

*Discussion on Paper No. 6585**

**The primary sludge digestion plant at the Minworth Works
of the Birmingham Tame and Rea District Drainage Board**

by

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and

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Mr S. H. Dainty (Chief Engineer, Middlesex Main Drainage Department) said the Paper would take its place in a long series of Papers which had been presented by the Birmingham Drainage Board to the Institution and similar organizations. All those who were associated with the science of sewage treatment were indebted to the Birmingham Drainage Board for making so large a contribution to their knowledge. As the reorganization of the Main Tame Valley Works proceeded they could no doubt look forward to further Papers on the design work and experiences of the Board.

112. The planning of a programme of reconstruction spreading over many years and of such magnitude could itself make the subject of an interesting paper. Within the brief reference to centralization of treatment contained in § 6 mention was made of the construction of "sludge digestion plant with an associated generating station". That association seemed perfectly logical and he would be interested to know why in fact the construction of a generating station had not been proceeded with at the same time. Once the decision had been made to generate power it was surely desirable to produce that power at the earliest possible moment.

113. In § 15 it was stated that "The main pump-house . . . serves principally to fill and empty the tanks. Most other operations were carried out in the control chambers at the individual tanks." It seemed to him that here was a first-class opportunity for the application of remote control, and he would like to ask the Authors whether any consideration had been given to such a system, so that all the operations could be conducted by remote control at the pump-house. It would be of interest to know what labour was required to operate the present system and whether or not any shift working was required.

114. In § 18 it was stated that the points of discharge of raw sludge into the tanks were 5 ft below top water level. He would be interested to know what factors had decided the level chosen for those discharge points, particularly in view of Mr Gardner's statement in presenting the Paper that there was evidence of scum formation to something like that depth in the first tank opened. From a study of figures quoted Mr Dainty thought it would be true to say that under the correct operating conditions the tank level would fluctuate by something like 12 to 18 in. It might have been possible by putting the sludge inlets at a somewhat higher level to break down that accumulation or prospective accumulation of scum and eliminate some dead capacity in the tank.

115. The application of heat through individual heat-exchangers seemed to be an ideal way of applying heat to the digestion plant, because thereby one would expect to have a steady inflow of heat and a reasonably steady temperature. The rapid with-

* *Proc. Instn civ. Engrs*, vol. 21 (April 1962), pp. 761-784.

drawal of sludge from an individual tank would not prejudice that position in any way, but he was a little concerned about the equally rapid introduction of sludge to a digestion tank in this case. Obviously the precise method of operation had to be taken into account, but he could only assume that one tank only was charged at a time, and therefore that the rate of cold raw sludge addition would be some 10 times greater than that of the circulating sludge. The very short time for filling might seriously detract from the attainment of a constant temperature condition which should be provided. It seemed to him that the aim of producing complete operation of the plant in eight hours might be very expedient from a labour point of view, but he was not certain that it was the ideal arrangement to produce the most efficient digestion.

116. On the same subject, he would like to know whether or not any system of automation had been considered for the de-sludging of sedimentation tanks, so that something like a 24-hour supply of sludge to the digestion plant could be brought about. If that were possible, the conditions of digestion and maintenance of a steady temperature would be almost ideal.

117. On the constructional side, it was noteworthy to read that there had been a considerable economy in steel by the use of prestressed concrete. When he looked at Fig. 17 he wondered whether or not the same sense of economy had been applied to the design of the tank floors where it appeared that very heavy reinforcement had been placed. He was a little at a loss to understand why this was so and perhaps the Authors would give further details on this subject.

118. His last comment concerned the mounding of the tanks. There must have been quite a problem here due to the form of construction of the tanks, the operating galleries and control chambers, all of which constituted an obstruction to the placing of backfill. He felt sure that with the relatively light barrel construction of the tank walls this must have been a matter of some concern. Would it be true to say that the levels had been built up consistently all round the whole of the 16 tanks and had some form of selective filling been provided for this purpose, having in mind the possibility of slips and differential loading which might take place?

Mr G. D. Allison (Chief Engineer, Preload Limited) observed that his predominant interest in what was an excellent Paper was in the design and construction of the prestressed concrete walls of the digestion tanks. The juxtaposition of the tanks and the control chambers, shown in plan and section in Fig. 3, had been planned in detail for reinforced concrete construction of the tank walls as well as the chambers. In the design of the prestressed walls great complications arose owing to the necessity to adapt the design to the established layout. Similarly, the complication of the circumferential prestressing operation, due to the arrangement of pipe entries and bulkheads through the walls, was very evident from Fig. 8. Perhaps the Authors would agree that for any future installation of a similar type it would be most desirable at the outset to decide on the use of prestressed concrete tanks, so that the overall layout plan and the details of pipe entries and other essential penetrations into the tanks could be worked out to meet the needs of the structural medium as well as the operational requirements.

120. An example of adjusting detail design to the structural medium was given in § 60. The internal corbel shown on the reinforced concrete design had been found to be objectionable in the prestressed concrete design, for constructional rather than design reasons. After discussion with the Authors a perfectly acceptable alternative had been adopted, as there described.

121. In § 54 it was stated that the margin of economy of the prestressed concrete design had been reduced because of "the Board's insistence on the requirements of the Code of Practice and other details". He hoped the Authors would not object if he reversed those two criteria in order of significance. The original design met the essentials of the Code of Practice, and the few adjustments required to comply with the letter of the Code would not have resulted in any significant increase in cost. The Authors, however, had produced ambient temperature range figures which he had regarded as

somewhat extreme, having regard to the conditions usually obtaining in England, and these, coupled with the interesting value of Young's modulus mentioned in § 63, substantially increased the differential stresses to be offset by vertical and circumferential prestressing.

122. In presenting the Paper Mr Gardner referred to the failure of a similar type of tank at the Owl's Head sewage works at New York. That occurrence had been exhaustively investigated, and he thought it was true to say that there was undeniable evidence that it was a simple case of corrosion resulting from a most unfortunate piece of constructional design. As Mr Gardner had said, no such structural features existed in the Minworth tanks, or in any others of which Mr Allison knew in this country. He believed that a report would be issued by the Cement and Concrete Association.

123. Although the constructional side of the sludge digestion tanks was his main interest, he had over the past years been concerned with the design of a large number of such tanks, almost all of them to different proportions, and he was left wondering why the proportions were so different between one group of tanks and another and why there was such a big difference between the practice in this country and that in Germany, for example. Five years ago he had had the pleasure of seeing in Berlin a large battery of sludge digestion tanks being erected which were totally dissimilar to anything that he had ever seen in this country, and he understood that the Germans were continuing to build them in that way. The tanks looked like elongated eggs with very sharp points at the base and the height was at least twice the internal diameter. He had asked the German chemist in charge of the work why they built their tanks in that way, because the cost must be much greater, and he had been told "Our chemists say that this is how they should be built, and it does not matter what they cost". Was that the right approach to the design of sludge digestion tanks?

Dr S. H. Jenkins (Chief Chemist, Birmingham Tame and Rea District Drainage Board) thanked the Institution for inviting him to take part in the Discussion, though as a chemist speaking to an audience of civil engineers he now began to appreciate the feelings of Daniel.

125. Although Mr Gardner had made it abundantly clear in presenting the Paper that the plant described was working at half load, and therefore might be expected to give excellent results, it was worth drawing attention to a number of operating features which were of general interest. To begin with, it was interesting to know that the sewage sludge which was undergoing digestion in the Minworth plant already contained about 1.6% of the metals copper, chromium, cadmium, nickel, zinc and lead, and it was extraordinary that in the presence of such a high content of metals digestion producing satisfactory results was taking place. They knew from work which they had done in their laboratories that if such metals were added in a soluble form to digesting sludge the process either ceased altogether or proceeded at a very reduced rate, and so he concluded that these metals must be present in some insoluble form. They had confirmed recently that when most of these metals were added to ordinary domestic sewage a very considerable precipitation took place. It was comforting to know that they remained in an insoluble form and were therefore unable to exert their inhibiting effect on the bacterial action on which the success of digestion depended.

126. It was also interesting to know that the sewage sludge contained about 4% of iron, derived from metal pickling processes in the district. This had the effect of removing almost the whole of the sulphuretted hydrogen from the gas. Whereas domestic sewage sludge after digestion gave rise to a gas containing about 0.05% of H₂S, in the gas produced on the Minworth plant the content of hydrogen sulphide was only 0.00001%.

127. All those who were familiar with the digestion of sludge, whether on a very small scale in bottles in the laboratory or on a large scale, knew that separation of liquid took place during the process. The liquid was euphemistically known as alkaline water, but it might be a black liquid with a considerable amount of suspended matter. After

the removal of the suspended matter the liquor might still contain 10 times as much ammonia as was present in domestic sewage, though the amount of oxidizable matter might be no more than was present in sewage. Nevertheless, it was very important to ensure that when such a liquid was returned to the sewage inlet for further treatment mixed with the sewage it was returned at a strictly controlled rate and preferably after it had received additional settlement or digestion in secondary digestion plant.

128. Separation of such liquor had occurred on perhaps an unexpectedly large scale in the sludge digestion plant at Minworth. When one of the tanks had been under close observation for a period it had been found that although the crude sludge fed to the tank contained 5.9% of solid matter, in the upper part of the tank it was estimated that there was 13 ft of sludge liquor with only 1.1% of solid matter, whereas in the cone it was estimated that there was 7 ft of sludge with 8.5% of solid matter. In the remaining 11 tanks, which had not been under such close examination, it was concluded that there was only 0.8% of solid matter in the upper part of the tank, whereas in the cone there was 9.9%.

129. The effect of such separation of liquor might have very important operational consequences. That was demonstrated by a test which had been carried out over a period of a month. During the first half of the month more sludge was removed from the cone of the tank than from the upper part, and the gas yield obtained was about 11 000 cu. ft/day. When that procedure was reversed and more of the liquor was removed from the upper part of the tank than from the cone, the gas yield in the next fortnight rose to 30 000 cu. ft/day. It was possible, therefore, by the wrong operation of a digestion tank to withdraw so much of the dry matter from the tank that the gas yield would seriously fall. They had calculated that the rate of gas yield was equivalent to the evolution of about $\frac{1}{3}$ cu. ft of gas per sq. ft of tank surface per hour, and that was about $\frac{1}{230}$ th of the rate at which air was diffused through a diffuser plate in an activated sludge plant. From this they concluded that it would be very difficult to depend on the rate at which gas was evolved in a sludge digestion plant in order to maintain the circulation or prevent the separation of an aqueous layer.

130. Finally, he would like to draw attention to the scum, to which Mr Gardner had already referred. This 5-ft layer of scum had 25% of solid matter, an extraordinarily high content of solid matter for any sludge, yet its density was only 0.93 relative to water. On analysis it had been found that 35% of grease was present in this scum; more detailed analysis had shown that the whole of this grease was mineral oil, in addition to some soap that was present in the scum. He wished, therefore, to draw attention to what he regarded as an increasing problem in sewage disposal, the admission of oils in one form or another, and particularly in the form of cutting oils, which, if present in amounts sufficient to separate out into a mineral oil layer, could have an effect on treatment processes. In any large industrial area the separation of scum was inevitable during sludge digestion, and on the basis of their experience up to date it was likely that a considerable part of this scum would consist of mineral oil.

Mr E. H. Vick (Chief Engineer's Department, London County Council) congratulated the Authors on having prepared an extremely interesting and valuable Paper, dealing with one of the largest sludge digestion plants in the country and one using a form of construction which was quite novel.

132. As an engineer concerned particularly with sewage disposal, he would have welcomed more information on the functional aspect, and particularly on operational experience and results, because it was from these that others could learn. Some further information had been given in the discussion by Dr Jenkins and Mr Gardner. No doubt structural engineers would like to have more information on the structural side.

133. It was strange but true that the London County Council had built at its Northern Outfall works a sludge digestion plant of almost exactly similar capacity to that at Minworth and at almost the same time, without any prior consultation with Birmingham.

The plant had been commissioned in the autumn of 1959. He had some operating results of this plant which he proposed to use to point to the possible effect of differences of design of the two plants, but the real effect of those differences could be judged only if the actual performance of the Minworth plant was known. He hoped that the Authors would be able to give some information about this.

134. The plant at the Northern Outfall had 16 primary tanks of 16·8 million gal. capacity and four dewatering tanks, which could be converted to primary digestion tanks of 4·2 million gal. capacity. The size of the plant was almost the same as that of the Minworth plant, but there were very distinct differences.

135. All London's sludge was finally disposed of by loading it into ships and dumping it at sea, the cost of this being about 3s. 0½d. per wet ton. The object of digesting the sludge was twofold, (a) to reduce its volume and therefore the cost of conveyance to sea, and (b) to provide fuel to give a net saving over the cost of importing power. For London, the provision and operation of a digestion plant would have been uneconomical unless both those factors had operated.

136. At Birmingham, apparently, no power would be obtained from the digestion plant for some years and the old facilities for disposal would be available for a similar period. Why, then, had the need for the digestion plant become so pressing, as stated in § 8? Would the financial saving that it afforded in disposal of the sludge be greater than the cost of debt charges and operation during the years before power was generated and the old works abandoned?

137. Reference was made in § 10 to facilities for cleaning tanks. The bottom slope seemed reasonably steep at 30°. How often was cleaning expected? Owing to the considerable amount of groundwater at the L.C.C. works the bottom slope had been made at 8° to the horizontal to avoid the expense of deep hoppers. On laying off a tank after two years running and draining down from the bottom, a light scum about 12 in. thick had been found deposited on the bottom. This, with any sand which might have been underneath it, had been readily washed out with hoses and without other hand labour. He expected in future to lay off tanks for cleaning at about 5-yearly intervals. What was the Birmingham practice?

138. In § 11 it was stated that a digestion period of one month was desirable for adequate decomposition of the organic matter. This seemed rather long. What did the Authors mean by "adequate"? Presumably, since gas was not used for power, this period was necessary to condition the sludge for final dewatering. What criteria had been taken in assessing the period?

139. The L.C.C. plant was at present working on a 21-day digestion period, with a gas production of 3 million cu. ft/day. Reduction of this period—i.e., increase in the rate of passing sludge through the tanks—tended to cause foaming. He would like to know of any experience obtained at Minworth on the causes and prevention of foaming. The London tanks were 80 ft in diameter and slightly shallower on the average, allowing for the bottom cone, than the Minworth tanks. A recent average of daily gas production, when only 15 tanks had been working, was 2·86 million cu. ft. The water content of the sludge entering the tanks was 93·4%. Comparative figures of gas production were for Minworth (estimated) 0·336 cu. ft/day/cu. ft tank capacity and for London (actual) 1·135 cu. ft. Even allowing for the drier sludge in the London plant and the 50% longer digestion period at Minworth the discrepancy was still notable. It would be interesting to know what the actual gas production at Minworth was, and the analysis of the sludge solids. The analysis of the sludge going to the digesters at Northern Outfall showed 6·8% solids, of which 73% was organic matter, including 20·3% petroleum ether extract. The corresponding figures for digested sludge before final dewatering were 4·1% solids, 61·0% organic and 8·2% petroleum ether.

140. In Appendix I to the Paper the gas storage capacity was given as 700 000 cu. ft, which on the design figure of 1 030 000 cu. ft of gas per day would provide for over 16-hours production. Even with large variations in rate of gas usage that would seem a very generous storage. Since, however, the crude sludge, and he would assume the

circulating sludge also, was introduced into the tanks at 5 ft below water level, it would seem that the rise and fall of the gasholders could not exceed about 4 ft, allowing for the seal, in which case the effective storage would be only about 330 000 cu. ft for the 16 tanks. He would welcome the Authors' explanation, because the effective storage was the important figure.

141. While on the subject of gasholders he would like to mention a device in the gasholders at the Northern Outfall, which was also being used for the digestion plant now being built at the Southern Outfall, for maintaining a uniform level in the rise of the gasholders. The device (Fig. 12) consisted of an annular trough incorporated in the gasholder skirt which rose and fell, of course, with the gasholder. The trough was filled with sludge and topped up each time the gasholder moved to a lower position.

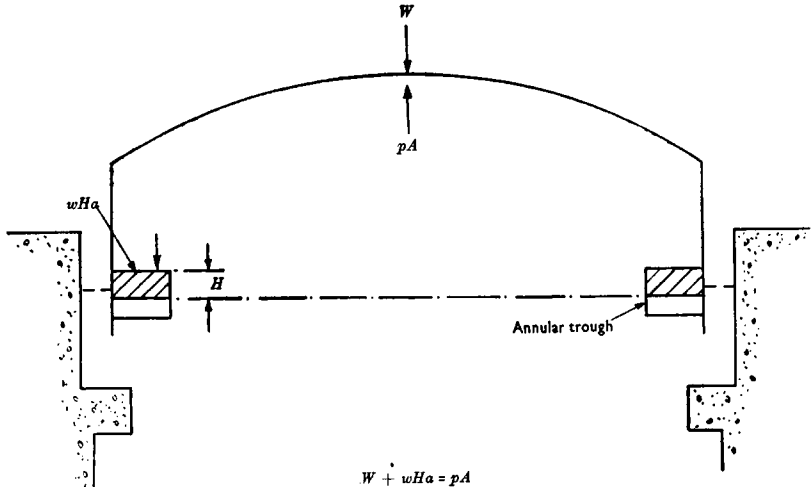


FIG. 12: NORTHERN OUTFALL WORKS, LONDON COUNTY COUNCIL, ANNULAR TROUGH TO GASHOLDERS

As the gasholder rose the trough, with its sludge, rose out of the body of the sludge in the tank and correspondingly increased the flotation weight of the gasholder. As soon, therefore, as the trough began to emerge from the body of the sludge any increase in height of the gasholder must be accompanied by a corresponding increase in gas pressure. In the first $3\frac{1}{2}$ ft of rise from the stops the trough remained submerged, so that for this distance the pressure remained, for practical purposes, constant at 5 in. w.g. As the holder continued to rise the gas pressure progressively increased to a maximum of 8 in. w.g. As the gas draw-off pipes were connected to a common main, the pressure equalized throughout and the gasholders travelled up and down at a uniform level. This was not to make them look pretty but to prevent the blowing off of gas from under the skirts.

142. Having been a member of the Institution Committee on safety in sewers and at sewage works, if time permitted he would join issue with Birmingham on their safety precautions, but the new Code had not been issued yet. With regard to the safety devices listed in § 66, he would like to know what form of gas leakage detector was used on the Minworth plant and whether or not it had been satisfactory in operation. His Council had tested various detectors, the two most satisfactory being the Ringrose detector and the Spiralarm lamp. The former, however, suffered from the disadvantage that it required to be checked each day for satisfactory operation, which also made it

necessary to site it in an accessible place. The Spiralarm lamps were completely reliable but frequent changing of the battery was necessary.

143. The description of the commissioning process given by the Authors was very short and he would like to hear more about it. Commissioning digestion tanks could be dangerous. There was not only the initial starting up to consider, when everyone was on his toes to avoid an accident; with a plant comprising 16 tanks, restarting after cleaning became a fairly frequent occurrence and familiarity might breed carelessness. Perhaps the Authors would say what instructions on safety precautions had been issued to their operators. Explosion risks could be almost entirely avoided if the tanks were purged of air with an inert purging gas before methane was generated. That had been done in commissioning the Northern Outfall plant.

144. Sludge circulation in the Minworth tanks was done by withdrawing it at a depth of 16 or 24 ft below the surface and, after heating, returning it at 5 ft deep. Why had this direction of flow been adopted? At Northern Outfall, circulating sludge was drawn off as closely as possible below the corbel supporting the gasholder stops at 10 ft below highest sludge level and returned at about 23 ft below surface in a tangential direction to give rotational motion to the sludge, the object being to provide good mixing. It was thought that this feature might have a large bearing on the high performance of the plant.

145. So far as it was possible with the figures available, he had compared the costs of the Minworth prestressed primary tanks and London's plain reinforced concrete ones and found that for civil engineering work only the costs were almost identical at £33,000 per million gallons capacity.

Mr A. W. Shilston (Messrs J. D. and D. M. Watson) expressed particular interest in § 11 of the Paper. He believed that the works operated by the Board at which heated sludge digestion was employed were those at Yardley and Coleshill. The former dealt with sewage from a largely industrial area and the latter with a predominantly domestic sewage. The Authors stated that sludge from Yardley would be treated in admixture with other sludges at the new Minworth sludge digestion plant, and it would be reasonable to assume that the works under discussion would deal with sludge containing a large trade waste element.

147. Reverting to § 11, a desirable average digestion period for sewage sludge might be influenced by one or more of the following factors:

- (1) The desirable level of gas production for power utilization purposes.
- (2) The limiting daily sludge feed rate to prevent upsetting the equilibrium of the digestion process, once successfully established.
- (3) Difficulties in obtaining a satisfactory level of destruction of organic and volatile matter, by reason of trade wastes in the sludge which might inhibit digestion agencies.
- (4) The degree of prolongation of digestion required to render the digested sludge amenable to water separation, either in the so-called secondary digestion stage or in a sludge-drying process.

148. He would like the Authors to expand on the reasons underlying the statement in § 11 with regard to the design detention period, particularly in relation to the appreciation that must have been made of the influence of trade wastes on sludge digestion.

149. He wished to refer to a subject which rarely received attention in discussions of this kind, the mundane subject of billing. From Fig. 12 it would seem logical to bill the excavation for the whole of the tank area to a general formation level of about 224.25 (that level being apparent in Section AA of Fig. 3) and then measure separately the excavation for the hopper bottoms of the 16 tanks. The strictly correct method, however, would be to measure the individual structures—the tanks, the control chambers and the subways—to obtain their respective plan areas and to bill the relevant excavation items for each structure separately. That would probably make the estimator's task

more irksome, as almost inevitably in this instance he would build up his excavation rates on the basis of massed excavation over the whole tank working area to a general level, excluding the hopper bottoms. There could be dangers in presuming a method of construction in billing and in departing from strict procedure, but in the case of a scheme such as this it might be tempting to depart from orthodox procedure and adopt what seemed to be a commonsense approach. With their experience behind them, what method of billing an excavation for the tank area would the Authors recommend for a repeat job?

150. Reference was made in the Paper to various pumps for dealing with sludge. What gland sealing arrangements had been adopted to mitigate the tendency of grit in sludge to cause excessive spindle wear? Finally, referring to the preparation and painting of the steelwork in the gasholders, was the plate prepared for painting by pickling or grit blasting? What painting sequence had been adopted, both inside and outside?

Mr E. C. Kottler (Director, Kottler & Heron Ltd) said that there were only two points in what was a very interesting and comprehensive Paper on which he wished to enlarge, namely the multiple layer winding for circumferential stressing and the use of galvanized wire for prestressing by the Preload method.

152. Multiple layer winding was adopted when the design requirements for the horizontally stressed wire exceeded 24 turns of 0.177-in.-dia. wire per ft. In the case in question they had used multiple layers of wire to ensure that the spacing was such that the gunite protective coat could be applied between the wires and the wire layers. In practice they found that this was not difficult because of the ease with which the wire-winding machine could be moved to any position on the tank quickly. Multiple layer winding was also sometimes required where it was necessary to accommodate large diameter pipes passing through the wall and it would be necessary to wind above or below the pipes, as opposed to using the bulkhead frame type of cover illustrated in the Paper.

153. The use of galvanized wire was referred to in § 102. One reason for its use was that with this protected wire there was no storage problem under site conditions and therefore no question of re-drawing rusty wire. Another and equally important reason was that once wound on to the wall, if the tank could not be tested for some time and, for reasons explained in § 104, the gunite protective coat could not be applied, the wire would not rust, so that when it was protected by the gunite it was in a sound condition, having had a stringent test first by re-drawing and then by being zinc coated.

154. Their tests on galvanized wire had proved very satisfactory at Minworth and they had had hardly any teething troubles whatever. They had been to a large extent assisted by the fact that this was standard works practice and it had been mainly a question of converting works practice into site practice. They had subsequently adopted this for all their circumferential stressing work and had successfully drawn nearly 100 tons.

Mr Eric Ingerslev (Consulting Engineer) referred to the fact that the tanks at Minworth had a conical bottom and said that recently digestion tanks had invariably been so constructed, but there seemed to be some variance in the conception of for what such a bottom should be designed. He had seen such bottoms designed down to 5 in. thickness with only a single layer in the centre. He understood that at Minworth the bottom was 15 in. thick, with $\frac{3}{4}$ -in. bars top and bottom. He would like to ask the Authors what basic assumptions underlay their choice of this particular bottom and whether or not they took into account such things as differential settlement, which did not affect the flat bottom but very much affected the cone. Did they have any special regard to shrinkage, inasmuch as the bottom was concreted in continuous rings without any gap or other provision for shrinkage to take place? Finally, had the bottoms as constructed proved satisfactory?

Mr C. B. Townend (Consultant, Rofe & Raffety) felt that the discussion would not be complete without some mention of the outstanding work of the Birmingham Drainage Board in the early years of the century in the evolution of the sludge digestion process, which had since made such enormous progress throughout the world. Indeed, the process might be said to have reached its jubilee in 1961, because, following earlier experimental work in the period 1905–10, Birmingham in 1911 had taken the courageous step of changing over completely to digestion at their main works, where the whole of the sludge from a population of about one million had been dealt with in this way continuously for 50 years. That Birmingham plant had, of course, been the first of its kind in the world.

157. Ten years later, in 1921, it had been Birmingham again which operated the first experimental gas engine running on methane gas from the digestion process. This had led to the installation of their larger power plant from 1927 onwards, progressing in the late 20's to increased efficiency of operation by improved design with the application of higher temperatures, and eventually coming to the fine plant described in the present Paper. As one who had been present at its inauguration by the Minister of Housing and Local Government in 1961, he could confirm that the guests including many ladies had been most impressed by the plant, but even more by the fact that a fine tea had been served underground in the palatial chambers between the digestion tanks, surrounded by vast quantities of digesting sludge. That was a tribute to the efficiency of a modern plant.

158. On the question of design, it was noteworthy that the three largest digestion plants in this country—(a) the new plant at Birmingham, (b) the Northern Outfall plant of the L.C.C. completed about three years ago, and (c) the Mogden plant which had been in operation since 1935—were all of the same order of size and all were based on 16 tank units. To provide sufficient flexibility of operation, it would not be necessary to have more than say six units. For these large plants, however, the controlling factor was the limiting economic size of one unit. For the three works mentioned, the units all had more or less the same dimensions—a depth of about 32 ft and a diameter in the range of 70 to 82 ft. Thus different designers at different dates seemed to have arrived at the same economic solution; but in Germany the trend in recent years had been towards much deeper tanks of 60 ft depth or more, though of smaller diameter. Depths of this kind would have been out of the question when the modern type of circular tank was being developed for Mogden 30 years previously, but greater depths had advantages in several directions, such as the smaller size of gasholder area and ease of sludge circulation; the operational requirements of the digestion process seemed to be vertical rather than horizontal.

159. Mr Gardner's mention of a burst main on the new plant took Mr Townend's mind back over 40 years to the Saltley Works at Birmingham where, as a new boy engaged on construction work, the first thing impressed on him by the works foreman was "Don't leave any sludge main bottled up by all the valves being shut, or the whole thing will blow up". That had quickly taught him that digestion would proceed at pressures at least of 600 ft head at which the heavy cast-iron pipes had been tested; for that reason, he had never been frightened of large tank depths so far as the efficiency process was concerned.

160. It was easy to appreciate the difficulties, recounted by Mr Daviss, that had been met with in estimating the ultimate amount of sludge to be dealt with by the new Birmingham plant, but nevertheless Mr Townend felt that the present basis of design was very conservative with a detention period of 30 days and the low estimated gas yield of 0·8 cu. ft/head. The capacity of the primary stage at Mogden had never been more than 20 days; that period had been adequate for very many years without any trouble. As the population increased it had been finally reduced to about 14 days, and even at this point it was still reasonably satisfactory, provided operations were watched very carefully. However, he thought 14 days was too low to give a safe margin in continuous operation, but twenty days should be adequate unless inhibitory trade wastes

were particularly unfavourable. He felt that the Birmingham estimates had been based on their experience with shallower horizontal tanks with inlet at one end and outlet at the other, which he considered were not so efficient from the point of view of sludge circulation and other process factors as the vertical type of tank. It would be very surprising if Birmingham did not obtain very much improved results from the new tanks; indeed, Dr Jenkins had mentioned a few points of importance in that respect. As he had said, a large amount of very liquid sludge would be found to accumulate just above the cone which if removed would lead to increased efficiency of the plant. It appeared that the emergency suction already provided (§ 21) was in a position suited to this purpose and could thus be used for such a routine operation. The Mogden plant had always been operated in that way with very good results.

161. The Authors had, of course, recognized the possibility of improved results in § 109, where they said that "The intervening years should provide more accurate information than is at present available for assessing the sludge digestion capacity required". Everyone would wish them well in this operation.

Mr W. H. Meredith (Senior Engineer, Howard Humphreys & Sons), on the question of costs, said that from the figures given by the Authors it seemed that the civil construction costs of the plant were equivalent to £54 000 per 250 000 cu. ft. It might be of interest to compare that figure for the cost of a primary sludge digestion plant with the cost of a similar plant of the same pattern but of less magnitude and so obtain an idea of the very material saving which resulted from large-scale construction. He had recently been concerned with a primary sludge digestion plant which consisted of four 50-ft-dia. tanks of conventional reinforced concrete construction, grouped in the same pattern as the Minworth tanks with a covered double-tier central control chamber and pipe gallery, and having an effective capacity of 250 000 cu. ft. In general they could be said to be of the same pattern as the Birmingham tanks. It was interesting to note that the construction costs worked out at something like £70,000 per 250 000 cu. ft. as compared with £54,000 for the Minworth tanks. It would perhaps be of interest to take the comparison even further and establish what further savings could have been made on the Minworth scheme with eight larger tanks. There might have been an even bigger saving than that which he had shown.

163. In § 48 reference was made to a flame trap with explosion relief lid. He had recently had cause to query this type of flame trap, which he believed had been regularly used in digestion plants for the last 20–30 years. It was perhaps more suited to open conditions than to an enclosed area, as in the control area in digestion tank chambers. The Authors might be interested to know that the National Gas Board had recently developed, and it was now available, an element which would function satisfactorily in a flame trap without recourse to a relief lid. He believed that this represented a considerable step forward in safety measures.

Mr J. A. Forrester (Chemist, Cement and Concrete Association) commented on the statement in § 70 that ordinary Portland cement (O.P.C.) concrete had not been used in the core-wall because of the possibility that steel placed at the interface of concrete made with O.P.C. and sulphate resisting cement (S.R.P.C.) would corrode and said that he saw no reason why this should happen. If two cements had been used there would have been a saving of about 3% of the cost of the prestressed concrete, so some economic advantage would have been gained.

165. Occasionally concern has arisen that the difference in electrical potential between steel and two concretes made with dissimilar cements give rise to anodic areas in the steel which can cause corrosion. For this concern to be justified some consideration of the composition of the solution in which the steel is embedded is necessary.

166. Work done by the Cement and Concrete Association and elsewhere on the composition of the solution in hydrating cement suggests that it is impossible to pick out a S.R.P.C. or O.P.C. purely on the basis of the ions in solution after 24 hours.

The range of compositions of solution from O.P. cements from various sources is wide enough to cover solution compositions from S.R.P. cements.

167. There is therefore as little chance of trouble using steel at the interface of concrete made with S.R.P.C. and O.P.C. as with steel at the interface of concrete made with two sources of O.P. cements, provided that the quality of the concretes is good, the aggregate used in each is of a similar type and that calcium chloride is not used in one of them.

The Chairman (Mr J. A. Banks) said that most of the matters he had in mind had been dealt with in the course of the discussion and two speakers had made some reference to elements of comparison in costs. In § 53 it was stated that when tenders had been invited the tender documents had been so framed as to obtain alternative tenders for design and construction in normal reinforced concrete and in prestressed concrete. It was true that the normal reinforced concrete job had not been executed, but it was of some importance to engineers who were faced with works of this kind to have if possible some comparative figures to show the order of economy that could be achieved by using a prestressed structure as compared with one in reinforced concrete. The specification had subsequently been altered to some extent so that the tender figures in themselves did not apply, but notwithstanding that it would be of interest to have a figure of percentage saving for general guidance.

The following contributions were received in writing:

Mr B. Storch (Technical Advisor, Chicago Pump company) wrote to say that he wished to further Mr Townend's remarks on capacity sizing and ask whether the Authors had considered using gas recirculation as a method of reducing the capital costs of construction of the digesters. The capacity saving was brought about by the gas giving complete mixing to the contents of the digester with the result that the bacteria were able to work most efficiently. Furthermore, since there was continual mixing the contents were completely homogeneous so that there was no chance of scum being formed and so no allowance need be made in capacity for such accumulations. The capital costs of tank emptying and cleaning equipment would be saved since periodic cleaning was unnecessary and a 5° slope to the floor was sufficient to allow any grit that fell out of suspension to be swept by the circulating contents to the centre for draw off.

170. This was by no means a new process, for in 1954 Professor Morgan of Iowa University in the United States of America reported that in laboratory and pilot plant experiments lasting more than four years, sewage sludge could be digested at loading rates of 0.345 lb of volatile solids per cubic ft of digester volume and at tank displacement periods of 7.2 days. Since that time, this process, modified for general practice to loadings of 0.2 lb volatile solids per cu. ft per day and known as C. R. P., had been used very successfully in many sewage works throughout the United States with a resultant tremendous capital saving in the works concerned. The cost of the equipment was small as it simply consisted of a gas compression plant and diffusion equipment built on the floor of the digester.

171. To demonstrate the possible savings, considering that the 16 digesters would cost £800,000 and by using C.R.P. at the above 0.2 lb loading, only 10 instead of 30 days storage would be required, one could say, then, that the cost of the digesters was £270,000. The cost of the gas diffusion equipment would be about £2500 and the licence fee for using the process would be £7500, this being equivalent to 1.5% of the savings for this size of plant.

172. If one assumed six 60-ft-dia. digesters, the total gas circulation would be 360 c.f.m. against a head of 40 ft. This would consume about 240 000 units per year and if bought from the grid would be about £1500. Taken over a 30-year period and assuming that repayment charges equalled the capital costs, the cost of the 30-day design amounted to £1,600,000 excluding recirculation pumping costs and periodic emptying

and cleaning. The C.R.P. system would amount to £605,000 including capital and gas recirculation costs and not requiring the regular maintenance, for there was no scum or silt to be cleaned out. This latter point would be, of course, a relief for the operators, and the saving of a million pounds a relief to the financial department.

Mr L. R. Creasy (Superintending Engineer, Ministry of Works) wished to raise two points arising from the thickness of the base slabs of the prestressed tanks and the procedure used for casting them. In this latter respect it was important to arrange a casting sequence so as to minimize shrinkage effects.

174. In casting the walls of a cylindrical tank it was common practice to cast them successively in complete rings. In such a case movement from circumferential shrinkage was transformed into a radial movement which was relatively unrestrained—thus avoiding shrinkage cracking.

175. That procedure seemed quite wrong when applied to the base slabs which were flat or nearly so forming a conical base. The radial movement was restricted by the supporting subsoil and any movement to shorten the diameter must be restrained by the inner slab previously cast. The last objection could perhaps be overcome in a flat slab by casting in annular rings from the periphery inwards. It could hardly be followed in a conical base.

176. In such cases the most efficient procedure would seem to be to cast the slab in segments much like the sections of an orange. The maximum dimension of each unit would then follow the Code recommendations of about 20 ft and they could be cast alternately as a further precaution if necessary.

177. The required thickness of the base slab seemed to depend on the practical minimum for the efficient compaction of the concrete rather than any capacity for water resistance. It could be shown in the laboratory that quite thin slabs were able to resist the penetration of a water head much greater than is normally met in practice.

178. Where the subsoil is firm many successful tanks have been built with a thickness of base slab of 6 inches, but perhaps this might be increased to 9 inches to simplify the compaction of the slab by vibration techniques.

The Authors, in reply, said that Mr Dainty had asked why the generating station had not been built at the same time as the sludge digestion plant. The supreme urgency of building the sludge digestion plant was that the plant at Saltley had silted up. They had tried to dredge it out, but the cost would have been prohibitive, and they had had a plant already on the drawing-board. That was inferred in the Paper to some extent. The delay in building the generating station had indeed proved fortunate since at the Ministry investigation into their full-scale programme the Board had suddenly been confronted with an anticipated additional 30 m.g.d. dry weather flow to the new works. Had they gone ahead with the generating station the Board would have been even more restricted than they now were in siting the enlarged new works, because the new generating station would probably have been too small in capacity and would certainly have been inconveniently positioned.

180. Mr Dainty also mentioned remote control and its effect on labour. The actual operation was carried out by three men for this plant, two working from 7.30 to 4.30 and one from 11.30 to 8 o'clock, with one man on Saturdays and Sundays. It would not be safe to reduce the number of operators for a plant of this size below that limit.

181. The level of the inlet pipes had been queried. The intention had been that they should be immersed below the lowest operational level during normal charging. They had at other works tried taking the inlet pipes above top water level in order to break up the scum, and one works superintendent had objected to the procedure on the grounds that the sludge was thereby being aerated.

182. Mr Dainty referred to the effect of rapid charging on the maintenance of a uniform temperature in the tanks. It had been found that the temperature drop brought about by charging was approximately 5° F which was usually fully recovered

within 24 hours. There was no evidence that this adversely affected the performance of the tanks.

183. Automation was being considered at the present time with the new sedimentation plant and it was intended to use magnetic flowmeters and sludge density meters of the radio-isotope type, but it was not possible to expand on that at the moment.

184. The apparently heavy reinforcement in the tank cones had been mentioned. The design had been based on the normal procedure, taking the hanging load from the footings and the bursting stress circumferentially. The cones were designed on the assumption that there might be bad ground below the cone and good ground under the actual peripheral footings. A design had been got out for the complete hanging load, but had been found impracticable and unrealistic. The cones had consequently been designed to carry only 25% of the hanging load; the rest was carried on the ground beneath the cone, and the Authors did not think that it would be advisable to reduce the reinforcement to a greater extent than that.

185. In backfilling some attempt had been made to balance up the backfill by limiting the variation in levels at any particular point to 4 ft. This did not apply so critically to the tank walls themselves as to the very tall subways, where it had been essential not to allow the contractor to build up the ground on either side with a greater variation than that stipulated. It had probably been the conditions at the subways which had caused them to keep a general balance of fill.

186. Dr Jenkins and Mr Kottler had both made most valuable contributions to the discussion which added considerably to the information contained in the Paper.

187. Mr Allison asked whether or not it would be desirable to bear in mind prestressed concrete tanks when designing the job. It was highly desirable, but there was a limit to what could be done, since many of the factors at Minworth were related to the type of construction and the system adopted and might not affect all types of prestressing. There was a limit to what could be done unless one restricted oneself to one particular type of prestressing. With regard to the Code of Practice, since the process and the system had still been relatively new in this country at the time the decision was made the Authors thought that the Board's inclination to be conservative had been correct.

188. The question of the variation in the type of sludge digestion tank used had been raised by Mr Allison and other speakers. Probably up to now the British designers had favoured a simplified approach to tank design which was obviously more economical, and which had proved so far as the Board was concerned a most satisfactory arrangement. No doubt if the German type of tank were proved to be more efficient and economic authorities such as the Board would follow the German example.

189. Mr Vick's comparison of the L.C.C. and the Minworth tanks was very interesting indeed. The L.C.C., as he had hinted, were very lucky in being able to put the sludge which they did not require into barges and take it to the North Sea.

190. Mr Vick had asked for details of the performance of the plant. The Authors in introducing the Paper had tried to explain that detailed information, which may be used for comparison with similar plants operating under normal conditions and to full capacity, would be of little value at this stage and could be misleading.

191. Until the solids now escaping at Saltley, Ashold, Tyburn and Yardley were contained by the new sedimentation tanks to be built at Minworth the capacity of the plant would be unrealistically high. Furthermore the bulk of the primary sludges received at present had already been partly digested at Saltley, for reasons previously explained. In consequence the present method of operation did not lend itself to a proper assessment of the efficiency of the plant.

192. If the figures given in the "Report of an informal working party on the treatment and disposal of sewage sludge" might be taken as a basis for comparison then the percentage of organic matter destroyed was at present, on average, low. This might be explained by the fact that a large proportion of the residual organic matter was mineral oil and other inert matter and would therefore not be easily destroyed. The

gas yield per lb. of organic matter added was normal, and the gas yield per lb. of organic matter destroyed was good. However, the present method of operation hardly justified these figures being taken as a guide for the future and of considerably greater interest were the facts given in Dr Jenkins' contribution.

193. The pressing need for a new digestion plant was brought about by the silting up of the Saltley plant as mentioned in the reply to Mr Dainty. The capacity at Saltley was no longer even sufficient to ensure prevention of nuisance to the neighbourhood. It so happened that some of the present excess capacity at Minworth, viz. two of the open reception tanks, had proved most useful and efficient in dewatering the secondary sludges from that works. As a result the old dewatering tanks, which had to be demolished to make way for the new sedimentation tanks at Minworth, could be dispensed with at an earlier date than was originally anticipated.

194. The digestion period of one month had been questioned by Mr Vick as being too long. The working party report already referred to suggested a period of between 28 and 30 days. On account of the presence of inhibiting trade wastes in the Birmingham sludge it was not the Drainage Board's experience that such a period is excessive in their case.

195. Although the gas would be used for generation of electricity, it was not expected that there would be enough gas for all the power needs and power would have to be taken from the grid for the new oxidation plant.

196. It had been expected that at Minworth tank cleaning would have to be carried out once every two years. The first tank had been examined after 2½ years and, as had been mentioned in the introduction, very little silt appeared in the cone. From that point of view the position was quite satisfactory; but it had not been expected that the accumulation of scum would be so great and they would probably for the time being continue to clean the tanks every two years, in order to maintain a check on the scum.

197. The pressure equalizing device mentioned by Mr Vick was most interesting. To equalize the pressure throughout, including the gasholders, there would have to be no reflux valves between the gasholders and the common main. The device would still of course promote the withdrawal of gas from the most favoured gasholders even in the presence of reflux valves. The existence of a common main to some extent resulted in the same object being achieved. At Birmingham the incorporation of reflux valves at this position was considered to be a necessary safety precaution and no great difficulty was in fact experienced in keeping the gasholder levels reasonably uniform.

198. With regard to safety precautions, tests were being carried out at the present time in Dr Jenkins' laboratory on the effectiveness of the Ringrose detector, but the conclusions so far reached were too indefinite for any statement to be made until more information was available.

199. On the commissioning of the plant, it had already been stated that partly digested sludge had been pumped to Minworth from Saltley. Part of the Saltley plant had been set aside prior to commissioning the Minworth plant and during that period sludge had been prepared at Saltley. Subsequently, actively digesting sludge had been pumped into the tanks up to the design top water level. The gas collector had been in its bottom position and gas and air had been expelled through a 2-in. valve in the roof. The valve had then been closed and the collector allowed to rise to the top position as the gas had been evolved. The gas-air mixture had then been discharged through the waste gas burner to atmosphere and the collector dropped to the bottom position. That cycle had been repeated a second time and then the gas had been tested for absence of oxygen by ignition after bubbling through a water tank to prevent blowback. Until the gas burned with a clear blue flame it had been assumed that oxygen was present. They had got this clear after the second attempt, the waste gas burner was lit and the sludge heater finally connected up. This was a method which the Board had used for many years and they considered it to be correct. Furthermore it was always under the supervision of the Board's Mechanical Maintenance Engineer and was not left to the judgement of the operatives.

200. The direction of sludge circulation at Minworth ensured that hot sludge was introduced near the surface in order to give a stirring effect in the region of the actively digesting sludge and cooling sludge was withdrawn as it tended to drop due to convection.

201. Mr Shilston had commented on the average digestion period. That period had been based on the Board's experience over many years and they had no evidence to cause them to reduce it. In any case they required gas for generation.

202. The orthodox method had been used for billing the excavation. The alternative suggested by Mr Shilston had been considered and rejected at that time but in a future job of this particular form it is possible that such a method would be used.

203. For gland sealing on the pumps at the present time the Board used a form of greasy packing but they were trying out a mechanical seal.

204. With regard to the painting of the gas holder steelwork a protective coating of red oxide to B.S.2524 was applied at the Works after removal of rust and millscale by wire brushing and scraping. After erection and testing all internal surfaces were painted with one coat of black bitumen and all external surfaces with one coat of red lead followed by one coat of natural graphite paint.

205. Mr Ingerslev's query regarding the design of the conical bottom to the tanks had been partly answered in the reply to Mr Dainty. It was not considered that with a deep cone of this type shrinkage effects would be very serious. The results had proved this to be true.

206. Mr Townend's succinct résumé of the development of the sludge digestion process and the use of sludge gas for power generation at Birmingham was much appreciated by the Authors who had to sacrifice this historical note when drastically pruning the original Paper.

207. In drawing attention to the Authors' remarks in § 109 Mr Townend had put in perspective the various criticisms of the capacity provided.

208. Mr Meredith's cost comparisons were interesting. The Board were in fact in the process of going out to tender for extensions to their Barston Works where two digestion tanks of 50-ft diameter were to be built. The tender figures should provide a further verification for the cost curve at which Mr Meredith appeared to be aiming.

209. Mr Meredith commented on the flame trap. It had not occurred to the Authors that this was not so effective as it should be and it would be interesting to investigate the Gas Board's new development.

210. Mr Forrester had referred to the use of different types of cement on either side of the prestressing and to what was said in § 70. The operative part of that paragraph so far as the Board's decision was concerned was the last sentence: "In view of the lack of certainty it was finally decided that sulphate-resisting cement should be used throughout on the tanks". At that time there had been no certainty.

211. The Chairman asked about the savings brought about by the use of pre-stressed concrete tanks. The relevant figures were:

Saving in original submission.	£28,000—8·2%
Saving after adjustment of preload design	£10,500—3·1%
Saving after allowance for sulphate resisting cement and bituminous tank coating	£5,000—1·3%

(Based on tender for normal reinforced concrete walls.)

212. It would be seen that although there appeared on the original tender to be a saving of 8·2%, when all considerations were taken into account this was reduced to 1·3%.

213. The choice was not however made solely on economic grounds but was influenced by consideration of the most suitable form of construction for the purpose.

214. Mr Storch in his written contribution demonstrated the savings which he claimed would have resulted from the use of gas recirculation in the process. The matter was being given some thought at the present time. It was as well to recall that

Professor Morgan's report was in fact not published until towards the end of the design period for the Minworth digestion plant and at that time the process had still to be proved on a large scale.

215. Mr Creasy in his written contribution commented on the thickness of the cone slab and the effect of shrinkage. The Board required the tanks to have a deep cone for operational reasons and therefore the structural benefits resulting from the use of a flexible flat bottom were not relevant in this case. The absence of difficulties due to shrinkage had already been mentioned.
