem. It was true that digestion had made the most significant contribution to sludge disposal, but he considered the problem to be still very serious. Disposal of sludge in Britain was becoming progressively difficult as suitable land became scarce and public opinion hardened against the unsightliness and degeneration of amenities caused by open drying

beds. On all future schemes, except perhaps very small ones in isolated places, or where sea disposal was used, artificial dewatering would be imperative. In that field, also, there was much scope for work on research and development.

160. He agreed with the Author's figure of 60s. per ton of dry solids as the cost of shipping sludge to sea. However, he felt that that figure must be used carefully. In the case of the London County Council the figure was about right but it included only for the running and maintenance of the ships and did not include the cost of piers, jetties, and pumping to the ships, and the cost of those items could vary considerably according to the nature of the river or estuary on which the works were situated.

161. The Author had drawn attention to the remarkable fact that sewage, if suitably processed, provided sufficient power for its own treatment. He agreed with the figures given in §§ 93–99. The Author referred only, however, to the use of piston engines to convert the sludge gas into power. Gas turbines, although of comparatively recent development, should also be considered in assessing the economic factors of power plant. Gas turbines at the moment used more gas per unit of power generated than did piston engines and when the waste heat could be fully utilized had an overall efficiency of only about 50%, compared with approximately 75% for piston engines. Nevertheless, against that must be set the simplicity and lower costs of maintenance of gas turbines. He could not give the exact cost of maintenance of gas turbines because the gas turbines which had been installed had been running only for about 3 or 4 months, but he hoped to be able to issue figures which would show whether the estimate of low maintenance costs for the plant had really been borne out.

162. Trade effluents was a very complex subject and he agreed that free discharge to the sewers, as required in London under the 1953 Act, led to carelessness on the part of the manufacturer.

163. Mr Vick suggested that, in view of the shortage of labour for sewage works and, indeed, to improve working conditions for the labour that there was, the aim of designers should be to provide mechanization up to the point of complete automation. However, if automation was used there was no point in providing someone to stand by and look after it. Practice in automatic pumping stations had shown that automation was reliable.

164. Intensive and properly co-ordinated research on sewage-treatment processes and on sludge disposal would be overwhelmingly repaid by the economies in the provision and running of sewage works that would result. In regard to sludge digestion, more gas and more power could be obtained from the sludge. Although he did not yet know the reason, he thought that the modern digestion tank was giving more gas per head than had formerly been the case.

165. He considered that greater attention should be given to the effect of passing ground garbage to sewers. The use of garbage grinders, both domestic and industrial, was growing rapidly, and it might grow very rapidly indeed. If the time should come when their use was much greater than it was now, the whole economics of sewage disposal and garbage collection would be completely altered, and in the case of a regionalized scheme, that meant quite an upset in existing political arrangements.

166. On the economic design of storm-water drainage, separate storm-water sewers from new towns might discharge large volumes of water at a high rate into quite small rivers, because nowadays towns were being sited artificially and not necessarily at places where the rivers had sufficient capacity to receive the waste water. Formerly towns grew up where there were rivers simply for that reason. Now towns were being placed where there might be only small streams—and probably valuable fishing streams at that. It was necessary to go carefully into the economics of the problem. Some of the discharges might necessitate costly river improvements for a long distance below the discharge. An alternative method of dealing with the problem, which was being used by many authorities, including his own, was to provide balancing lakes and reservoirs, thus avoiding the river works and maintaining the natural form of the river. This provided an additional amenity for a new town in the form of a lake.

167. In view of the demand of river boards in particular circumstances for effluents of higher than Royal Commission standard, very careful consideration should be given to the point of discharge of an effluent. Tertiary treatment should be avoided. In many cases the problem could be overcome by the proper discharge of the effluent at the appropriate point. A good length, perhaps some miles, of effluent drain could be constructed to carry Royal Commission standard effluent to a point of discharge lower down the river where another tributary joined it, and that would probably be preferable to embarking on expensive tertiary treatment, which was not only very expensive in first cost but also in operating costs.

Mr L. B. Escritt (Principal Assistant, Professional, London County Council) said that the cost of sewerage depended on local conditions, including both density of population and the physical geography. It was not practicable to say that any particular cost per head of population was justified by comparison with other localities, but expenditure must be related to the needs of the populace.

169. Since sewers were laid by local authorities and drains by private developers, sewerage and house drainage were considered apart, with the result that the utmost overall economy was seldom achieved. The local authority would decide on a system of sewerage which suited them: the building developer would have to conform to that system and then often attempted to secure economy in cost by reducing standards of drainage to the lowest that could be approved under by-laws. When sewerage and drainage were considered together, it was possible to make large savings without reduction of technical standards. But this seldom happened.

170. He did not agree that soil-sewer capacities were tending towards 240 g.h.d.: on the contrary, practice was becoming more diverse than formerly. He did not consider that there was ever any excuse for discharging untreated storm-water from new combined sewerage systems or without partial treatment at disposal works.

171. The cost of sewage-treatment works per head of population was fairly regular and it had been the habit of many engineers to make preliminary estimates purely on the head of population to be served. The Author's curve (Fig. 4) could be expressed by the equation:

Cost per head of population = $\pounds 55/P^{0.16}$, where P = head of population.

172. Mr Escritt had not found a resistance level at about £20 per head for very small works. At the other end of the scale he had found that, for very large works, cost per head tended to increase a little because, once the maximum size of unit had been reached, there were no further economies on tank size, whereas there were additional costs of length of connecting culverts, roads, cables, etc.

173. Over the past 40 years, percolating filters and activated-sludge works had been in competition, each alternately showing advantage in economy of cost as improvements were made. Percolating filters had never been used to full advantage. The methods of alternating double filtration, recirculation, and construction of very deep filters, as in enclosed filtration, had shown that, in suitable circumstances, filters could be made to treat much larger quantities than formerly allowed without reduction in standard of effluent. All the figures which he had examined suggested that percolating filters did not work to their maximum efficiency until the load in gallons per day per superficial yard of top surface was increased sufficiently to ensure wetting of the total surface of the particles of media in the bed, with no dry ineffective patches on the individual particles. This theory, however, had not been proved by experiments specifically made for that purpose and he thought that this was a matter which deserved attention.

174. The tendency in all the activated sludge processes had been in the improved efficiency of utilization of power in aerating the mixed liquor. It had also been found that higher power input accompanied by reduced detention period tended towards greater overall economy of annual charge, including repayment of loan. At any particular works producing a Royal Commission effluent between the limits of a biochemical

oxygen demand of 10 and 20 parts per million, the performance of the plant appeared to be expressed by the formula:

$$\text{m.g.d.} \times \text{B.O.D.}_1 = K \times \log_{10} \text{B.O.D.}_2 \times \sqrt{C} \times \sqrt{\text{h.p.}}$$

where: B.O.D._1 = biochemical oxygen demand of primary sedimentation tank effluent in parts per million.

B.O.D._2 = biochemical oxygen demand of final treated effluent.

K = "performance index" dependent on efficiency of power utilization, difficulty of treatment of sewage, etc.

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

h.p. = total aeration horse-power.

175. An observed factor of considerable importance was that it was the total capacity of aeration plus final sedimentation tanks which should be equated with the load on the works, and not aeration capacity only. It was also observed that very considerable reduction in aeration tank capacity could be made without any effect on the biochemical oxygen demand of the final effluent, provided that the final sedimentation tanks were increased in capacity by the same amount. The formula, when used for comparing the results of different works, was not without value, although it was much affected by local characteristics, in particular the degree of nitrification.

176. When the optimum working conditions for percolating filters, including both size of medium and load per superficial yard, and the optimum working conditions of activated-sludge works in terms of proportion of horse-power to detention period, had been found, it would be possible to reassess the comparative economic advantages of the processes.

177. Apart from considerations of cost, the activated-sludge processes had their well-known amenity advantages offset by the nuisance value and possible risk to health of foam formation and, perhaps, a greater risk, by droplet formation than the percolating filter. They also had a snob value; and this led to the useful information which the Author had given on costs of sludge treatment. Simple lagooning and open air drying and, where practicable, shipping to sea were generally most economic. The extent to which mechanical or process-drying was used was a tribute to the business acumen of the salesman of proprietary machinery, together with the snob value of the new and complicated.

Mr H. R. Oakley (Partner, J. D. & D. M. Watson, Consulting Engineers,) said that economy was a fundamental of good design, and he wished to discuss the Paper from that angle.

179. Mr Calvert had already commented on the increasing cost of improved standards in sewage treatment. Fig. 8 showed this principle in a simple fashion and related the percentage purification of various stages of treatment to the cost per unit flow. As the Author had pointed out, increased periods of retention in sedimentation tanks did not give a proportionate increase in efficiency, and at some stage it would become economic for filtration or some other method of biological treatment to be adopted. Similarly, as the loading of the biological filters was decreased the cost would go up at a rate greater than the increase in purification capacity, and eventually it would become economic to adopt some form of tertiary treatment. Thus for each stage of treatment, and overall, the purification of sewage followed the law of diminishing returns; and this should not be forgotten when considering the standard of effluent required.

180. Fig. 8 also served to demonstrate that skill was required in determining when one form of treatment had reached its economic limit, and a different method should be introduced. Although experience gave a guide in normal circumstances, there were special cases, particularly where trade wastes predominated, and preconceived ideas about the economic limit of any particular stage of treatment might be upset. Again, Mr Oakley was not altogether satisfied that the right balance between sedimentation and biological filters was the same as that between sedimentation and activated-sludge

treatment, and it was probable that a shorter period of sedimentation could be justified where activated-sludge treatment was to be applied.

181. Fig. 9 illustrated the same principle in a different application, and related to the cost of heat drying of sludge: the two elements of cost—initial dewatering and subsequent heat drying—were plotted below and above the abscissa respectively, for different methods of treatment and different end results. Fig. 9 was diagrammatic but if accurate costs were available, a diagram of that sort would indicate the minimum overall cost for any desired end result.

FIG. 8.—COMPARISON OF CAPITAL COSTS OF WASTE-WATER TREATMENT

182. Economic design could also be considered in relation to the last subject dealt with by the Author—the national aspect. On the one hand, sewage-disposal works were adopting traditional water-treatment methods; on the other hand, at the Ryton waterworks, Coventry, a biological nitrifying filter had been adopted for pretreatment of the river water. Thus water purification and waste-water treatment were coming together, and if sewage purification could be regarded as the end result of water treatment and distribution, so equally well in many cases was it the beginning of a fresh cycle.

183. Consequently there was the need for some broad consideration of the economics of the case of sewage effluent discharged to a river and being later abstracted and treated for water supply purposes. Was it cheaper to treat the sewage effluent to the very highest degree; or to adopt a lower standard in respect of that effluent and to undertake slightly more treatment at the other end after dilution and abstraction?

184. That question, he submitted, could best be answered by a body which was responsible for some broad overseeing of policy. Would the Author agree that there was some case to be made out in those circumstances for a body similar to a river board, but having duties and responsibilities which went far beyond the present scope of the river boards?

185. Finally, he commented on that part of the Paper which dealt with the financing of capital expenditure. Did the Author think that a 30-year load period in respect of works and a 15-year loan period in respect of machinery were the correct periods, having in mind that sewers might last for 100 years or more, and that most modern plants could be expected to give efficient service for a long period after they had been completely paid for. It was perhaps a question of whether or not future generations should be expected to contribute towards the services which they would inherit.

Mr N. J. Tatman (Partner, D. Balfour & Sons, Consulting Engineers) gave some information relating to a group of adjoining towns in the River Lee Valley, where, just after the war, the new towns of Harlow, Stevenage, Hatfield, and Welwyn were established.

187. The system of trunk sewers which had been laid or could be continued for the drainage of those towns made provision for other and existing towns on the route of the sewers and for draining certain rural districts through which the trunk sewers passed.

FIG. 9.—COMPARISON OF COSTS OF HEAT DRYING OF SLUDGE

There were twelve all told. The scheme provided for the drainage of about 320,000 persons over an area of about 60 sq. miles. The total cost of the trunk sewers which had already been constructed or could be laid to cater for those communities would eventually be £3 million. The cost of the outfall sewerage system was about £9.4 per head of population served. The figure related only to the outfall system, and he had no figures available of the cost of the internal sewerage of the various towns. Many of the towns were old and had systems on which the loan charges had expired generations ago.

188. The figures given in Fig. 2 appeared to relate to internal sewerage of towns up to a point, evidently a sewage-disposal works not too remote from the town. From this graph the average cost of the internal sewerage of the twelve towns would be £20 per head.

189. He had adjusted the above figure of £9.4 for outfall sewerage to bring it to present-day costs, according to the Author's graph and had made allowance for the difference between 300 g.h.d. provided in the Lee scheme, as against the Author's figure of 240 g.h.d. The resultant figure, added to £20 per head for internal sewerage, gave a total of £35 per head, which compared with £25 per head in Fig. 2 for a population of about 320,000, thus showing an increase of 40%.

190. The case he quoted was a straightforward one of trunk sewerage with disposal works at the confluence of the two main valleys of the Stort and Lea. There was no long or expensive sewer beyond that point. It would seem that the line of the graph in Fig. 2 should be considerably elevated.

191. He had also tried to analyse the capital cost per mile per 1,000 gal d.w.f. Taking 300 g.h.d. and bringing the costs up to date on the graph, which showed about 124% p.a., he found that for 5.47 miles of one sewer draining a population of 113,000, the cost would be £3.4/mile/1,000 gal, which compared closely with the Author's figure of £3.2. The other of the larger trunk sewers in the scheme was about 6.4 miles long, draining 200,000 population, and that came out at exactly the same figure—£3.4 per mile, which would compare with £2.6 in Fig. 3. A possible reason for that was that the more expensive sewer was laid in more difficult circumstances. The other sewer was laid up a valley from beginning to end with no obstruction except a few river crossings.

192. In the case of larger works dealing with, say, 100,000 population and more, there seemed to be a strong case for mechanization in every respect. In the case of smaller works for, say, 10,000 population, Mr Tatman did not think that the balance between loan charges and operating expenses and productive effort by providing machinery on the one hand and what was saved in operation on the other should be the criteria in deciding for or against mechanization. It must be accepted that much of the manual operation in sewage works was extremely dirty, and in times past labour was available only because of unemployment. Dirty manual labour itself was attractive to no one, particularly in present times when a great deal of dirty work could be accomplished with the aid of a machine. Operators would always be found who would not mind the dirt provided that they worked with a spanner and not a shovel or squeegee.

193. Very recently in the case of a works for a population of 10,000, a careful analysis showed that with such mechanization as was possible, including the mechanical lifting of the sludge, there was an annual excess of cost over the hitherto conventional methods equal only to the labour of $1\frac{1}{2}$ men. It was evident that, with the present shortage of labour for distasteful work, and with a situation which was likely to deteriorate and not improve during the life of the works, there was every reason for mechanization even at an increase in initial capital cost.

194. Supporting the Author's remarks about the national aspect of sewage disposal he quoted the City of Westminster. The total rate was 15s. in the pound, and it produced an income of £16 million per annum. The drainage rate, including the London County Council main drainage precept, was 8.41d. in the pound. The highest figure on the rate demand form was 9s. 7.6d. for education. How often did a council or a client say "They could afford a sewerage scheme" and how seldom did they say "Education is too costly"? Surely both health and education were related in regard to the raising of the standard of living, but, unfortunately, at the present time the relation seemed a very distant one.

Mr M. R. Vincent Daviss (Engineer to the Birmingham Tame and Rea District Drainage Board) said that in general the figures which Birmingham had supplied to the Author were higher than those which he had quoted.

196. There was an indication in the Paper that there was no doubt at all that generation of power using sludge gas was always an economic proposition compared with taking the public supply from the electricity authorities. The figures which they had in Birmingham did not bear that out. There was probably very little difference.

197. He asked for more information on Table 2. Prices were quoted in pounds per kW for the various sizes of set. Figures quoted to Mr Daviss recently for the delivery on site of the generating set itself, added to the cost of the generating station, and also the cost of the auxiliary plant required for the operation of the station, gave a figure about 50% higher than that quoted in Table 2. In addition, it was not clear whether the Author had included any allowance for standby plant. He suggested that that had not been included, and it would account for probably a further 25% on the capital cost.

In the case of a small station it was probably higher than that. When it was a question of only one engine taking the load, obviously it would be 100% of standby plant.

198. There was also the question of fuel oil for ignition, figures for which were given in Table 2. The figure for fuel oil for ignition given in Table 2 decreased as the size of the set increased. Apart from the allowance for bulk supply, how did that arise?

Mr W. Fillingham Brown (Consulting Engineer) commented on points to which two of the speakers had referred.

200. Mr Braine had remarked about the present difficulty of drying sludge. Mr Fillingham Brown confirmed that that was so. His own view was that the standard of living had been very much raised since the war and, therefore, today people ate very much more meat and fats. As was well known, the difficulty of drying sludge depended very largely on its protein content, and he thought that it was the increase in protein content in sewage sludge which led to the increased difficulty in drying sludge in recent years.

201. Mr Vick had mentioned another fact on which that point had a bearing, and that was the increase in the amount of gas produced in recent years. Mr Vick attributed that to the better design of digestion tank. There might be something in that, but Mr Fillingham Brown thought it was the increase in the protein content of the sludge which gave rise to the better yield of gas from sludge in recent years.

Mr A. W. Shilston (J. D. & D. M. Watson, Consulting Engineers) said that he wished to consider aspects of the economics of operation of activated-sludge plants.

203. In § 103 reference was made to the interdependence of the activated-sludge and heated-sludge digestion processes.

204. Also, in § 101 the Author suggested that with populations of less than 50,000 the introduction of dual-fuelled engines was not a serious proposition. Mr Shilston felt that the population figure might be much higher than 50,000.

205. Despite such assertions, there seemed little doubt that activated-sludge plants would continue to be provided in sewage-treatment works the size of which would not perhaps warrant the use of dual-fuelled engines. In such circumstances the mechanical plant would of necessity be driven by electric motors energized from the grid. Rather closer regard would then have to be given to power consumption costs since virtually free potential energy would not be available as would be the case with methane gas available to serve a dual-fuelled-engine generating installation.

206. The Author was well known as an advocate of taking the activated-sludge process to the advanced nitrification stage as an aid to successful operational control. He had also, Mr Shilston thought, said on more than one occasion that in a diffused-air plant the air supply was critical to within fairly fine limits, suggesting that with proper control air wastage could be reduced to the minimum. Such a statement, he thought, implied that the facilities existed for detecting expeditiously a dropping of effluent standards and for varying finely the air application rates. The Paper had been prepared against the background of an effluent standard of that recommended by the Royal Commission, and such a standard could usually be obtained if the fermentation of the carbonaceous matter was substantially complete without significant oxidation of the nitrogenous matter.

207. In that context, and with an installation dealing with a sewage which was amenable to biological treatment and in which the power was derived entirely from the grid, was it economically justifiable to take oxidation to the advanced nitrification stage as an aid to operation control?

208. How quickly in practice could a deteriorating effluent be detected in order to take the necessary action to ameliorate the adverse conditions?

209. He had heard it suggested that, in view of the chemical changes that took place during the biological oxidation of the carbonaceous and thereafter nitrogenous impurities, speedy control could be exercised by virtue of the changes in pH value. Had such an approach any merit?

The following contributions were received in writing.

Mr L. F. Phillips (Deputy General Manager and Engineer, Sheffield Sewage Department) observed that the figures given in the Paper for the power demand of an activated-sludge plant appeared to be a little generous for all but the smaller size of sewage works though the average amount (50 h.p. hours per day per 1,000 persons) probably reflected the tendency to squander power which was generated cheaply from sludge gas.

211. At the Blackburn Meadows Works of the City of Sheffield where a d.w.f. of 26 million gal, including 10 million gal trade effluent, from a population of 510,000, was given full treatment to more than Royal Commission Standard in an activated-sludge plant the total average daily power consumption of the bio-aeration units for aeration, and returned and surplus sludge pumping for the year ended 31 March, 1960, was 16,500 kWh or 43.3 h.p. hours per day per 1,000 persons.

212. By contrast, the Coisley Hill Sewage Works, Sheffield, where a d.w.f. of 800,000 gal of wholly domestic sewage from a population of 35,000 was treated on similar bio-aeration units, the average daily power consumption for the same period was 51 h.p. hours per 1,000 persons.

213. These figures supported the suggestion by the Author in § 60 that the activated-sludge system was usually less economic for smaller sewage works.

214. The Author stated in § 60 that the total costs of biological treatment were between 4s. and 6s. per head, while in § 58 the capital costs were given as 50s. to 60s. for filters plus 10s. for final settling tanks giving a total average cost of 65s. per head.

215. Where a recirculation system was adopted it was usual to permit a dosage rate of tank effluent per cubic yard of filter-bed capacity at least twice that on a straight filter scheme. The volume of filter beds required in this case would then be reduced by half with a consequent saving of about 25s. per head. Offset against this were increased costs for pipelines and final settling tanks to cope with the increased flows involved and also the capital and annual cost of pumping the recirculated effluent.

216. Taking the average figure for "straight" filters, 55s., it appeared reasonable to assume that 50s. of this was for structure and media and 5s. for pipework. If it was found necessary to provide, say, 60% more capacity in pipelines and final settling tanks

TABLE 3

Section	Type of plant		
	Activated sludge	Bacteria bed system	
		"Straight" filters	Recirculation
Biological plant	22s. 6d.	50s. 0d.	25s. 0d.
Final settling tanks	10s. 0d.	10s. 0d.	16s. 0d.
Pipelines	(included above)	5s. 0d.	8s. 0d.
Pumping station	—	—	1s. 6d.
Total capital cost per head	32s. 6d.	65s. 0d.	50s. 6d.
Annual charges per head	2s. 0½d	4s. 1d.	3s. 2d.
Add for electric power at 1½d. per unit	1s. 4¼d. (§ 58)	—	3d.
Total per head	3s. 4¾d.	4s. 1d.	3s. 5d.

the total increase on this account will be 9s. while a complete pumping station for recirculation of the effluent would probably cost between 1s. and 2s. per head.

217. To the capital cost for a recirculation scheme must be added the cost of power for pumping. For a works of 100,000 with a d.w.f. of 5 m.g.d. and a recirculation ratio averaging 1:1, the power consumption could be estimated as followed. Using pumps having an efficiency of 75% and a total overall efficiency of, say, 60% when operating against a static head of 10 ft and a friction head also of 10 ft, the average power absorbed to pump 3,470 g.p.m. (5 m.g.d.) would be about 26 kW, i.e. 228,000 units per year or 2.28 kWh per head. This would involve an annual cost for power for pumping of 3d. per year per head.

The costs, exclusive of maintenance and labour charges, could thus be summarized as shown in Table 3.

218. Table 3 showed that, under present-day conditions, economically there was, in general, nothing to choose between the activated-sludge system and filter beds operating on a recirculation system, though in specific cases particular conditions might favour one or the other. For instance, where power was generated on the sewage works or in industrial areas where it was possible to obtain electricity for as little as 0.85d. per unit, including the maximum demand charge, then in such instances, other things being equal, activated-sludge schemes would be more economic than filter beds.

The Author, in reply, said that the questions raised had been unusually large in number and wide in scope; he would deal with them collectively as far as possible.

220. Several members had mentioned the variations in costs as between towns of the same size. As was to be expected, the figures obtained in practice presented a wide band of scatter when plotted. He had particularly drawn attention to the variation of conditions from one place to another in § 10 and § 20 of the Paper. For works, such differences included the type of plant adopted and its degree of mechanization, the source of power supply, the proportion and types of trade effluent to be dealt with, the standard of amenity adopted, the kind of subsoil with water conditions and other factors affecting construction costs, and so on. In many cases there was some overhead charge peculiar to the site such as that caused by the diversion of a river, the demolition of existing structures, the general lowering of the natural ground level, or other special features. Any of these might cause a higher-than-average cost. For sewerage, the density of urban development on the one hand, or the provision of long sections of unproductive sewers in more open country elsewhere, as well as other factors mentioned in the Paper, would obviously affect the per capita cost.

221. For these reasons, in fixing mean curves he had not used statistical methods, but after taking into account the known individual circumstances, he had used his own judgement in assessing as fair a mean value as possible for the particular size of town concerned. The main objective had been to establish the relation between cost and size as such, and while there could be many reasons for considerable divergence on either side of the mean which in those cases mentioned by speakers would account for costs being higher, or lower than average, the factor of size nevertheless would of itself control the final result on the lines indicated by the graphs.

222. In comparing with any particular works, he would stress that all costs given in the Paper were related to modern plant at 1959 price levels. Operating costs equally referred to modern plants such as would now be constructed, these costs tending to fall with better design and mechanization.

223. In reply to Mr Calvert, he had not included rates as these did not concern economics. He regarded the levying of rates on sewage works as financial juggling and nothing to do with engineering. The sewage works might get some very small amount of service from the rates in the use of local roads and a very little police protection, but that was about all. Although rates had to be paid by the authority owning the sewage works, the total public expenditure was not increased thereby and from a national point of view this merely represented the transfer of money from one pocket to another in a

most inequitable manner. Indeed, if one authority should carry out a large sewage works improvement in one part of a county, its increased rate contribution might quite well be subsidizing the services of another authority elsewhere in the county which was neglecting its duty to the same river. For such reasons, the incidence of rates had no place in an engineering paper. The deduction of rates amounting to 28½% of the costs quoted by Mr Calvert would bring them more into line with those of the Paper.

224. Mr Braine's point that house connexions in small communities were costing as much per head as the sewerage system of the town itself gave a comparative indication of the considerable economy of modern public systems. There seemed to be no good reason, however, for including the cost of private connexions, drains, or other appurtenances forming part of the house property in the cost of sewerage.

225. Several speakers had commented on the subject of separate and combined sewers, and there appeared to have been some misunderstanding of his reference to the trend towards the common capacity of 240 g.h.d. for both systems. He agreed with Mr Vick that combined sewers must be designed primarily on rainfall and run-off; this might indeed require a capacity as much as 3,000 g.h.d. or more in certain built-up areas of limited size, but in such cases the designer would seek to relieve the sewer as early as possible by overflow to the nearest available watercourse. The general practice in Britain of overflowing all volumes in excess of 6 d.w.f. meant that the majority of combined sewers did not exceed 240 g.h.d. in capacity—except of course in limited areas before overflow to rivers had been effected; equally, outfalls to sewage works from combined systems rarely exceeded 240 g.h.d. and usually were less than this. At the same time, modern systems of separate sewers also were commonly provided with capacities of the same order.

226. In using the term "separate", he was referring to the duplicate system of sewers by which foul water was conveyed separately to the sewage works—but not to strictly separate sewers from which all surface-water was rigidly excluded.

227. Mr Braine was quite mistaken in thinking that the Author had ever been an advocate of the strictly separate system; on the contrary, apart from the fact that it was virtually impossible to maintain any system as strictly separate, he had always supported the view that the more polluted surface-water from paved yards and other such sources should be taken into the foul-water sewers for treatment at the sewage works. For the proper prevention of river pollution, no overflow from a foul-water sewer should be allowed, and this condition could be achieved with a partially separate system of the type mentioned if a capacity of around 240 g.h.d. were provided. This had been the basis adopted 30 years before for the West Middlesex undertaking, which had been operated quite successfully without overflows; it had been the basis of a memorandum¹ published by the Institute of Sewage Purification in 1945, and it had been stressed again by the Author in a previous Paper² to the Institution in 1947. He did not think it would be wise to adopt a figure very much less than 240 g.h.d., as Mr Manning had suggested, if overflows were to be avoided with a reasonable safety margin.

228. With combined systems, it was quite impracticable to avoid heavy pollution; if the flow reached 50 d.w.f. at an overflow set to discharge at 6 d.w.f., then 90% of the total impurity load of the sewer would go into the river. Some limited assistance could be obtained from storage in sewers or special basins, but Mr Braine had exaggerated the effect which could be achieved in this way. The total storage capacity of the West Middlesex main sewers was about 50 million gallons, but this did not prevent the sewers running full over the entire district simultaneously in times of prolonged rainfall. If the surface-water discharge were increased perhaps fourfold or more by the adoption

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¹ Memorandum on the Establishment of New Towns in Great Britain. J. and Proc. Inst. Sewage Purification, Part 2, 1945, pp. 189–190.

² C. B. Townend, "West Middlesex Main Drainage—Ten Years Operation". J. Instn civ. Engrs, vol. 27, pp. 351–414 (Feb. 1947).

of combined systems, obviously several hundred million gallons could not be accommodated. In view of the careful watch which had to be maintained by the local authorities in West Middlesex over the drainage development of their areas, Mr Braine's claim that it would hardly matter whether the sewerage was separate, partially separate, or combined, appeared to be a little reckless.

229. Nevertheless, as Mr Vick had pointed out, storage had its economic uses where lakes could be provided cheaply for storing separate surface-water discharged from new towns at the heads of small rivers.

230. Regarding Mr Vick's question on the long-term economics of sewer construction, there was much to be said for using the best quality materials and workmanship available. In practice, the difference between the best and the worst was comparatively small; excavation and safe structural requirements were more or less common to all sewers, the only variation being that of inner lining materials. Differences were proportionately even smaller with tunnelling or in busy city conditions where overhead costs were high. With best materials, difficult and expensive maintenance would be reduced or eliminated, with increasing savings as price levels rose by long-term inflation. The life of modern materials might well extend to several hundred years, but such savings as could be made by cheaper methods would appear to be scarcely worth considering. With smaller sewers constructed of unlined pipes, it would be even more important to ensure the best materials. Some economy was perhaps permissible in districts where change in industry or in other ways affecting sewerage was to be expected, but duplication or alteration of sewers was generally expensive.

231. He agreed with Mr Calvert that in a series of towns down a valley there was something to be said for discharging a treated effluent from a number of points at intervals along the river, but in an industrial area of large centralized works at the bottom end would normally be able to accept all the trade wastes of the area, many of which a small works could not tackle. He thought that in this respect the large works had the greater advantage as well as being more economic.

232. A number of speakers had raised the question of the cost of purification to an improved standard beyond that of the Royal Commission. Up to the present time, that had been achieved in Britain by micro-strainers, sand filters, and grass plots, all of which had not been unreasonably expensive. There had not yet been enough experience, however, to reliably assess the economic effect of this trend. He would stress that tertiary treatment of this kind had usually been confined to percolating filter effluents which often suffered from excessive humus solids of 30 p.p.m. or more. A good activated-sludge plant, on the other hand, could be operated steadily for years on end to produce an effluent well in advance of the Royal Commission standard with solids of no more than about 7 p.p.m., as at Mogden, where average results over individual months had been as low as 3 p.p.m. without special treatment. The cost of proceeding to such a point should not be excessive.

233. If still further improvement were required towards complete oxidation, he thought the nitrifying filter working at perhaps 2,000 gallons or more per cubic yard would be the answer. While the cost of oxidation normally would be expected to rise considerably in the final stages towards completion, it might be that the expense of such a tertiary stage would not be altogether unreasonable. The suggestion of Mr Vick that effluent of Royal Commission standard could be conveyed by conduit to a point lower down the river where it would be acceptable was an excellent alternative where economic.

234. The curves of Mr Oakley gave excellent representations of the trends of costs per unit flow in relation to the degree of purification achieved, and of the desirable choice of processes to carry out the successive stages of procedure. The relatively high cost expected in the tertiary stage was well illustrated.

235. He shared Mr Vick's view that pre-aeration would be employed more in the future. He also agreed on the considerable economic gains to be obtained from research.

236. Regarding Mr Aitken's contribution on sedimentation tanks, the development of large upward-flow tanks for water treatment might well have application to sewage purification, but there were always many points of difference which must make the sewage problem a peculiarly individual one, especially where rapid biochemical changes might be taking place in a highly organic sludge.

237. Mr Shilston and Mr Phillips had both suggested that closer control of power consumption had to be exercised in activated-sludge-plant operation when power was purchased from the grid than when generated from methane gas. This did not follow at all; power should never be wasted, but it was to be remembered that the use of a more generous supply of power was usually accompanied by a more vigorous biological process with a reduction of plant capacity and capital cost. Power supply and tank capacity were interdependent factors which could not be studied in isolation.

238. There were great advantages to be obtained by working at maximum activity with a vigorous activated sludge. He agreed with Mr Escritt that experience showed that higher power input with reduced capacity tended towards greater overall economy of annual charge. Moreover, as capital costs tended to rise faster than power costs, the advantage in favour of the use of power should become more pronounced as time went on.

239. With vigorous operation of this kind, it was possible to establish a robust nitrification procedure in some cases with less capacity than required for a non-nitrifying sludge giving treatment to the point of clarification only. Nitrification would normally be found quite economic, although with certain sewages it could not be reasonably achieved.

240. The control of air supply at the minimum point of nitrification was quite easy, and needed adjustment only at infrequent intervals of perhaps a week or more. The indicator used at Mogden was that of total oxidized nitrogen in the effluent; this was maintained at about 10 p.p.m. If during successive days, the figure were steadily falling below this level, a small increase in air supply of usually only 2% was sufficient to restore it to 10 p.p.m.; if this action were not taken, the oxidized nitrogen was likely to continue to drop and nitrification would be lost. In the reverse direction, a figure well in excess of 10 p.p.m. could be accepted as the signal for reducing the air supply.

241. The figures of comparative costs of the activated sludge process and percolating filtration by recirculation supplied by Mr Phillips confirmed the general competitive position of these rival procedures. As Mr Escritt had remarked, this competition would encourage still further improvements in both processes.

242. Mr Escritt's formula for the performance of an activated-sludge plant was novel but he could not accept the view that the capacity of the final tanks should affect the position unless active sludge remained there in good dispersion with an adequate oxygen supply—a state of affairs which should be avoided.

243. On the subject of sludge digestion, he confirmed the statement in § 72 that heated plants of reduced capacity were cheaper than unheated plants of *similar construction*. In quoting lower costs of unheated tanks for smaller plants, Mr Manning appeared to be referring to cheaper types of construction such as the Author had described in § 84 as being suitable for austerity conditions.

244. In quoting the figure of 1s. 8d. per head as the return value of gas as against 12s. to 16s. for fully heated digestion plant, Mr Manning had presumably not appreciated that the gas value was an *annual* income which would completely cover the capital value of the plant in less than 10 years.

245. Regarding Mr Vick's comments on standardized plant, he thought much of the best equipment had been dictated by the requirements of the sewage-works designer rather than the other way round, although in certain cases the design of sewage plant must be affected by the limitations of mechanization. The digestion plants of Birmingham and London quoted by Mr Vick were both examples of good practice which had been developed elsewhere, but each had new features making further contributions to progress. To obtain the cheapest form of tank in cost per 1,000 gallons, the diameter would be about 70–100 ft and the side-water depth about 32 ft; practically all large

digestion plants were in that range. The dimensions were not affected by the limitations of gasholder size.

246. Replying to Mr Braine, sludge lagoons filled with consolidated sludge to a depth of 8 ft could be dried to a thickness of 2 ft to 2 ft 6 in. for machine excavation in about 5-7 years depending on the weather. Shallow areas filled to 3 ft deep would give rather better results by yielding 9 in. of dry material in about 18-24 months. The drying of undigested sludge should not normally be practised because: (a) of odour nuisance, and (b) the untreated grease content of material in this form would prevent its use as a fertilizer.

247. If there were more difficulties in drying sludge now than 25 years before, it was probably due to higher proportions of secondary sludges in the form of surplus activated sludge and humus due to improved sewage treatment.

248. Artificial dewatering of sludge, mentioned by Mr Vick, had been practised as long as 60 years or more before, but never yet on an economically competitive basis with drying beds; it might well be that economics could often become of secondary importance.

249. Mr Vick and Mr Fillingham Brown had mentioned increasing gas yields. That might be due to improved digestion plant at any given works, but did not appear to be due to a general change in sewage composition or other such cause. Where the same plant had been in operation at Mogden at a constant level of loading and efficiency for the past 25 years, no change in gas yield had been observed.

250. A number of speakers had questioned the figure of 50,000 mentioned in § 101 as the population below which it would not be profitable to use methane for power generation. He had not intended to imply that a power plant would always be practicable at above the 50,000 mark and would not disagree with a figure of 100,000 in many cases; he had rather stressed the various local factors which had to be considered in treating each case on its own merits. Additional buildings and shift engineers were not necessarily involved, nor indeed in some cases would it be necessary to operate the plant outside ordinary working hours.

251. Regarding the queries of Mr Vincent Daviss, he had already stated in § 100 that to the costs quoted in Table 2 must be added an allowance for buildings, administration, and miscellaneous costs. On the other hand, as stated, the figures did not fully reflect the economy to be achieved with a large installation of engines. Regarding standby plant, this had been covered by basing all calculations on 5,000 running hours per annum (see Table 2); for a station operating 24 hours/day, this provided an allowance for standby plant of 75%; the factor of capital cost in most cases, however, was not large. The fuel oil for ignition represented a greater proportion of the total fuel used in small engines than in those of large size.

252. The Author had not claimed that methane power generation was always economic, but in comparing with the costs of a grid supply, he had stressed in § 102 the need to cover properly all the secondary expenses involved in excess of the normal price per unit. In the case of the main works of the Birmingham Drainage Board where the sewage outfall was gravitational and percolating filtration was used for treatment, the demand for power was relatively small and the economics of generation from methane would not be so attractive.

253. The advantages of gas turbines mentioned by Mr Vick could be valuable where power load was low in relation to the methane supply and mechanical efficiency was not important.

254. He agreed with Mr Vick and Mr Tatman that labour shortage might override economics in accelerating the use of mechanization and automation wherever possible to avoid unpleasant or uninteresting work.

255. In reply to Mr Manning, the cost of water supply assumed in § 122 was inclusive of distribution charges; if more remote sources of supply had to be used because of pollution of local rivers, these distribution charges could be greatly increased. The problem of economic balance between improving the standard of sewage treatment and

the alternative of providing more treatment of river water for public supply (also mentioned by Mr Oakley) did demonstrate the need which might often arise for decision by a co-ordinating body.

256. Regarding Mr Oakley's comments on loan periods, that was a matter of policy for which the Ministry were responsible. There were obviously many points which had to be considered, including the probable useful life of the structure and its obsolescence, with the possibility of a particular process being superseded by later developments; this was not so likely to happen now as it was 30 years ago. There was also the question of unusual local conditions such as mining subsidence. In all these things, proper caution had to be exercised to avoid the possibility of having to replace works before they were paid for. On broader issues, it was reasonable to spread the payment over the years during which the community would continue to benefit but at the same time one generation should not seek to escape its just liabilities by passing them on to posterity. Nevertheless, in rapidly growing towns when populations in the early years were small, a greater deferment of liability was justified. It was always financially preferable to keep the period short and avoid long-term interest charges whenever possible. To sum up, every case should be treated on its merits.