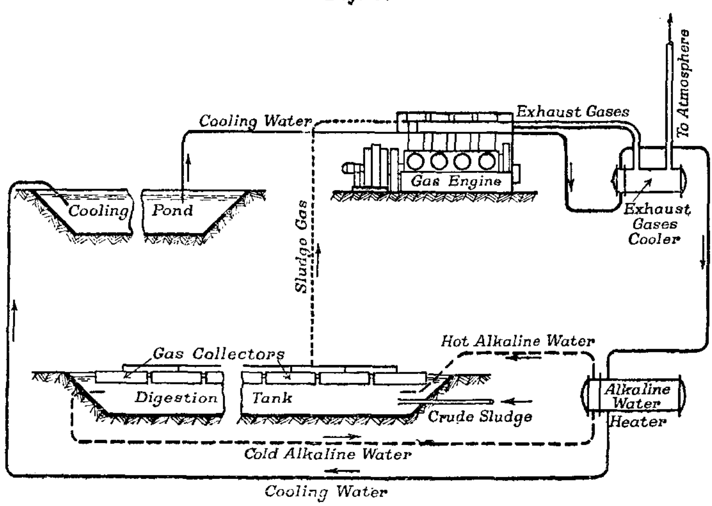
Discussion.

Mr. WHITEHEAD exhibited several lantern-slides, including *Fig. 9*, which illustrated the latest development of the Birmingham sludge-digestion plant. Although 2,400,000 units of electricity had been generated in 1930, no heat was yet being passed from the gas-engines into the digestion tanks. The diagram showed how the waste heat from the gas-engines might best be utilized. Speaking approximately, a gas-engine converted one-third of the heat of the gas into power, leaving two-thirds in the cooling-water and in the exhaust gases. Mr. Whitehead.

Fig. 9.



In the scheme illustrated the cooling-water, after passing through the water-jackets of the gas-engines, was further heated by the exhaust gases. Alkaline liquor from the outlet end of the digestion-tank was passed through a heat-exchanger and returned to the inlet end of the digestion-tank. After circulation through the heat-exchanger, the cooling-water returned to the cooling-pond. It was anticipated, as a result of some large-scale trials, that by that means it would be possible to return to the digestion-tank approximately one-third of the heat value of the gas. After allowing for loss of heat by radiation and conduction to the ground, the effect would be that

Mr. Whitehead. the average temperature in the digestion-tanks would be increased by about 10° F. and the gas-production by about 33 per cent. The plant shown in *Fig. 9* would cost £5,700 to install. An alternative method of producing the same quantity of gas would be to provide further digestion-tanks and gas-collectors at a cost of about £9,000.

Mr. O'Shaughnessy. Mr. O'Shaughnessy explained a lantern-slide which he had prepared for the purpose of conveying an idea of the general phenomena lying behind the whole process of digestion. The magnification was about 100 diameters and the two photographs side by side showed living sludges, which were undergoing aerobic and anaerobic fermentation respectively. The general character of the action which occurred in anaerobic fermentation was disintegration. On the other hand, the general character of aerobic fermentation was integration. It might be said that the vast bulk of living things were produced under aerobic conditions by a process of integration; but certain of these lowly organisms were wonderfully adaptable and had the unique characteristic among living things of being able to adapt themselves to both aerobic and anaerobic conditions, that was to say, they could live in the presence of air or in the absence of air. Organic material produced under aerobic conditions might, in its mass and in its form, be considered to represent potential energy. The anaerobic biochemical attack disintegrated it and split up the energy into its various parts. A portion escaped even from the liquid system and passed off as gas into the atmosphere under natural conditions. Mr. Whitehead and other engineers had various devices for trapping that portion of the energy, the dispersed energy, and had shown the way in which it could be utilized.

Mr. Watson. Mr. J. D. Watson considered the Paper to be one of the best on the subject to which he had ever had the privilege of listening. It was clear and comprehensive, and recorded the facts without stressing any phase unduly. As far as he was aware, it omitted nothing of material importance. It made one feel that this country was still in the van with regard to work of the kind described. He was reminded of a remark made by Professor Whipple many years ago, when speaking to the American Society of Civil Engineers, namely, that England took the lead in regard to Sanitary Engineering largely because her cities were large and her rivers were small. If that description was true generally, it was certainly truer of Birmingham than of any other town in the country, because Birmingham was in the heart of England. The population was large and the difficulties were great, because the city was highly industrial and the character of the sewage, judged by the Ministry of Health standard, was strong; in respect to strength it had, to his knowledge, changed considerably several times during the past 30 years. In addition to that, the

Mr. Watson.

river was a very small one. During the summer season its volume was only half of that of the sewage effluent discharged into it. Not only was that the case, but the river itself came from the Black Country, and contained a considerable proportion of trades waste and domestic sewage effluent, in addition to its normal flow. He agreed with the Authors that there were three ways in which it was possible to dispose of the solid matter of sewage satisfactorily. The first was by shipping out to sea, which was effective and complete. Secondly, the sludge might be used as manure, as at Wolverhampton. That, however, was not always practicable; indeed it was frequently impossible in the case of large towns, because the area of land needed was not always available. The third way was that described by the Authors. The stage had been reached when the third way was regarded as a practical method of sludge-disposal. It had been admitted for many years—and expression had been given to the view by one of the Royal Commissions—that sludge-disposal was the crux of the whole matter of sewage-treatment. Birmingham had had so much difficulty many years ago in keeping down smell nuisance that an injunction against the Local Authority had been granted at the instance of some residents, and the problem had been to find a way out of the difficulty. Nearly five hundred patents—chemical patents mostly—had been taken out for dealing with the problem, but most engineers had come to the conclusion that no one of them was capable of giving much help. When in 1900 he first had to do with the problem at Birmingham he found that a chemical precipitant was being used to coagulate suspended solids. Coagulation was given up and instead the sewage was septicized. At that time, it would be remembered, the virtues of the septic tank were very popular; indeed they were much over-rated; at the same time considerable benefit was found to result from septicizing the sewage. Incidentally the volume of sludge was reduced as the result of septicization. When the use of lime as a chemical precipitant was stopped, the amount of sludge to be dealt with on the land, reckoning the added lime plus water, was reduced by nearly 50 per cent.; and when septicization of the normal organic matter was completed and it was partly formed into methane gas the volume of sludge was reduced by a further 30 per cent. That, of course, was due to gasification. The transition from the one method to the other had been a great advantage, and it had led to the discovery of which the Authors spoke on p. 39. Seeing that malodour was the bugbear of all sewage-farms, it had been somewhat surprising to him to notice one day a whole field, recently irrigated with sewage after being horse-ploughed and sown with mangold seeds, altogether without smell, although it was consistently covered with a pasty-looking deposit. The wind was

Mr. Watson. passing over the field towards him at the time, and knowing that his sense of smell was keen, he was rather surprised. On close examination, he found that there was a very slight odour of tar, but nothing beyond that. That observation led him to go into the question of further digestion, and very soon afterwards he tried to separate septicization of liquid from that of solids, but unfortunately he failed. He then consulted Mr. O'Shaughnessy, but neither of them succeeded in achieving success in the matter. Almost immediately afterwards, however, Dr. Travis brought out his hydrolytic tank, and a year or two later Dr. Karl Imhoff, Engineer to the Emschergenossenschaft patented his Emscher tank. His impression was that the advances now being made in the matter of sludge-digestion were largely due to the way in which gasification had caught the public imagination in 1922. He might be wrong, but such was distinctly his impression. The function of the septic-tank process had been largely misunderstood. Engineers continued to septicize sewage far too long, and did not grasp the advantages that would accrue from allowing fresh liquid to pass forward to the oxidation stage, where it was distributed over percolation filters, and dealing with sludge *per se* by the anaerobic fermentation or septic process described by the Authors. Every one ought to have realized earlier the great importance of separating the one from the other. In the Paper a comparison was drawn between the Birmingham method and the German method, as illustrated by the Imhoff and Prüss tanks (p. 50). The Imhoff tank had become popular not only in Germany but also in America, whereas the Birmingham method had not until recently been followed to any extent. It was being followed now much more rapidly, but until quite recently the only great towns which had adopted that method were Baltimore, U.S.A., and Pretoria, South Africa. They had taken the matter up and had done the work very well. The Authors had been quite fair in their comparison of Birmingham primary and secondary tanks with the Imhoff tank, yet it seemed to him that, for a stranger to grasp the situation correctly, it was necessary to have some knowledge of the Birmingham works. He presumed that some of those present regarded the primary and the secondary digestion tanks and the Imhoff tank, which was a two-storey one, as strictly comparable, whereas Birmingham had a sedimentation tank in addition to the primary and secondary tanks. The engineer, of course, had always to keep economics in view, and it would be very interesting, though it might be asking too much, if the Authors could give a comparison between the cost of constructing the digestion and sedimentation works on the Birmingham system and digestion works on the Imhoff system, not forgetting the relative digestion merits of each. He thought he was right in saying that the Birmingham digestion tanks, quite apart from the sedimentation tanks, had a capacity of 9 million cubic feet. The population of the district was rather over 1,000,000, so that the provision for digestion was equal to about 9 cubic feet per person. In the German tanks, only 2½ cubic feet per person was allowed. The Birmingham digestion tanks were made to function immediately they were changed from septic tanks. On his return from Germany in 1910, he consulted his chief assistants about what he had seen, and they all came to the conclusion that it would be a wise course to set aside certain tanks—called "finishing tanks" by a Past-President of The Institution, Mr. Hawksley—for the purpose. The policy of using existing septic tanks and improvising sludge lagoons went on and on until they had the capacity to which he had just referred, but the tank construction was all more or less of a temporary character, so much so that he had always been afraid to ask the Drainage Board to allow him to make application for a loan, because he feared the Local Government Board (as the Ministry of Health was called at that time) would regard it as purely experimental and unworthy of a 30-year loan. The work had therefore been done out of revenue. All that should be taken into account in making cost comparisons. If plenty of land were available the matter was a different problem from what it was where no land was available. For instance, Dr. Imhoff proposed in 1912 to put his tanks at the end of the various streets on Manhattan Island, which was a perfectly feasible scheme, whereas the Birmingham system would not be practicable; but in the case of a town surrounded by agricultural land of considerable extent it certainly was worth very careful consideration whether it would not pay better to adopt the Birmingham system of long-period digestion, rather than concentrate on a short-period digestion which implied the construction of comparatively small well-designed tanks. Mr. Watson.

Mr. J. S. ALFORD remarked that the Paper was not only a landmark in the "Proceedings" of The Institution, but was also written with an absence of dogmatism that was very refreshing. The same could not be said of all Papers written on the subject of sewage-disposal. He could not deal with the details of the Birmingham works, because it was many years since he had been there and he was not qualified to do so, but he wished to make one or two general observations because he thought the Paper indicated that a distinct step forwards had been taken, and that it was now possible to generalize in a way which had not been possible hitherto. Digestion was apparently a stage process. It was not like boiling water in a kettle, which was a unified process. It did not matter whether there was a partition across the kettle from top to bottom or not; there was no difference between one part of the boiling water and the next. But apparently Mr. Alford.

Mr. Alford. that was not the case with sludge-digestion. If that was true, he thought it must follow that a one-piece sludge-digestion tank was wrong. If it was true, it was surely, he thought, still more wrong to mix up the whole of the contents of a one-piece digestion tank two or three times a week, knowing all the time that fresh undigested sludge was coming in at one end and the completely digested product was going out at the other. Nobody would suggest for a moment that a percolation filter, which was a stage-process apparatus, should be put through a centrifugal pump three times a week. It would spoil the process, apart from being impracticable. It also seemed to him to follow, if not with quite such certainty, that, if sludge-digestion was a stage process, eventually the Emscher and Travis tanks would be found to be on the wrong lines, because there the sludge was kept for a long time in continuing association with fresh sewage. On p. 49 the Authors spoke of the possibility of obtaining an 85-per-cent.-water sludge from a horizontal-flow sedimentation tank. He did not know whether that statement was intended to apply to the whole of the product of the tank, but he did not think he had ever come across anything as good as that. It was accompanied, however, by the condition that the tank was emptied once every 2 or 3 weeks, and he thought that also was wrong. The sedimentation process and the sludge-digestion process were two different things. One was mainly mechanical and the other was mainly biological, and it could not be the true method of progress to mix sedimentation with digestion. It was necessary to keep them apart as much as possible, and, if they were to be kept apart the sludge ought not to remain in the tanks for 2 or 3 weeks. Most people knew places where the sludge was allowed to remain in that way, and the vicinity of those tanks was not always a pleasant spot. It was the duty of the sewage-disposal manager to take care of the complete process from beginning to end, and not to concentrate on one particular part of the process at the expense of the others. In spite of what Mr. Watson had said, he was inclined to doubt whether the publicity that had been given to the production of gas from digestion-tanks had done good to sewage-disposal as a whole. He quite agreed that it had encouraged the production of digestion-tanks, but he was inclined to think that it might have been detrimental to other parts of the process. He thought it was unfortunate that statements should be made about the sums of money that were being obtained by towns, chiefly in Germany, from the sale of gas from sewage-digestion tanks, when those statements were not accompanied by information as to what the municipalities were doing with the whole system of sewage-disposal. If they looked after the whole process of sewage-disposal properly, from beginning to end, and could then sell some gas, by all means let them sell it, but first they ought to carry out their own job, and he was not at all satisfied with a statement which seemed to him to go only halfway. The heat energy obtained by digestion of sludge, it seemed to him, ought to be directed, in the first place, to preserving or maintaining a proper temperature in the sludge-digestion tank, and possibly in the sedimentation tank. Secondly, it should be applied to driving any machinery necessary for the sewage-disposal plant itself; and, thirdly, it should be used for supplying heat for the more rapid conversion of the digested sludge into a condition in which it was easily transportable. If those matters were attended to and any gas was left over, it would probably be found to have such a heavy seasonal fluctuation that no one would buy it; but if they did buy it, so much the better. Mr. Alford.

Mr. G. Bransby Williams remarked that the Paper contained in a concise form a large amount of valuable information and also raised many interesting points, but he would confine his remarks to one point, namely, the question how far the results obtained at Birmingham could be considered likely to be applicable to countries where the local conditions were fundamentally different. In England the cold moist climate had rendered the question of getting rid of the sludge the most difficult problem in connection with sewage-disposal, and, as was known, that difficulty was enhanced in the case of sludge from bio-aeration works. In a country like India, on the other hand, where the climate was hot and dry for the greater part of the year, no particular difficulty was experienced in getting rid of the sludge. In the plains of India, sludge from all kinds of septic tanks, from sedimentation tanks, or from bio-aeration works, could be very easily and quickly dried to an inoffensive substance. The sludge from septic tanks was not of much manurial value, but that from bio-aeration works contained 4 to 5 per cent. of nitrogen and was therefore a valuable manure. Consequently, in a country like India the problem became entirely an economic one, and, in order to justify the introduction of a system of sludge-digestion, it was necessary to show that it was likely to pay better to dispose of sludge in that way rather than in some other way. Recent work in India had shown that the bio-aeration system, whether by mechanical agitation or by air blowing, was peculiarly suited to Indian conditions, and he thought it might be assumed that in future most of the large sewage-disposal works in India, when they came to be carried out, would be on that system. He found that from a bio-aeration plant, preceded by partial settlement, there was obtained about 0·2 lb. per day per head of the population, of sludge dried to 55 per cent. moisture, so that, from a town of 100,000 inhabitants about 9 tons of dried sludge per day would be obtained. The commercial value of that sludge as manure Mr. Williams.

Mr. Williams. was, at a conservative estimate, not less than Rs. 15 per ton, so that the value of the sludge obtained from a town of 100,000 people would be about Rs. 135 a day, or, in round figures, Rs. 50,000 a year. According to his estimate, if the whole of the sludge were digested, enough gas would be obtained to drive a 75-HP. engine for 24 hours a day throughout the year. It might be assumed that the engine would be used for driving machinery at the sewage-works or for municipal purposes, and therefore the value of that gas to the authority concerned would lie in its use as a substitute for some other fuel, such as oil. In India the average cost of oil for a 75-HP. engine would be about Rs. 30 a day, or about Rs. 11,000 a year. It thus appeared that the theoretical manurial value of the sludge was about four-and-a-half times the value of the gas that would probably be produced. India was an agricultural country, and at least 90 per cent. of the inhabitants were in some way or other concerned with the productivity of the land. It therefore seemed very difficult to suppose that the destruction of a valuable manure in order to generate power, which could be obtained more conveniently and more cheaply in some other form, could be justified in India.

Mr. Jackson. Mr. HARRY JACKSON remarked that it seemed to him that there had now been recorded for the first time in the "Proceedings" of The Institution a clearly set out scientific account of one of the most difficult problems that had been exercising the minds of engineers for a long time; and the fact that the present stage had been reached was due, he thought, to co-operation between the chemist and the engineer. He would like to say how strongly those who were interested in the problems dealt with but who had taken up the study of them quite late, and had not had the advantage of following the subject in the way Mr. Watson had done, appreciated being able to find in the Paper the actual desired effects and processes, and not merely arguments for the manufacture of gas, a subject which was relegated to the last portion of the Paper. He thought that to engineers dealing with sewage-disposal the question of gas-production was an entirely secondary one, and that the primary object was to get an inoffensive sludge that could be dealt with easily, and to have a clean works to deal with it. On p. 41 the Authors said: "At Birmingham the major factors influencing the course of the digestion of the sludge are found to be . . .": that was a modest way of putting it, and, from what he had been able to gather, the same thing might be said of all sludge-digestion plants. The three items mentioned were the water-content, the temperature, and the degree of alkalinity. The Paper went into what might be controversial topics when it dealt with the water-content, but it pointed out clearly what had been the experience of the Authors, namely, that unless there was a certain minimum amount of solids, any success with the sludge-digestion process was unlikely. That was the first point, and, if he had interpreted it wrongly, he hoped the Authors would correct him. Much might be said about the question of temperature. More than once in the Paper it would be found that the optimum temperature for the emission of gas, which was given as 75° F.—he presumed it would range from 75° to 79° or 80°, according to figures in his possession—was not necessarily the most economical temperature at which to work the digestion process; and the Paper went on to say that the higher temperature was more effective in the initial stages than in the later stages. He could not help feeling, in reading the Paper, that there was a lingering desire on the part of the Authors not to increase the temperature at all, but that, as it had been brought home to them that they must increase it, they increased it at the commencement and more or less trusted to luck later on. He felt sure that the Authors had some sound reason for their statement, and perhaps they would give it in their reply, but he would like to point out that if, instead of increasing the temperature in the first tank in the manner adopted at Birmingham, it was possible so to regulate the temperature as to have all the sludge in that tank at the optimum temperature of 75°, there would necessarily be a quicker action going on; otherwise it would not be the optimum temperature: and, if quicker action was going on, sludge-digestion tanks of less volume could be employed. It so happened that he was responsible in some measure for a case where arrangements were being made to vary the temperature as desired, and it would be possible to ascertain definitely the result of having the higher temperature or the lower temperature. Farther on in the Paper it would be found that the biological action was described as zoning. Whether the wish was father to the thought or not he did not know, but it seemed to him that, if the particular microbes which worked at the optimum temperature could be got to work all the time, the arrangement was likely to be more efficient from the point of view of financial economics. He could imagine that certain bacteria would operate more effectively in a less rich sludge, and he could also imagine that other bacteria would act more effectively in a much richer sludge; but that was not proved in the Paper. There was nothing to indicate whether it was the case, and that, it seemed to him, was the criterion whether the horizontal-flow tanks and what the Paper insisted on, namely, second digestion, was the plan which should be followed. The question of temperature was very largely dependent on the knowledge of the bacteriologist as to the kind of bacteria required for the quickest breaking-down of the organic compounds into the materials that it was desired to produce. The third point mentioned by the Authors was the alkalinity. So

Mr. Jackson.

Mr. Jackson. far as he had been able to find out, that was a matter of the conditions in which the particular microbes were able to live. It was an external condition of their activity that a certain amount of alkalinity should exist. A moment's reflection as to the immense complications of that problem and the necessity for its investigation on scientific lines would indicate how much was owed to those who made such investigations. It was no longer necessary to spend large sums of money without a clear understanding of the conditions necessary to yield the desired results. On p. 48 the Authors referred to the importance of obtaining accurate data in connection with the operation of digestion tanks on a large scale, and said it could not be over-stressed. Thereafter they mentioned eight particular points. Those who had looked into the question and had experienced the difficulty—mentioned elsewhere in the Paper—of comparing figures, by reason of their multiplicity and their deficiencies in certain particulars, would understand the need for that; but it seemed to him that the Authors had sent up a *ballon d'essai* to see whether it was not possible to arrange statistics of sludge-digestion in such a comparable form as to enable methods to be improved. That had been done in the electrical industry with great benefit. It seemed to him that the time had come when the definite particulars required might be settled by some such representative body as The Institution of Civil Engineers; and that would mean a very great advance. In the particular case to which he had referred, he had felt it incumbent on him to draw his own conclusions as to what would come into the sludge-digestion tanks, what would go out, where it would go, and what should be done with it; and he was pleased to say that so far, the Local Authority had agreed to the expenditure of the money necessary to measure those quantities. It was another thing, however, for the engineer to ask his client to spend money on studying the bacteriology of the matter. In dealing with such a Board as was in charge at Birmingham it might be easy, but that would not always be the case. To come to another point, the Authors put forward an argument which they had expressed in a subtle fashion, without stating any definite conclusions, but which those who knew them personally recognized as being implicit in the Paper, namely, that single-tank digestion was not a desirable thing. He thought that depended on circumstances. If the monetary value of sludge were put out of mind, and if a readily settlable sludge could be obtained by an optimum operation in one tank by mixing, and could be disposed of, the economic aspect of the question might be easier and sounder. The actual total cost of getting the sludge under those conditions might be much less than it would be if two tanks were employed. He thought the Authors were quite sound when they

Mr Jackson.

said that in the discharge of a single-process tank some material which was not thoroughly digested must necessarily be carried away. In the particular case referred to the volume of the tank would be somewhere in the neighbourhood of twenty-four times the dose of sludge coming in; and it would be clear that, in such a tank the percentage of gas-producing material in the tank was not much altered by the material coming in. Further, if the supernatant liquor were taken from that tank, it might be possible to put into the tank in the first instance sludge containing more water, and to concentrate the sludge-content in that particular tank. It must be granted that in a single tank it was not possible to get all the material that was taken out of the sludge completely dehydrogenated. He would be able to satisfy the Authors as to that if they would take the opportunity later to see in operation tanks which could be worked either in parallel or in series. If when the tanks were worked in parallel all the desired results were obtained, possibly the Authors' views would be somewhat modified.

Mr. Furphy.

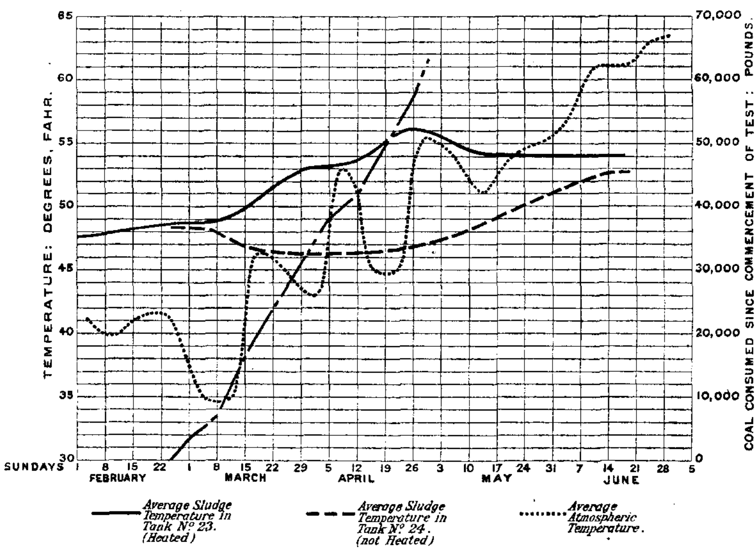
Mr. H. G. Furphy remarked that it gave him great pleasure, as a visitor from a far corner of the Empire, to be present and to hear a Paper by the Authors, whose names were well known in Australia. He could not add to what other speakers had so well put before the meeting, but he would like to ask a question. There could be no doubt that, as a result of the Paper, interest would be stimulated in the idea of stage digestion; and, that being so, it would be of great value to practical engineers if the Authors would give some idea of what the maximum daily addition to a first-stage heated digestion-tank was, expressed as a percentage of the tank's capacity. Recent practice at Essen-Rellinghausen, where digestion-tanks were being used at the present time in two stages, was to add 6·4 per cent. of the capacity of the first-stage digestion-tank. He would like to know whether, in the Authors' opinion, that figure was anywhere near the limit, and whether the percentage depended on the water-content of the sludge, to which they had properly drawn attention.

Mr. Vokes.

Mr. F. C. Vokes remarked that the Authors had referred to the increased rate of digestion and evolution of gas which resulted from higher sludge-temperatures and had also mentioned the desirability of utilizing, for heating purposes, the waste heat from internal-combustion engines operating on sludge gas. It might therefore be of interest to give the following description of large-scale experiments carried out at the works of the Drainage Board at Birmingham. In order to determine the extent to which the rate of evolution of gas was increased by raising the temperature, 200 cubic yards of sludge in a primary digestion tank were heated by the injection of steam, the temperature at the centre of the tank being maintained at an average

Mr. Vokes. of 74° F. for a period of 9 months. The rate of gas-evolution was found to be more than 100 per cent. higher than with the tank unheated and an average sludge-temperature of 51·6° F. That information had been required in connection with the digestion-tanks now being constructed at the Board's Colehall Works. At the main outfall works of the Board at Saltley, the question of heating the sludge was rather more involved, owing to the following circumstances: firstly, the digestion-tanks already existed and were not of the compact form most suitable for the retention of heat; secondly, the whole of the gas collected was used to drive gas-engines, so that only the waste heat

Fig. 10.



from the engines was available for heating the sludge; thirdly, the digestion-tanks were situated at a considerable distance from the gas-engines, so that the heat would have to be conveyed a distance ranging from 350 to 500 yards. To obtain the necessary information Tank No. 23, containing approximately $2\frac{1}{4}$ million gallons of sludge, had been heated by the injection of steam. From the curves shown in *Fig. 10* it would be seen that, during a period of 9 weeks, approximately 28 tons of coal was consumed for that purpose. The gradual rise in the average temperature throughout the sludge was shown by the higher curve, from an initial temperature of 48·5° F. to a maximum of 56° F., at which point the injection of steam was discontinued. Temperatures were also taken in Tank No. 24, which was similar, and

Mr. Vokes.

was not heated. Those were shown by the lower curve. The fluctuating curve showed the variation in the atmospheric temperature. It would be seen that the addition of heat to the sludge in Tank No. 23 modified the effect upon it of the cold weather, whereas the temperature of the sludge in Tank No. 24 gradually fell. The quantity of heat imparted to the sludge was regulated to coincide with the amount of waste heat, which was recoverable from the gas-engines, when carrying the present load. The curve showed, therefore, that towards the end of April that quantity of heat had sufficed to raise the sludge temperature by 9° F. above that of the sludge in the unheated tank. In order to determine what the effect of such an increase of temperature would be on the rate of evolution of gas, the records of the power-plant had been studied over a period of 3 years (1928–30), as had been also the records of the sludge-temperature. Those investigations had shown that the additional sludge-gas now required for running the gas-engines could be obtained most economically by utilizing the waste heat for maintaining the sludge at a higher temperature. When due allowance was made for the conditions under which the plant was operated, it would be seen that the results obtained, both at Colehall and at Saltley, tended to bear out the evidence obtained by other investigators.

Mr. Easton.

Mr. W. C. Easton wished to express his indebtedness to Mr. J. D. Watson and to Mr. Whitehead for the privilege granted to him throughout the past 30 years of following closely the developments, including sludge-digestion, at the Birmingham Tame and Rea Drainage Works. He must add that evening his cordial acknowledgment of the advice which Mr. Whitehead, with the consent of his own and of the Coatbridge authority, had given him in regard to the design of the tank shown in *Fig. 5* (p. 51). The Authors rightly emphasized the confusion on the subject of sludge-digestion which had resulted from incomplete information. He was sorry that, with regard to Coatbridge, he could do little to remedy that deficiency. The construction of the sludge-disposal works there had only recently been commenced, although that of the sewage-purification works on an adjacent but different site was well advanced. The whole works should be completed in 10 months' time. Thereafter they would require to be put into operation and run efficiently, and the responsibility and credit for that would lie with the manager of the sewage-works. Then, and then only, would it be possible to discuss what the Coatbridge authority had done. That should be about 2 years hence. The treatment of the crude sewage would include further purification by the "Simplex" process, the only process for which tanks could be built on a site so severely restricting their area, while giving ample liberty as to their depth. *Fig. 5* showed a tank specially designed to

Mr. Easton. meet such conditions. On his first visit to Coatbridge a year ago, Mr. Whitehead had remarked that the site seemed to preclude any suggestion of putting down an additional tank or even making the units larger, and he had agreed that arrangements entailing larger tank-capacity, with fewer or simpler expedients, were out of the question. Mr. Easton hoped that the four types of tank illustrated in the Paper—two British and two German—would lead to the desirable full discussion on the choice of methods for a given site where absence of nuisance was essential and the deciding factor was the cost of operation.

Mr. Cotterell. Mr. A. P. I. Cotterell remarked that the Paper was, in his opinion, a sober and conservative review of a fascinating subject. Sewage-treatment had always been a fascinating subject, and often it had been found that anticipated swans were merely geese, and that a promising development had not fulfilled expectations. However, the treatment of sewage-sludge by bacterial digestion had undoubtedly in the last few years opened up many avenues, and it was now being found that there was something to be gained from that part of the sewage which had previously been regarded as a nuisance and a drug on the market. He agreed fully with the Authors' opening statement that the principal object was to facilitate the task of sludge-disposal: he was glad they had borne that in mind, and he hoped it would be kept in mind throughout the discussion. At the same time, the developments in the matter of sludge-digestion had shown that it was possible to recover valuable products from sludge; and fortunately—unlike the old story of farming and sewage irrigation—the recovery of those products fell in line with proper disposal of the sludge. He thought that a debt of gratitude was owing to Birmingham, to the Birmingham sewage-works, and to Mr. Watson, for having pointed the way, between 1911 and 1914, to the improvement of the treatment of sludge by bacterial digestion. He could not help wondering, however, whether, if at Birmingham they had an opportunity of starting again to-day, the same type of open tank would be constructed. At that time the advisers of the Board had had in mind only the digestion of sludge, as learned from the experiences of Dr. Imhoff in Germany, and had not given much thought to the possibility of the recovery of gas that could be utilized for power. It seemed to him that the type of tank illustrated in *Fig. 6* (p. 51) was scarcely the best and most efficient for carrying out the object of sludge-digestion. *Figs. 1* and *2* (p. 49) showed a distinct advance in the type of tank and he appreciated the reasons given by the Authors on p. 46 for adopting the horizontal-flow type. He agreed with them in regard to the sludge-forming ingredients of sewage. The quantity of fermentable matter—that was, gas-forming material—per head of population did not differ widely in the various parts of the world, and, although the Authors later on compared American and British sewage, he believed that there was really no great difference in respect of the quantity of fermentable matter present. So far as sludge-digestion was concerned, therefore, he submitted that the conditions in, say, Germany were much the same as in England. A direct comparison was drawn in the Paper between the requirements of the Ministry of Health and German and American practice. It was true that to a large extent the Ministry of Health, having to deal with much smaller rivers and streams, required a much greater reduction of solids in England than was required where the sewage or the sewage effluent flowed into a larger stream. It was obvious that at Stuttgart, on the river Neckar, where there was a large and very rapid flow, the degree of purification and of elimination of solids could be less than in the case of smaller streams elsewhere. There were, however, places abroad—for example on the Ruhr—where it was all-important that the purification should be at least as high, because in certain years the water that entered the Ruhr from the sewage-works had to be used again two or possibly three times for drinking. Such conditions were scarcely paralleled in England, so far as the requirement of purity was concerned. Dr. Imhoff was now responsible for a number of sewage-works on the Ruhr, and for the water-supply in the Ruhr basin to a population of about 5 millions, and therefore what he had to say as to the degree of purity was of great importance. Dr. Imhoff had recently stated in a letter that he considered a shorter period of retention in the sedimentation tank was advantageous rather than the reverse. It was true that Dr. Imhoff advocated a longer period of retention now than formerly, but his figure was 2-hour retention. Mr. Cotterell had no doubt that at Birmingham the retention period was much longer. As to the treatment of sewage-sludge, he agreed with the Authors on the main factors influencing the design of a sludge-digestion plant set out on p. 48. With regard to the reduction of the water-content, his firm had for a long time used the method of running-off water collecting in the secondary tank, somewhat in the way adopted in the Coatbridge tank (*Fig. 5*), thereby concentrating and greatly reducing the total bulk of the sludge to be digested. The temperature was an extremely important point, and it was one which he had long felt Birmingham was unable to tackle, because of the special form of its original tanks; but he had been very glad to see the scheme explained by Mr. Whitehead, whereby it was proposed to utilize the heat from the exhaust gases for raising the temperature of the sludge in the new type of tank illustrated in *Fig. 2*. Mr. Whitehead in his preliminary remarks had pointed out that by recovering 33 per cent. of the waste

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Mr. Cotterell. heat in the exhaust gases it was possible to raise the temperature of the sludge by 10° F. and to increase the gas-production by 33 per cent. That pointed to a distinct gain in the quantity of gas obtainable and therefore in the power available—in other words, improved efficiency of the plant. He had been rather struck by the fact that one point was only casually mentioned, namely, the stirring of the sludge. He would be glad if a little more information could be given as to the views of the Authors on the value of stirring or mixing. In the Coatbridge tank there were mixers both for the scum at the top and particularly for the settling sludge at the bottom of the tank. The method was being very largely adopted in America and mixing had been incorporated in some of the more recent tanks in Germany, both by Dr. Imhoff on the Ruhr and by Dr. Prüss on the Emscher; so that it would be of interest to learn whether the Authors thought it really worth while to go to the expense of providing power and machinery for the purpose. He felt very strongly that any stirring should be extremely gradual. He knew that Dr. Prüss, of the Emscherbund, believed—until recently at all events—in considerable mixing of the sludge in the digestion-tank. But it seemed to him that the right course was to stir the sludge extremely slowly, so as not to mix the various zones too violently. Generally he thought that sludge-treatment was another example of how knowledge was constantly being passed from one country to another. About 40 years ago he adopted the vertical sedimentation tank somewhat after the pattern of the Dortmund tank, and about 1909 he put in a double-storey tank, in that way clearing out sludge from the sedimentation tank on the lines that were being adopted to-day. That method had been learned from Germany. Then America had come into the picture, possibly in consequence of the war, and had developed the method a stage further, and thereafter in England further progress had been made; so that the ball had been passed, as it were, from one country to another, and continual improvement was being effected in each. That seemed to him to be the proper method to adopt with such a universal matter as that under discussion, and the Paper under discussion would be a noteworthy and valuable record of the advances made.

Mr. Roechling. Mr. H. A. Roechling proposed to confine his remarks to general observations on what might be called the philosophy of sewage-treatment. The Paper dealt with the digestion of the visibly suspended matters in sewage, not with the invisibly suspended matters which were known to exist. It was important to bear in mind that the reason why more was not known about the invisibly suspended material was that the microscopes available were not sufficiently powerful. When the power of magnification was increased—as he

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hoped it would be before very long—many things would be found out which would afford an explanation of numerous baffling problems. However finely divided matter in suspension might be, it did not *constitute a true solution. There could be no doubt that in sewage,* both in the liquid and in the visibly suspended solids, there must be a host of minute particles, many of which would act as agents in the destruction of the organic matter in the long passage from the primary stage of organic matter to the final stage of mineral matter. So far there had been a disposition to regard many of those agents as chemical or biological agents, but he doubted whether that view would not be abandoned before long, for there were other agents of which very little was known at present. The Authors referred to the fact that there were serious discrepancies between the views of experimenters. It could not be otherwise. Sewage underwent continual changes: if those changes were represented numerically by 100 stages, and if one experimenter examined the sewage at the fifth stage and another at the fiftieth stage, they were examining different liquids—or at least liquids which differed so materially that it could not be expected that the results would agree. In addition to that, many experimenters were probably not as well qualified to judge of sewage changes as were the Authors. He was quite satisfied that what the Authors put forward was reliable, but, in his opinion, much other information could be disregarded. Not all experimenters, moreover, had the same elaborate apparatus as the Authors. Some had very inferior apparatus, so that the conditions under which they worked differed. It was therefore only natural that there should be a great deal of difference of opinion among the various workers, and even that some of them should contradict others. Taking, for instance, the question whether digestion should take place in one double-storey tank or in separate tanks, Dr. Prüss had modified the Imhoff tank because, he said, he had wished to get better results; but there could be no doubt that the results obtained by Dr. Imhoff had been quite good. The Emscher was a horrible black stream, and difficulties were now being experienced with phenol. He had been told that fish caught in the Rhine as far down as the Dutch frontier smelt of phenol when they were cooked. Nature had a very efficient way of dealing with dry organic matter. She purified it on the land. If that were not so, the Chinese, who for 4,000 years had put their sewage on the land, would no longer exist. Nature had unfortunately not provided a quick and efficient method for purifying liquid organic waste matters carried in water, and it was that problem that the Authors tackled when dealing with visibly suspended matter. In 1930 he had occasion to spend two months on the Continent and he took the opportunity of visiting the principal

Mr. Roechling. sewage works. He might add a little to the Authors' information in regard to some of them. At Berlin, with a population of $4\frac{1}{2}$ millions, the sewage was formerly treated entirely on the land. They had now an estate of 67,000 acres, of which only about 30,000 acres was under sewage treatment. Their experience had been that 1 acre of land should not take more than 4,000 gallons of sewage per day, and that of the whole farm area about one-third should be under sewage and two-thirds under ordinary agricultural treatment. If the area were to be extended on that basis to meet the growth of population, by 1955 the sewage-farm area would be 215,000 acres (about 336 square miles), and, as it was not desired to enlarge it to that extent, they now assisted the land treatment by previous artificial treatment. They had installed two large works in the south of Berlin, one of which had just been completed. The one at Wassmansdorf treated about 20 million gallons a day. The sewage passed through two-storey tanks and afterwards the effluent was passed direct to the land. In the $3\frac{1}{2}$ years since their completion those works had treated 428 million gallons of sewage and extracted on an average about 70 per cent. of the visibly suspended matter. They obtained 4 million cubic feet of gas, the calorific value of which was equivalent to about 0·84 therm per head per annum. At the other (Stahnsdorf) works they had changed the treatment of the sewage by using separate tanks for the treatment of the suspended matter. The works were very interesting, and the scheme was one of the best-designed that he had ever seen. They proposed to treat 30 million gallons a day; and, to show the thoroughness with which they went to work, he might mention that, when they needed additional ground they scrapped 110 percolating filters erected only 25 years ago. They hoped to get 353,000 cubic feet of gas a day, which would be used for heating and lighting, for power, and in a destructor which dealt with material from the catchpits. There were two sets of digestion tanks: after the sludge left the preliminary tanks it was heated, and then it was gradually sprayed into the final digestion tank. Another interesting feature there was that two of the engines which were worked with sludge gas could be converted into Diesel engines very quickly if the sludge gas should fail at any time. At Munich 60 million gallons of sewage were treated daily. The Paper did not say how much was treated at Birmingham, but he imagined that it was about 30 million gallons a day. At Munich some very interesting experiments in the final biological treatment of the effluent had been made with fish-ponds covering an area of 576 acres, and they utilized the effluent from those fish-ponds in the turbines of an electric power-house close by, so that it might be said that they utilized practically the whole thing. They had two-storey

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tanks, but 2 per cent. of the daily flow into them was passed into secondary digestion chambers for further improvement. At Stuttgart they now treated 20 million gallons a day, and the volume of the gas ranged from between 0·28 and 0·53 cubic foot per head per day. Each case must be treated on its merits, and for that reason he thought that a great many of the details given in various publications should not be adopted without further investigation. When he joined The Institution, the chemical stage of purification had been reached. Justus von Liebig had just finished his famous researches in agricultural chemistry, and every one thought there was a vast amount of money to be made out of sewage. Immense sums had been lost in various schemes of sewage-treatment and in patented processes. Next had come the natural biological treatment on land, but unfortunately that had not been a great success. The process had been misunderstood, because the laws governing it had not been fully known, and the management of it generally had not been good. That had passed, and artificial biological treatment had come in, first in contact beds and then in trickling or percolating filters, and finally there had arrived what looked like a very good process, namely, the activated-sludge process. No one knew, however, how long that would last; it might in its turn be superseded. Not enough was known yet about the laws and principles underlying the changes from organic to inorganic matter. He thought The Institution was greatly indebted to the Authors for their Paper, and Birmingham might well be proud of its sewage works.

Dr. Calvert.

Dr. H. T. Calvert felt sure that the valuable Paper under discussion would come to be regarded as historic. The work done at Birmingham was an outstanding example of team work, in which engineering, biological, and chemical science had participated. It was, he thought, very opportune that a Paper on the treatment of sewage sludge by bacterial digestion should emanate at the present time from Birmingham, the home of separate sludge-digestion and the Mecca of persons from America and the Continent, even more than of Englishmen, who were interested in the subject. Sludge-digestion was at the moment commanding a great deal of interest and there was a tendency to design plant on insufficient data, a tendency to which attention had, he thought, been well directed in the Paper. Mechanical appliances were being used more and more, but whether that was a desirable trend he would not care to say. It was, however, in keeping with developments in almost every other direction of human activity. He submitted that the Paper began on a wrong note in saying that the principal object of sludge-digestion was to facilitate the task of sludge-disposal. If the view that sewage-works were factories which received sewage as their raw material

Dr. Calvert. and turned out valuable products were more generally prevalent, he thought it would be conducive to greater progress. Many cloth-manufacturers in the West Riding of Yorkshire would feel rather hurt if their mills were termed rag-disposal works, and many other instances would occur to the members in which the wastes of one activity formed the raw material of another. He would therefore like sludge-digestion to be regarded as a manufacturing process. Another point of criticism, but not by any means of disparagement, was that he could not help feeling that the two questions of heating the sludge to encourage fermentation and of thermophilic digestion had been dismissed too hurriedly; because although it was difficult to point to any particular passage in the Paper, he was nevertheless left with the impression that the Authors did not favour the application of heat. They expressed the definite opinion that artificial heating was more advantageous in the early than in the later stages, but it might quite well be imagined that in the later stages, when the concentration of the fermentable matter in the sludge was less than in the early stages, heat would assist in completing the changes. Again, neither the rate of gas-production nor the volume of gas produced was necessarily a correct measure of the fermentability of a sludge, because fermentation changes of a useful character took place even after gas-production had practically ceased. A point which had, perhaps, been too little stressed in the past was that there was an optimum water-content of the sludge which, he thought, the Authors would place at somewhere between 85 and 95 per cent. It was well known that air-dried sludge was fairly stable and encouraged the growth of moulds rather than of organisms which produced methane gas; but sludge containing more than 95 per cent. of water encouraged the growth of organisms which produced acid conditions and gave rise to objectionable smells. The Authors had brought out those points very clearly. On p. 43 the Authors referred to the capacity of the digestion tank per head of population, and said that that criterion might prove altogether misleading. He would like to say, however, that as a first approximation it was nevertheless the best criterion, and the capacity could be increased or reduced according to local conditions. There must be some basis for design. The second and third of the Authors' eight factors influencing the design of a sludge-digestion plant might well be grouped together, as the indication of the quality of the sludge; and it would be very interesting if the Authors would say what they regarded as the best measure of, or the best method for estimating, the fermentability of the sludge. *Fig. 7* (p. 53) brought out very clearly the fact that in the colder months of the year the temperature of the sludge was higher than that of the atmosphere, and in the warmer months, *generally speaking, it was lower. A drop in the atmospheric tem-* Dr. Calvert. perature at the end of July seemed to be rather anomalous. A third curve, showing the temperature of the incoming sewage, would, he thought, have been very useful. The two curves given showed the atmospheric temperature and the sludge temperature, but it might be suspected that the temperature of the incoming sewage might have exerted an effect on the temperature of the sludge, and that the temperature of the sludge would probably have followed more closely the temperature of the incoming sewage than the temperature of the atmosphere. Finally, he would like to say a word about the more scientific aspect of sludge-digestion, an aspect which was really fundamental and most likely to lead to useful modifications in methods of applying the process. The special types of organism which were necessary had not yet been so well-defined as in the case of several industrial processes in which micro-organisms were used, and he would like to refer to the pioneer work in that direction of Messrs. Söhngen, Bejerinck, and Kessener on *B. methanicus*, which was specially active in the decomposition of cellulosic material. That was not the only fermentable constituent of sewage-sludge, however, and experimental work might very well be directed towards investigating the types of organism most suited to the individual constituents of sewage-sludge, such as paper, fat, and so on, and then those organisms might be cultivated and specially applied. It was, perhaps, not too far-fetched to connect a change in the raw materials used in the paper-making industry with a very considerable falling-off in gas-production from the digestion of sewage-sludge. Mention was made in the Paper of the question of biological zoning, and the best methods of attaining it were indicated. It seemed to be suggested that no such biological zoning occurred in the activated-sludge plant, but he was inclined to think that there was a very definite variation in the types of micro-organism present in the mixture of sewage and activated sludge as it passed along the channels. That same principle might be applied in sludge-digestion, and the thought and consideration which had been given to the development of the activated-sludge process might well be applied to the digestion process. After all, the danger to be avoided by the use of stirrers was merely the danger of short-circuiting, and stirring could probably be applied with advantage in a long tank or channel or tube, to one end of which the undigested sludge was pumped along with some returned sludge from the later stages of the process. There were, indeed, many analogies between sludge-digestion and activated-sludge, bio-aeration, and bio-flocculation methods of dealing with sewage, and the process of digestion warranted as much forethought and attention as had been given to those other major processes. A

Dr. Calvert. study of the nitrogen cycle in sludge-digestion would also be well worth while. Perhaps the Authors would say whether the production of ammonia by the breakdown of complex nitrogenous compounds was responsible for the alkalinity of the medium which was so desirable, and whether that ammonia served as food for the organisms and was again converted into protein nitrogen.

Mr. Mountfort. Mr. L. F. MOUNTFORT stated that he was wholeheartedly in agreement with most of the points brought forward and the criticisms made in the Paper. On p. 47 the Authors remarked: "Where digestion is carried out in a single chamber it is a common practice to draw off a quota every day and add a corresponding quantity of fresh sludge. By this means the difficulty may be avoided, but a certain amount of partially digested material will be drawn from the tank with each discharge. Where daily mixing by mechanical devices is resorted to, the amount of immature sludge discharged from the digestion tank is probably greater." He thought a quantitative idea could be formed of the effect of that mixing. When there was a daily quota coming into the tank and a daily withdrawal, combined with complete mixing of the contents between those operations, some difficulty was caused. Obviously a small portion of each quota of the sludge must be withdrawn from the tank after having been in it for quite a short period, and, assuming a given ratio between the dose and the contents of the tank and complete mixing of the sludge, it was possible to calculate definitely the effect of the withdrawal of a small quantity. Supposing the ratio were one-twentieth of the tank contents, on the first withdrawal one-twentieth of the dose left the tank after a short interval. On each successive withdrawal, one-twentieth of what remained left the tank. By summing that series it would be found, he thought, that the reduction in the digestion of organic matter, owing to small quantities of sludge getting out of the tank too soon, was of the order of 20 or 30 per cent. It was almost invariably in the case of deep vertical-flow tanks that mechanical mixing was carried out, for that kind of mixing was more or less impracticable with large horizontal-flow tanks. Instead of saying that mixing was beneficial to the process of digestion in deep tanks, it would be better to say that it helped to counteract an inherent defect of the deep tank, namely, that the sludge tended to pack in the bottom of the tank. Mixing did avoid, to a certain extent, the difficulty caused by the tendency of the worked-out sludge to consolidate in the bottom of the tank. Obviously mixing in itself had a detrimental effect, for the reasons he had already stated. In referring to the use of the heat in the cooling-water and in the exhaust gases from the gas plant for heating the sludge, the Authors said: "It is a comparatively simple matter to effect a transfer to the sludge of approximately 50 per cent. of this waste heat." He suggested that any one contemplating those large tanks at Birmingham—an ocean of sludge—would be inclined to doubt the practicability of transferring so much heat usefully to the sludge. Fortunately it was possible, by using the information given in the Paper and in the discussion, and taking some information from the Paper by Messrs. Vokes and Townend,[1] to put some kind of check on that statement of the Authors. He believed he was right in saying that the quantity of liquid sludge produced at Birmingham was about 1,000 tons per day, from a population of about 1 million. It was stated on p. 56 that in a recent year 58 million cubic feet of gas had been produced from the sludge in the sewage from a population of about 400,000, which would mean about 400 tons of sludge a day. Thus the quantity of gas produced daily per pound of liquid sludge was about 0·17 cubic foot. The calorific value of the gas was about 650 B.Th.U. per cubic foot, so that the heat value of the gas from 1 lb. of sludge was about 110 B.Th.U. It had been proved by experiments carried out at Essen that the specific heat of sludge was practically the same as that of water, and it was known that the transfer of heat by conduction and convection took place much more slowly through sludge than through water. That was not due entirely to the viscosity of the mixture but partly to the fact that it contained a large amount of entangled gas, the bubbles of which were bad conductors. It was also known that destructive anaerobic fermentation, being a process of disintegration, produced heat in the sludge. That fermentation and the resistance to convection and conduction operated, he thought, to assist in the retention of heat by the sludge. If the whole of the 110 B.Th.U. per pound of sludge could be conveyed to the sludge without any loss, then, taking the specific heat of the sludge as equal to that of water, it would be possible to raise the temperature of the sludge by 110° F. The Authors said that, roughly speaking, two-thirds of the heat in the gas was rejected from the gas-engines—one-third in the cooling-water and one-third in the exhaust gases—and that it was a simple matter to transfer one-half of the rejected heat (or one-third of the total heat) to the sludge. The proposal illustrated in *Fig. 9* (p. 59) involved two heat transformations. It involved taking the cooling-water at 110° F., passing it through a boiler heated by the exhaust gases, and then using that heated water, by means of a heat-exchanger, to transfer the heat to the alkaline liquor pumped from the sludge through the heat-exchanger. If an efficiency of about 70 per cent. were postulated for the boiler and for the heat-exchanger it would not be far wrong.

Mr. Mountfort.

[1] Minutes of Proceedings Inst. C.E., vol. 226 (1928), p. 4.

Mr. Mountfort. The combined efficiency would thus be 50 per cent. He was inclined to think that, in saying that it was a simple matter to transfer one-half of the rejected heat to the sludge, the Authors were dealing with that 50 per cent. to which he had just referred, and it was not a case of transferring the heat to the sludge but merely of transferring it to the water which was to be used for heating the sludge. It was interesting to see how far the Authors succeeded in transferring the heat to the sludge. One-third of 110 B.Th.U. was equal to about 36 B.Th.U. per pound, so that there were 36 B.Th.U. per pound to be transferred to the sludge. The experiments to which Mr. Whitehead had referred had been made by heating large tanks full of sludge, by burning coal and introducing steam into the sludge. Mr. Whitehead had said, however, that the experiment had been arranged to imitate as closely as possible the scheme of heating from the exhaust gases, and it was justifiable to take the results as indicating what would happen when the exhaust gas was used. With the 36 B.Th.U. per pound in the hot water they had succeeded in raising the temperature of the sludge by about 9° or 10° F., so that the efficiency of the heat-transfer to the sludge was about 25 per cent. If that 25 per cent. efficiency were combined with the 50 per cent. efficiency of the apparatus, it would be found that of the available heat from the gas-engine only about $12\frac{1}{2}$ per cent. had been transferred to the sludge so as to raise its temperature. No one who saw those immense tanks open to the atmosphere would be surprised at that low figure; and the difficulty of heating large open tanks containing masses of sludge would be realized. The Authors referred (p. 49) to the fact that by retaining the sludge in horizontal-flow sedimentation tanks for a period of about 2 or 3 weeks they were able to get a sludge with only 85 per cent. of water. He believed he was right in saying that those tanks were operated manually. For the past 4 or 5 years he had been operating sedimentation tanks of precisely the same type, manipulated in the same way, and where, owing to limited facilities for disposal, the sludge had to be retained for at least 3 weeks and sometimes 4 weeks. He had never succeeded, however, in getting a lower figure than 90 per cent., and the usual water-content was about 92 per cent. He suggested that the degree of concentration which the Authors were able to obtain was probably due as much to the fact that in the trades wastes there was a great deal of matter which acted as a precipitant as to the fact that the sludge had been retained for 2 or 3 weeks. On p. 49 the Authors mentioned sludges containing 95 per cent., 90 per cent. and 85 per cent. of water, and said that the relative volumes (and approximate weights) were 3, $1\frac{1}{2}$, and 1. He suggested that that statement should be put the other way round, and that it should be said that the relative weights (and approximate volumes) were 3, $1\frac{1}{2}$, and 1. It was the weights which were in exactly that proportion; the volumes were only relatively so. Mr. Mountfort.

Mr. H. J. FEREDAY remarked that, although he had not had to deal with the subject professionally in any way, he was particularly interested in it, because he was able to compare the wonderful systems which existed to-day with the conditions when there was no system at all. He could remember very well the period immediately following the introduction of the Rivers Pollution Prevention Act, and the trouble that it gave the City Fathers in deciding what should be done. It was really a wonderful Act, because it brought home to the people who were polluting the rivers the fact that they would be penalized if they did not stop their practice. People nowadays could have no idea of the horrors that existed then. He lived in a small town in the Black Country in those days, and the effluent from the sewers went straight into the small River Tame, the water of which was black or dark brown in colour and ran over and between bottoms and banks of thick black mud. At that time all the closets were open and therefore solid matter did not get into the water, but those places were emptied in the dead of night and the soil taken away in carts, with the result that horrible odours were produced. He remembered the discussions which took place as to what should be done to comply with the Act, and eventually twin settling tanks were constructed of brick, which could be used alternately to receive the effluent from the sewers. That effluent went into the tanks, in each of which there was a weir of considerable length, and it rose through beds of gravel and later through coarse canvas. In the summer, the length of the weir enabled the water to flow over it slowly, but in the winter the conditions were much worse. When the thick mud or sludge rose in the tank to the weir level, the water was changed into the other tank and the horrible liquid was ladled out of the first tank and put over the land close by. Fortunately that land was suitable, being porous, so that the mud dried quickly and was soon so solid that one could walk on it; he remembered particularly that at that stage on digging into the mud it was found to be almost red with earthworms. He would like to ask the Authors what conclusion they would draw from that, as to whether the mud was purified or not. It was a long time before the people in the district understood that the dried mud was very beneficial in their gardens, but after a time they did use it, and he believed that to-day a great deal of it was used mixed with the pit spoil which was one of the features of the Black Country. Those who had lived in that district would be grateful to such men as the Authors and others who had done so much for the health of the community by developing the wonderful systems of sewage-treatment now in operation. Mr. Fereday.

Mr. Hanssen. Mr. C. T. A. Hanssen remarked that he had had 45 years' experience of sewage-works and during that period a number of processes had been introduced which had been expected to give a perfect sludge and a perfect effluent, but nearly all had led only to disappointment. A satisfactory effluent had been secured, but every sewage-works had been greatly bothered by that obnoxious compound, sewage-sludge. The farmers evidently did not want it. It could not be denied that there was much manurial value in it, but, on the other hand, there was also a great deal of inert matter, and it was very variable in constitution. The manurial value varied from day to day, and inert matter formed the great bulk of the sludge. Besides grit, paper, grease, and other things, there were certain materials in it which were actually detrimental to plant life. There was, for example, a great deal of soap in it, as well as salt, soda, and bleaching-powder, and in industrial towns there was a vast quantity of factory wastes, which were generally of anything but manurial value. It was difficult to know what to do with that immense quantity of sludge. In London it was simply shipped out to sea. If it could be used to produce gas and drive machinery a wonderful advance would be made. That process was, of course, in its elementary stages at the present time, and no doubt many improvements could be made in it. The walls of the tanks, for instance, might be more non-conducting than they were at present, and the floating roof might be made gas-tight. Gas-tight floating roofs were now used for petrol-tanks, and only a very small percentage of the petrol vapour was allowed to escape. There might also be a very considerable increase in the quantity of gas produced per head of population. As far as effluents were concerned, he thought there was little room for improvement. He had visited recently the installation at Hampton where the first Travis tank was put down in 1905, several years before the Imhoff tank was invented. It had often been referred to as a model installation. That tank had been at work for 26 years and was still giving an almost perfect effluent. Without using any chemicals or aeration it separated 94 per cent. of the solids in suspension and about 45 per cent. of the colloids, and it was difficult to imagine that anything better could be done by any form of tank. In addition to the tank there were sprinkling beds, with sprinklers driven by pneumatic engines travelling over the beds backwards and forwards. The sewage effluent was distributed over two separate sprinkler beds, one coarse and one fine, and was finally passed through a lagoon and through an air lift which aerated it. The effluent looked just like potable water, and more than that could not be done. He thought that very little improvement had been made on the Travis tank. It was used in Norwich, Luton, Durham, Mr. Hanssen.

Cairo, and other places, and it had given complete satisfaction wherever it had been put down. The Imhoff tank contained generally not more than 2½ hours' flow of sewage, and he was satisfied that that proportion was too small. In the Travis tanks at Hampton and at Luton the other extreme was reached, because the tank contained 8 hours' flow. The use of the Hampton tank was free to all: there was no patent. At Hampton 500,000 gallons of sewage passed through daily. The sludge was extracted by means of ejectors, so that it could easily be measured, and it amounted to 6,500 gallons a week. It was always taken direct from the bottom of the tank, so as to get the thickest sludge out first; the various compartments were emptied in rotation, so that the whole tank was emptied in about 1 week. The sludge was simply deposited in trenches and left on the ground. Fortunately the soil there was very porous. The great drawback of sewage-sludge was the number of seeds of all kinds contained in it. The farmer did not want those seeds on his fields, because they only produced what to him were so many weeds. It was not surprising, therefore, that farmers did not want sewage-sludge. Unless some method could be devised for eliminating seeds and for producing sewage-sludge of a more uniform quality and with more concentrated manurial properties, he did not think much success would be met with in trying to get the farmers to use it. He admitted that it might be useful for reclaiming land. In the sandy tracts around Berlin sewage-sludge had done an immense amount of good. There it had consolidated the ground to such an extent that trees and plants would now grow. Again, sewage-sludge ploughed into stiff clay soil would lighten it and make it more suitable for agriculture; but as manure for ordinary farmed land he thought sewage-sludge was almost valueless. At Hampton it had to be buried and there was no smell. One other thing done at Hampton should be mentioned. The light volatile sulphides to which the Authors referred were extracted from the Travis tanks by means of a fan and sent through a coke filter sprinkled with water. It was possible to pick up sulphur almost by the handful at the outlet from that filter. There had been some complaint about the smell at the beginning, but since a system of ventilating the tanks themselves had been introduced there had been no complaints. The sewage-works there were certainly worth inspection before going to Germany or elsewhere to get information about sewage-treatment.

The Authors.

The AUTHORS, in reply, remarked that they were glad to find Mr. Watson's views so much in accord with their own, and consequently any comments they had to make thereon must be concerned with details. Much of the reduction in solid matter to be disposed of when the septic tank process was in use in Birmingham was due to the

The Authors. fact that, owing to the limited size of the tanks used there for that process (5 to 10 hours retention) a considerable amount of solid matter in suspension was carried forward in the septic tank effluent on to the land. One of the Authors had given precise information on this head in the Paper referred to at p. 57. Other details, not given by Mr. Watson, relating to the chronological development of the anaerobic digestion of sludge at Birmingham would also be found in the same Paper. As to the reason for the present more general interest in the matter of sludge-digestion, the present Paper made it clear that that must of necessity be due to the universal need for an inoffensive and economical method of sludge-disposal; but the utilization of the gas would depend entirely on local circumstances. It was perfectly true that the Imhoff tank had been even more popular in America than in Germany; but perusal of the literature describing developments during the last few years showed a marked reaction in favour of the separate digestion of sludge, because its merits were at last being recognized. Mr. Watson had mentioned the fact that the capacity of the Birmingham digestion tanks was 9 cubic feet per head. It was 9 cubic feet about 10 years ago; but it should be remembered how the Birmingham works had come into being. They started in 1910–11 with an available capacity of about 1 cubic foot per head, and it was found that that was hopelessly small, even though it was possible to discharge into the tanks sludge containing between 85 and 90 per cent. of water. Then the war period ensued and various additions to the tanks were improvised. One of the largest units had been constructed by German prisoners of war; all were of a very rough-and-ready type, being merely square tanks with earth floors and earth embankments, and no doubt quite a number of them were somewhat inefficient. Some were too big and some were too shallow, and in certain cases the tanks were poorly equipped for working purposes. In the last 10 years those tanks had been largely remodelled and some of the less useful had been discarded, so that at the present time there was a gross capacity available—the Authors used that term because it was convenient, although it embodied certain pitfalls—of about $7\frac{1}{2}$ cubic feet per head, though the average quantity of sludge in the tanks was only about 5 to 6 cubic feet. The secondary tanks were used as balancing tanks, and once a year they were emptied completely. In the new plant at Colehall now being constructed for a population of 100,000 provision had been made for heating the primary tanks and using unheated secondary tanks. The gross capacity provided there in the primary and secondary tanks was rather more than 3 cubic feet per head. Respecting this question of digestion capacity, a most important fact which seemed to have received no consideration elsewhere was that wide experience was demonstrating that the process might often be rendered very unstable by cutting the space too much. Further, the universal need for provision against the interruptions in drying-off the sludge, due to climate, was met by the Birmingham method of dividing the separate digestion process into two stages, the second-stage tank being used also for storage. The view they had endeavoured to elaborate in the Paper as to the development of the attack on the sludge problem by anaerobic fermentation was that the Imhoff-tank method and the separate-digestion method represented two entirely different procedures for accomplishing the same result. Considerable success in practice had attended both modes of attack, and their view was that it was both desirable and inevitable that experience over long periods should intervene in order that the working-results furnished by each under varying conditions should be available. Some outstanding points had already been demonstrated, but it was probably too early yet to make fair and complete comparison. One important point should not be forgotten (it had been indicated by the Authors), namely, that the Imhoff tank had been designed originally to cope with the grosser polluting matter in sewage (that was, the readily settling solids) in a country where large rivers were available; and in the Authors' view that accounted for the considerable vogue of the Imhoff tank in America, where conditions were similar to those in Germany. In England, with its small rivers, very little suspended impurity in the effluent waters could be tolerated, and consequently the Imhoff tank was not adopted. The separate digestion of sludge process must be regarded as a logical and direct development of the septic tank by limiting the water in contact with the digesting sludge; and the Authors had endeavoured to show that what was needed in that direction was reliable evidence from careful and accurate observations of the results of large-scale operations. Dr. F. W. Mohlman, Editor of the American *Sewage Works Journal*, pointed out in 1931 that plant records from sludge-digestion plants were almost non-existent, and the Authors were in full agreement with him when he expressed the hope that the next few years would see that necessary evidence forthcoming. Mr. Alford had remarked on the absence of dogmatism in the Paper, and the Authors were pleased with this recognition of their endeavour to make their criticisms as impartial as possible. Even in such a mundane field as that of sewage-disposal a great deal of futile effort could be saved by a well-reasoned attack on the problems involved, and in the Authors' experience that method had played an essential part in producing successful results. It was necessary to qualify Mr. Alford's objection to keeping sludge in a sedimentation tank in contact with the sewage for more than a few hours. Anaerobic The Authors.

The Authors. fermentation required time to assert itself and the time varied greatly, depending on such conditions as the cleanliness of the tank, freshness or staleness of the sewage, temperature, the presence or absence of antiseptic trades waste in the sewage, etc. It was common experience in England that industrial sewage contained sufficient antiseptic material to permit a sedimentation tank to run for 2 to 3 weeks without serious anaerobic action being set up in the contents of the tank. Bradford sewage, to which acid had been added, remained inert for 12 months. Sewage of domestic origin only would usually set up septic action in a clean sedimentation tank in a few weeks, whilst sewages containing highly fermentable materials, such as sugar and allied matters, would set up anaerobic action in a couple of days or even less. Mr. Bransby Williams had considered the cost of activated sludge alone, but the whole cost of the complete purification process should be taken into account in making comparisons of the kind. Digestion of sludge could not be ruled out, even in India, where sludge dried rapidly. Questions of nuisance and cost would determine the choice there, as elsewhere. In the Paper the Authors had stated that the use of the digestion process should be directed to modifying the condition of the sludge so as to facilitate disposal. Evidence which was accumulating from various sources indicated that it ought to be possible to make even activiated sludge more suitable for the farmer by predigestion, and any gas which was formed during digestion might still be collected and used. Mr. Jackson had suggested that the influence of the water-content of crude sludge on the subsequent course of digestion was problematical and that the topic was therefore controversial. In septic tanks, where the proportion of water to fermenting solids was always very high, the gases produced were offensive and almost invariably contained sulphides. That experience was so universal that it was a matter of common knowledge. On the other hand, crude sewage sludge with a water-content of, say, 90 per cent. gave off volatile compounds of acidic and extremely offensive character (but not sulphides). Again, when the very same materials were fermented in the presence of about 90 per cent. of water with a sufficient reserve of alkaline material to maintain the pH value on the alkaline side (between, say, 7 and 8), and also with sufficient of the sludge containing the "methane ferment," the chemical changes due to the fermentation produced inoffensive volatile products—methane and carbon dioxide mostly, with traces of volatile paraffin bodies and ammonia which together gave rise to the well-known faint so-called "tar-like" odour. The Authors regarded the suggestion "that unless there was a certain minimum amount of solids, any success with the sludge-digestion process was unlikely" as misleading, for their experience was indicated briefly

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in the foregoing statement. References to the other physical factors which influenced the digestion, namely, temperature and reaction (or, as it was called, pH value), were of interest and important. What did not seem to be appreciated was that pH value had qualitative biochemical significance ; but there was also an indirect quantitative relationship between temperature and pH value which was of the greatest practical importance in large-scale work on the digestion of sludge. That relationship, which seemed to prove so baffling to many workers, might account for many difficulties and in particular was no doubt partly responsible for the extraordinarily slow progress to which Mr. Watson had drawn attention. The Authors claimed no priority for the term " biological zoning." The idea was originated by the late Mr. Scott-Moncrieff, and American observers had since confirmed the fact that digestion was completed by a succession of groups of bacteria. Nevertheless, although such evidence was very difficult to obtain and needed to be further reinforced, there was no doubt whatever that the notion associated with the word " zoning " was supported by the whole of the biochemical evidence, and, indeed, followed inevitably from the nature of the action, as Mr. Alford had indicated. The implementing of that idea in a practical fashion took the form in this case of dividing the operation into two stages, and it might be pointed out that it was neither accidental nor a mere coincidence that current literature was indicating a steady gravitation of workers on this problem towards the two-stage plan. Mr. Jackson's intention to provide facilities for testing the merits of the one-stage and two-stage procedures in parallel on a working scale was highly commendable. With regard to Mr. Jackson's later remarks it might be pointed out that the digestion of the sludge was strictly speaking a de-watering operation, but it was generally found that separation of the water was not always possible in the vigorously fermenting contents of the primary tank. That again was a plea for two-stage treatment ; but even more cogent was the fact that as the digesting sludge changed, its viscosity was lowered, until finally the solids dropped out of the aqueous system. Mr. Furphy's question dealt with a vital point in procedure, or in other words the mode of setting about the business of getting the sludge digestion process going on a working scale. The Authors' experience convinced them that the factors at work in the successful manipulation of the process were manifold and involved, so that a proper sense of values called for a keen appreciation of the relative importance of those factors, which was not always in evidence. Many workers seemed to regard it as essential that the process should be a continuous one, that was, that batches of sludge should be dealt with daily in each tank unit. The weakness of that procedure had been pointed out in the Paper, The Authors. and the limited amount of material which could be dealt with (3 per cent. to 6 per cent.) each day served to confirm it. At Birmingham it had been shown in the laboratory, and by large-scale practice over nearly 20 years, that excellent results could be obtained by additions of 25 per cent. of sludge at long intervals (14 to 21 days) to each tank unit, coupled with proper organization of the operations on the whole installation. The water-content of the crude sludge should be kept as low as possible. The answer to Mr. Furphy's question how often a primary digestion tank could be filled was that it would vary with the conditions maintained, chief amongst which would be the temperature: at Birmingham with unheated tanks it might be, roughly speaking, about six times a year. In reply to further points raised by Mr. Furphy, the water-content and the amount of volatile matter in the sludge, etc., must be known before any proper comparison could be made between what was being done at different places. Mr. Cotterell had asked whether the same type of open tank as had been originally constructed at Birmingham would be put into use if starting again to-day, and the reply was furnished by the type of tank being constructed at the Cole Hall Works (Birmingham). With regard to the technical aspect of the policy being pursued on the River Ruhr to cope with impure waters from towns and industrial establishments, it might be pointed out that that policy represented a complete departure from traditional practice, and time alone could show, when the policy had been fully implemented, how far it was justified. The effect, on the problem of sludge treatment, of the brief time-retention in sedimentation tanks had been dealt with by the Authors at some length in the Paper. They would point out also that the residual impurity discharged to the Ruhr was quite substantial, and had to be dealt with by the river itself. Respecting the question of mixing in the digestion chamber, the evidence as to its advantages or disadvantages was very conflicting. Dr. Sierp had shown recently that the increased yield of gas claimed as the result of mechanical mixing consisted largely of the inert gas CO_2. The purpose of stirring devices, as of higher temperatures, was to stimulate the rate of gas-production. Large-scale experience over many years had shown beyond all question that other things besides rate of gas-yield must receive proper consideration if satisfactory results were to be assured. The Authors' view with regard to stirring was that it should be very moderate, and further, its value depended on how it was done. Dr. Calvert's suggestion that sludge digestion should be regarded as a manufacturing process was interesting. In that respect it might be pointed out that from the time of the laying of the great intercepting sewers in towns which began in the early fifties (Birmingham was one of the first provincial towns to be so equipped) there had per-

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sisted well into the twentieth century the notion that valuable materials could be recovered from sewage. The money, time, and energy expended on the exploitation of that idea had been enormous, and in spite of constantly recurring failure and disappointment the idea still obtained. The danger lay in unduly stressing the importance of the recovery of by-products and losing sight of the fact that the main purpose of a sewage-purification works was to produce clean water, without creating a nuisance and at a reasonable cost. In the Paper they had made it plain that they were of the opinion that finality had by no means been reached in the development of the technique of the digestion of sludge from the point of view of its utilization and therefore of disposal. Their feeling was that better utilization would inevitably lead to better disposal—just as in manufacture—so that in that respect their view was really in accord with Dr. Calvert's. That view determined their attitude towards the proper use of heat in modifying the fermentation, to which Dr. Calvert has alluded. They considered that it was far more important to avoid allowing the temperature in a digestion tank to fall below a certain minimum of about 10° C. (50° F.) than to endeavour to attain a biological optimum temperature. They were in perfect agreement with Dr. Calvert that there must be some basis for design, and if all the conditions were similar (as for instance in inland towns in England) then capacity per head was a thoroughly sound basis. But where the flow of sewage per head reached the excessive volumes that were common in America, or where only part of the sludge was arrested in the treatment plant, as in many European towns, then allowance must be made for the effect on the amount of resulting sludge which was introduced by these variants. As to the criterion to be used in estimating the fermentability of a given sludge, a first approximation which gave a good working guide was the rate of gas-yield per day per gram of organic matter in the sludge when fermented under standard conditions (say at 25° C. and pH round about 7·5). As to the organisms responsible for digestion, much remained to be done; but experience at Birmingham had been very strikingly confirmed by the work of Dr. Heukelekian, of New Jersey, which showed that sludges collected from different parts of the same sedimentation system varied greatly in their amenability to fermentation. That seemed to suggest that the knowledge of the biochemical aspect was of more importance than the description of the microbiology of the process. In answer to Dr. Calvert's final questions, there could be no doubt that the ammonia which was found in large amount in the alkaline sludge liquor resulted from the destruction of complex nitrogenous compounds and also contributed largely to the very substantial reserve alkalinity ("buffer salts") also found therein.

The Authors. That ammonia, when the sludge liquor was diluted and submitted to one of the aerobic processes, would just as certainly contribute to the formation of protein as the organisms took it up for food. The Authors were glad to have Mr. Mountfort's calculation of the amount of immature or partially digested sludge which would escape too soon from digestion tanks where daily dosing together with stirring was the practice. That as much as 30 per cent. of ill-digested material might be discharged from such systems showed how important the matter was; and the Authors would endorse Mr. Mountfort's observations by emphasizing the correct way in which the evidence from such systems should be presented. Instead of stating that mechanical stirring operations were always beneficial, it was much nearer the truth to say that such stirring was found to be necessary in the cases referred to, in order to correct the evil results (as for instance packing of solids at the bottom of the tank) of a badly-designed system. Thus mixing or stirring in this case increased one evil in order to avoid a greater one. Already in the discussion the Authors had indicated that experience was demonstrating that cutting down digestion capacity made for instability, and per contra that a large reserve of alkaline material made for stability when used in a skilful manner. When it was remembered also that the installation at Birmingham catered for about 1 million people, it was not necessary to apologize for the size of the installation; but it might be suggested that Mr. Mountfort's term "an ocean of sludge" was slightly exaggerated. His discussion of heat-transfer losses well illustrated the difficulty of attaining a moderate increase of temperature in large masses of sludge. Mr. Mountfort's account of his endeavours to get a dense sludge having a water-content lower than 90 per cent. was of great interest and as a statement of carefully ascertained fact was very valuable. The Birmingham figures were obtained by continuous sampling during sludging operations over very long periods; and it might very well be that the denser sludge obtained at Birmingham was due, in part at all events, to the presence of industrial precipitants, as Mr. Mountfort suggested. A factor of considerable importance in producing the observed dense sludge at Birmingham was the presence of antiseptic materials in the sewage, which prevented septic action and thus allowed the sludge to consolidate under the action of physical forces. If antiseptics were not present, then anaerobic fermentation would be sure to occur and interfere with the consolidation. This suggestion was put forward to account for Mr. Mountfort's results. The Authors could see nothing wrong with their statement of volume on p. 49, despite Mr. Mountfort's criticism.