A comprehensive scheme for sewage sludge disposal in north-west England

J. HAYES, E. W. FLAXMAN & J. B. SCIVIER

Mr G. Truscott, British Hydromechanics Research Association

I should like to compliment the Authors on covering the various aspects of a topic which poses an increasing number of problems. It strikes me as a pity that, in this case, the most economic solution proved to be final sludge disposal at sea, rather than further use on the land, unless the value as a fertilizer is not very great.

65. This project provides a good illustration of the desirability of carrying out experimental work before embarking on a complex design. I should like to give a few more details concerning the operation of the viscometer developed by the British Hydromechanics Research Association (BHRA) specially for this job. Mr A. Linford was responsible for the viscometer design. The most notable feature was that the three tubes were arranged horizontally, rather than vertically, as for most normal slurry viscometers. This resulted from consideration of the space available on site, as the relatively large diameter tubes necessary for use on sludge meant additional length for a given pressure drop. The three tube sizes were intended to cover the range of expected viscosities. It was not expected that settlement of solids would occur with this type of sludge, even in laminar flow, in a horizontal tube.

66. Proving of this device was carried out at the BHRA on a chalk slurry with a similar range of viscosity as the actual sludge. Operation is relatively simple, and viscosity may be calculated from measurement of shear stress ($PD/4L$) and shear rate ($8V/D$) for laminar flow.

67. Departure from ideal Bingham plastic behaviour at low shear rates may be explained by the central core or plug of fluid starting to move before that adjacent to the pipe wall.

68. The Paper mentions marked differences in viscosities of sludges having similar solids concentrations. Was there any marked difference in the particle size distribution? Did the reported gas content of the sludge have any adverse effect on the accuracy of pressure measurements in the full-scale trial?

69. I was interested to note the reasons given for the choice of positive displacement primary pumps rather than centrifugal pumps. With the general trend to larger single pumping units, would the Authors envisage centrifugal pumps being considered for the primary pumping duty if the abrasive wear and screening problems could be overcome? Presumably these problems also exist to some extent with positive displacement pumps. Abrasive wear in both pumps and pipelines is currently being investigated at the BHRA.

Mr W. T. Greer, Depute City Engineer, Glasgow

The disposal of sewage sludge can be a considerable undertaking and the Paper deals with an alternative solution to that put forward by Dainty *et al.*¹

71. Without doubt, the disposal of sewage sludge to sea is a very attractive proposition to those authorities able to obtain access to shipping facilities. Sludge dumping has been going on for a long time and within my experience no cause for alarm has been substantiated.

72. The past decade or so has seen the development of a few regional sludge disposal schemes. Further south, the creation of the GLC encouraged such thinking and the Government's proposals for reorganizing local government throughout the UK is tending to favour them now. Glasgow has been involved in these developments, although to date much less formally than is the case in Lancashire and Cheshire. The original Glasgow main drainage schemes undertaken at the turn of the century connected a number of surrounding communities' sewerage systems to the city's three sewage works, but it was not until 1939 that serious consideration was given to accepting other authorities' sludge for sea disposal. In August of that year an agreement was concluded with the Burgh of Paisley, but the first sludge was received from Paisley only in 1971. The effective start of Glasgow's regional sludge disposal scheme took place in 1962, when the sludge heat treatment plant at Barrhead broke down completely. In desperation, Barrhead approached Glasgow for help and the first sludge was brought to Shieldhall Sewage Works in a converted Pink Paraffin road tanker. This scheme has developed entirely without Glasgow's active encouragement; in fact, the reverse is nearer the truth. Once the other neighbouring authorities realized the potential of the scheme, they quickly requested similar facilities.

73. The geography of an area obviously has a great effect on the type of scheme adopted. In Lancashire and Cheshire there are many more larger communities reasonably adjacent to each other than is the case in the West of Scotland and this, of course, favours a pipeline scheme. In addition, there is the problem of navigating in the Manchester Ship Canal that Glasgow does not have to contend with. However, the actual number of authorities and sewage works that are involved is similar in both regions. My own Authority is now receiving sludge from 49 sewage works belonging to 16 other authorities, covering an area of very similar size.

74. The Glasgow scheme at present is centred on one of the city's three sewage works: Shieldhall Sewage Works. Two pipelines run to Shieldhall: an old 230 mm dia. pipeline built in 1914, which runs from Glasgow's original sewage works at Dalmarnock, for a distance of 9.6 km, underneath the city's streets, and a new 305 mm dia. sludge main, 6.1 km long, constructed for the Burgh of Paisley in 1971. In addition, the other 15 local authorities deliver sludge to Shieldhall by road tankers and at present about 400 tanker loads are brought every week from as far away as the outskirts of Edinburgh. The city's third sewage works at Dalmuir has separate shipping facilities and Glasgow Corporation is disposing of about 250 000 tons of sludge per annum at present for other authorities. In 1962, when the scheme started, the first year's total was 2000 tons of sludge.

75. As in the case of the Lancashire and Cheshire scheme, the appropriate Government department, the Scottish Development Department, has taken an interest in this development and fact finding meetings were held in Glasgow in 1971. These also indicated a probable considerable further development and it was anticipated that by 1985 the surrounding local authorities might wish to dispose of over one million tons to sea from a contributing population of about 900 000. A consortium has not been formed in Glasgow as, under the Scottish plans for reorganizing local government, Strathclyde Region will be responsible for sewage disposal from as far away as Mull and Tiree, to South Ayrshire.

76. Against this background, I obviously take a keen interest in the Paper and my subsequent comments are based on my experience of Glasgow's conditions. I note that it is intended to accept many kinds of sludge and I wonder if the Authors have fully considered the possibility of smell problems. Smell has been very troublesome in Glasgow in recent years. It is thought that much of the trouble comes from dealing with undigested surplus activated sludge, but a number of foul-smelling road tanker loads have also been received. If sludge is put into a regional pipeline system in poor condition, it is unlikely to emerge any fresher!

77. In neither the Glasgow nor the Paisley sludge mains is the sludge pumped within the turbulent range. In Glasgow's case, because of the date of installation, it is not

surprising that the original pumping machinery could not achieve this. The pipes forming the main are reckoned to be between class B and class C and it has been necessary to keep the maximum working head to about 70 m. The Paisley main comprises class D 305 mm dia. spun iron pipes and their pumps have been designed to work up to a head of 105 m. In neither case have the pipes been lined with cement mortar and the condition of any pipes opened up in Glasgow for examination has been good.

78. No special precautions are taken to keep the pipeline full. Both the Scottish pipelines are laid along relatively flat stretches of country and, in an effort to reduce smell problems, both discharge directly into overhead sludge tanks some 8 m above the inverts of the incoming sludge mains. The Glasgow main has been broken and diverted on a number of occasions and no special precautions had to be taken when bringing it back into operation. An operational feature that did create problems was the introduction of comminutors. These appear to tear up rags and so on into long stringy material which reforms as it travels through the mains. In both Glasgow and Paisley additional screening was subsequently provided to remove as many rags as possible.

79. I was interested to note that it has been decided to adopt two types of pumps. Altogether, three different pumping systems have been tried in Glasgow. For the first 40 years of operation the sludge was dealt with by compressed air ejectors, which operated at a pressure of 60 lb/sq. in. and discharged sludge at the rate of 1 ton/min. In 1955 these were replaced by single stage centrifugal pumps. These were in use for the following nine years, but were not very satisfactory. One pump pumped the sludge the whole 9.6 km to Shieldhall and at no time was it possible to achieve the designed output of 500 gal/min. The best that could be achieved was about half that quantity after the sludge had been appropriately diluted. Several attempts were made to improve the performance, but no matter how small a size the pump clearances were adjusted to, the impeller and casing quickly wore away until more stable conditions were achieved.

80. It was finally decided to introduce three cylinder single acting reciprocating pumps. To protect the main against excessive pressures, a booster pumping station was introduced at approximately mid point. These pumps have operated satisfactorily and I can confirm the importance of ensuring that the plungers are kept effectively water flushed. A pre-fabricated metal panel tank was provided to form a wet sump for the booster pumps and its capacity is 9600 gallons. Considerable thought was given to ensuring that the two pumping stations worked in unison. Each pump was provided with a four-speed gear box to enable any slight differences to be accommodated. By good fortune it was possible to install the booster pumps within an existing main drainage pumping station at Kinning Park. No special land link was provided and the system now operates so smoothly that the pumpman at Dalmarnock does not even need to inform Kinning Park when he starts up or stops his pump. The Kinning Park pumps are entirely float controlled and as long as the electrodes are hosed down regularly the system operates trouble free. The tank levels are controlled within a range of about one metre.

81. I confess that I cannot agree with the intention stated in § 43 to install only two pumps in many of the pumping stations. Long experience has underwritten the soundness of providing a minimum of three units for each installation: one in use, the second on standby and the third stripped down often for several weeks during overhauls. I am also unenthusiastic about the proposal to adopt unmanned pumping stations. I do not think that this is very sound practice when pumping sludge and I note in any case that many of the proposed stations appear to be located in existing sewage works. Recently, manned pumping stations have been found to be better protected against vandalism.

82. The statement in § 51 makes me realize how much geography has favoured Glasgow. It was within my knowledge that the Manchester sludge vessels could be

held up in the Ship Canal and so on, but I did not realize that it was such a frequent occurrence. Fortunately, voyages seldom have to be cancelled in the Clyde and during the past two years, 1129 sailings have been made, whereas only three had to be cancelled. In view of the possible hold-ups to shipping, I presume that the Authors will take special measures to ensure that the sludge will remain in good condition while it is stored. Perhaps that is why they are proposing a berth in the middle of the Mersey.

Mr D. H. Hughes, J. D. & D. M. Watson

I have been concerned with the sludge mains which are now operated by the GLC, and my remarks relate to comparisons with them. These mains are 7 miles from Mogden to Perry Oaks, $3\frac{1}{2}$ miles from Deephams to Rammey Marsh and $13\frac{1}{2}$ miles from Deephams to Beckton. They are all 12 in. dia. and the pumping rates are 100 g/min. from Mogden to Perry Oaks, 670 g/min. from Deephams to Rammey Marsh and 720 g/min. from Deephams to Beckton. These velocities are about one third of those proposed in § 33. This suggests that larger pumping plant will be needed and higher operating costs will be incurred compared with the GLC schemes.

84. I wonder if the Authors are right to conclude in § 32 that pumping in the turbulent range would be essential. An alternative design, in my opinion, might be to provide air valves at high points, and to pump at lower velocities and lower heads. Air valves require maintenance, but they are great assets on a sludge main because, apart from allowing for lower head pumping, they create large air cushions which take care of all surge problems. Also they release gas which inevitably arises in the sludge main. The Perry Oaks main, built in the 1930s and rising for most of its length, was not provided initially with air valves, but I believe they were added later.

85. Mogden was built in the 1930s as part of a large scheme, partly directed at providing employment in a period of national depression, and its sludge main has dual pipelines. Mr Townend, the famous chief engineer of the Main Drainage scheme, had clear views on stand-by plant. He was not a man to be caught out in an emergency. I am quite sure therefore that no one would have had the courage to suggest a single pipeline between Deephams and Rammey Marsh. However, I think a single pipeline would have been satisfactory for Deephams–Beckton sludge main. The same argument can be applied to the proposed Mogden–Crossness line, and I support the Authors in their conclusion in § 34 that single pipelines are adequate.

86. In § 34 the Authors state that all pipes will be of ductile iron. Ductile iron has good features, but it is more expensive than grey iron, and I suspect it is less corrosion resistant. In particular, the pipes are thinner, and this means there is less barrier against external rusting. I would say that except where there may be special needs for higher strength or impact resistance grey iron is preferable. Experience in the Mogden main has shown that there is no internal corrosion when digested sludge is being pumped at low velocities. In the main to Beckton it was necessary to use a good deal of steel pipework in order to go round obstacles that were met. On one occasion it was necessary to make square pipes out of steel in order to get through awkward places. I am sure the same sort of problems will arise in and around Manchester.

87. My own view is that there will be plenty of smell, especially at the bulk storage, and I imagine the population of Liverpool will be up in arms about that. I suggest also that the local sludge storage equivalent of three days' production will quickly be shown to be inadequate, and again there may be smell problems.

88. On cost, I think the Authors are very courageous to talk in millions of pounds and take their estimate to two decimal places. The Paper makes this huge scheme seem quite straightforward, but it is not of course. It will be a Herculean task to carry out design and construction of this array of pipelines.

Mr H. R. Lupton, F

Surge hardly enters into the pumping of sludge as an enemy because sludge is soft and compressible. When pumping starts at one end of a main, the far end will not for some time know anything about it; starting impulses along the main are spread over an appreciable period, and there will be no shocks. However, the installations here concerned have also to be suitable for pumping effluent or water, which are much less compressible, and must be proof against surge shocks on such duties.

90. Instead of being an enemy, surge may, in the process of starting up motion in a column of sludge, be looked on as a friend. Viscometer tests show that it behaves on the whole like a Bingham plastic, i.e. to start a column moving involves the breakdown of a certain amount of shear strength inherent in the sludge structure. A quick start of pumping imposes in an elastic column local pressure gradients which are far greater than any of the resistive forces inherent in the Bingham structure. The sudden pressure increase—the surge—is thus a friend.

91. The potential scale in Fig. 10 is not linear, but logarithmic. The slope of the Schnyder lines (which represent the observations of a wave-borne frogman), being proportional to the wave velocity, would on the usual linear scale for potential in a fluid of non-uniform elasticity no longer (as in the ordinary diagram) be constant. However, because with a gassy fluid the wave velocity is reasonably nearly proportional to the absolute pressure, the slope of the Schnyder lines on a diagram having a suitable logarithmic potential scale is sensibly the same at all potentials (assuming a roughly level pipeline). Unfortunately, the synchronization of pressure wave arrivals and departures on which the diagram depends ceases to apply, so that only the initial stages of the surge phenomena can be helpfully represented by this device.

92. Figure 15 shows the comparative present values of the total cost of the service over the lifetime of the pipe scheme compared with two of its competitors. One factor in the assessment of present value of the cost of a service covering 50–70 years is the discount rate chosen as applicable to future expenditure. An incorrect choice of that discount rate can cause the order of economic merit of the schemes to change, because the curves cross near the mean of the range of rates shown.

93. In choosing the most probable ruling rate over the expected lifetime, a service of this kind must be compared with an alternative representative activity covering the same period of time and using equivalent resources. Such an activity might consist of buying land and growing crops on it. The present value of the land, plus the present value of future annual profits from the crops, would be calculated by the ordinary interest and sinking fund method. I suggest that to assess the present value of the sludge service a similar process must be employed.

94. Before the Second World War it was customary to assume a rate of growth of wealth, in the case of low-risk activities, such as were contemplated, of, say, 5% per annum. I suggest a similar rate should now be assumed when considering a life of 50–70 years.

95. The accountant of an authority I worked for during the Second World War advised me, in dealing with comparable problems, to work on a discount rate of 3%, because they borrowed at that rate. That was true, but they borrowed with Government aid, which I thought unlikely to persist for a large proportion of the expected continuation of the services concerned. So I refused to adopt 3% as a discount rate and stuck to 5%. Now interest rates are very high and an assumption that they will continue high throughout the working lifetime would err in the opposite direction. I see no reason to suppose that wealth in the next half century will reproduce itself very much faster than in the recent past. Although implements and processes become more effective, they absorb more labour in their own production and maintenance, and working hours tend to shrink. So I think that over the next 50–70 years the discount percentage should be based on the growth of wealth in low-risk activities, and expect that it will average 5–6%. This would make the pipeline scheme the winner on Fig. 15.

DISCUSSION

96. One large national undertaking is, I understand, now using 6% for schemes comparable with this one. I also note, from the most recent accounts of a large commercial undertaking, that they were earning about 4½% (after tax deduction) on the assets which were employed.

97. Factors such as the useful life, load factor, upkeep and repair costs, obsolescence and so on can be far more reliably judged by the engineer than by accountants, bankers or politicians.

98. Inflation should not invalidate a diagram such as Fig. 15, because it purports to deal with present values. 'Currency' is a very elastic measure of real value.

Mr G. Ainsworth, Rivers Department, Town Hall, Manchester

Basically I do not like centrifugal pumps for pumping sludge, but they are probably acceptable as boosters.

100. I hope that sufficient heed will be paid to the recommendation of the Liverpool Bay Working Party that screenings should not be macerated and put back in the sludge. I am pleased that some authorities in the Consortium are now taking definite steps to take them out and keep them out. Screenings may be chopped up but being non-degradable they do not decompose and can end up on someone's beach.

Mr H. R. Oakley, J. D. & D. M. Watson

Referring to § 17, the Authors appear to have dealt inadequately with the basic issue of the quantities of sludge to be dealt with, concluding that there were wide variations for which they could find no reason.

102. Sludge composition is also important, and mixtures of digested and undigested sludge would be difficult to handle and would probably generate a great deal of gas in the pipeline. Had thought been given to the desirability and economics of digestion both from this point of view and to reduce the quantities for disposal? The whole scheme depended on the feasibility of disposal at sea, and it was difficult to accept the view that disposal at sea might not be the end result and that sludge should be concentrated in the centre of Liverpool for disposal on land by incineration or other means.

Mr G. McGeachie, M

My work in connexion with an MSc thesis² is in general agreement with the Authors' work and Figs 2-4 are typical of results on Dalmarnock sludge.

104. The Authors comment in § 28 that sludges containing surplus activated sludge have a tendency to be more viscous could help explain why the predicted behaviour of Dalmarnock sludge shows a high frictional characteristic compared with the Authors' findings for most of the sludges which they tested particularly in the laminar range of flows.

$$\frac{\text{ratio of raw primary at Dalmarnock}}{\text{surplus active sludge}} = \frac{1}{1.66}$$

105. In my opinion 'thixotropy' is a significant characteristic in sludge rheology. The viscosity of sludge reduces not only with rate of shear but also with duration of the time of application. I am not surprised that there is no significant difference shown in Fig. 5 between the two sludges after they have been passed through the pump. However, with time a falling off of the pressure readings is indicated for both sludges. This observation indicates a breaking down of the sludges' resistance to being made to flow. During sludge viscosity determinations this breaking down effect continued over a period of about five minutes (with a constant applied rate of

shear) before stabilizing. After the sludges in question were left to stand for a significant period of time the same sludges again exhibited this break down characteristic, having apparently regained their resistance to being made to flow.

106. The desire to avoid the hydraulic gradient of a pumping system intersecting the vertical profile of the associated main is highlighted (Fig. 7). The Authors refer to pumping in the turbulent zone as being essential. I feel they do not specifically state their reasoning for this criterion. I agree that the figure of $1.5 \times$ the head loss predicted while pumping water is realistic—but only if complete turbulence is guaranteed when pumping a sludge of say 94–96% moisture content by weight.

107. The Authors imply in § 32 that the main criterion is that the pressure head creating the hydraulic gradient is such that no intersection between it and the vertical profile of the main occurs. This criterion could surely in the case cited be met by pumping the thicker sludges within the laminar range of flow, instead of diluting these sludges to reduce the cost of the pumping sets which could then pump the diluted sludges in the turbulent range for a reduced pump frictional-head capacity. The Authors do not state their case for turbulent flow precisely in the Paper. What their work as presented suggests to me, in relation to the question of turbulent flow criteria, is as follows.

108. When one is considering such a scheme as that proposed, where sludges of varying characteristics and from numerous sources have to be considered, then the hydraulic design involved must be based on a practicable design range which is chosen to meet most, if not all, cases. Fig. 4 shows that such a design range is obtainable from the turbulent region of flow for the sludges in question. In this region the sludges' velocity and frictional head loss relationship is approximately parallel to that of water but displaced by a factor of up to, say, $+1.5$.

109. In the laminar region of flow for the same sludges the range of frictional head losses and velocity of flow is far too wide to be of practicable value in the design of such an expansive scheme, in terms of sizing pumps and so on.

110. I feel that turbulent flow is to be advised in all cases of sludge pumping. This helps to ensure a self-cleansing pipeline which is less likely, therefore, to silt up and require frequent scouring. However, the thick sludge referred to in § 33 cannot justifiably, in terms of size and cost of the pumps required, be pumped in the turbulent region of flow. Hence dilution is favoured to enable the turbulent flow criterion to be achieved and at the same time to avoid the negative head situation developing in the associated pipeline.

111. The principle of diminishing return in terms of quantity pumped against head loss and hence cost of pumps, limits the degree of turbulence one would aim at in pumping sludge. However, I feel that critical velocities should be the minimum objective of the designer when considering velocity of flow in terms of quantity of flow and pipe diameter. A sludge main should not be less than 152.4 mm dia.

112. Aspects such as odour control, quality control of the sludges and operation of the scheme when executed really need closer examination by interested parties than is possible by the reading of the Paper in isolation. However, reorganization and regionalization of local government functions appear to present an excellent opportunity to finance, execute and operate such a praiseworthy and practical scheme for the benefit of the region as a unit.

Mr W. Bacon, Department of Construction, Oxford Polytechnic

I note from § 17 that there was substantial variation in the output and quality of the sludge from the various sewage works and that this was not due to the effect of industrial effluents. Has any attempt ever been made to correlate this variation with the social characteristics of the local residents, in terms of socio-economic factors, housing characteristics, income levels and so on? The use of the technique of multiple linear

regression would clearly be appropriate, and the results might prove useful for forecasting purposes. Middle class behaviour of today presumably represents the future behaviour of the working classes, in this context as in many other situations.

Mr Hayes, Mr Flaxman and Mr Scivier

Mr Greer and **Mr Hughes** mentioned the problem of smell. It may appear that we have suggested a mooring position for ships 1000 yards out from the shore in order to minimize the smell nuisance arising from the ship loading operation. Actually this is a benefit resulting from a navigational requirement. At that distance from the shore the depth of water is of the order of 60 ft; closer to the shore it would not be possible to moor large sludge ships at all states of the tide because the bed of the estuary shelves rapidly near the suggested mooring position.

115. The question of storage tanks presents a problem because, although there is vacant land immediately ashore, tanks built there would be fairly close to residential property. To load the ships by gravity it is necessary to have balancing tanks on shore on the rising ground but, nevertheless, close to the loading position. This would enable each of the 3000 ton ships to be loaded in about half an hour. Precautions will need to be taken to prevent smell nuisance from these tanks. It may be that the 14 day bulk storage tanks could be placed further back along the pipeline at a position remote from residential property.

115. **Mr Truscott** amplified the information given in the Paper about the viscometer which was developed for this work by the BHRA. The instrument proved effective and easy to handle. It was generally operated by two men—an engineer and a chemist—who were able to carry out the 20–30 test runs required to define the shear stress/shear rate curve in 4–6 hours.

117. No measurement of particle size distribution in the sludges was attempted. Examination of sewage sludge under the microscope generally shows the solids to be composed of bacteria, fibrous matter and larger lumps of inorganic material. Although some of the particles are discrete, many more are agglomerated and it seems doubtful whether particle size analysis produces meaningful results on such material.

118. The presence of entrained gases in the sludge did not affect the accuracy of pressure measurements in the full-scale tests. A 30 ft high vent column was fitted to a vertical branch on the circuit some distance upstream of the first test length and this eliminated most of the entrained gases; manually operated gas release cocks were also fitted at two high points on the circuit. The tappings for the pressure transducers and water manometer connexions were located horizontally at the sides of the 157 mm and 300 mm dia. pipes so that any remaining gas passing along the soffit did not enter the tappings.

119. **Mr Greer** provided an interesting account of recent developments in regional sludge disposal around Glasgow. After the re-organization of local government the new Strathclyde Region will be responsible for sewage disposal throughout the area. Similarly in north-west England, the new Regional Water Authority will take over responsibility for sludge disposal throughout the area of south Lancashire and north Cheshire shown in Fig. 1.

120. The 230 mm dia. pipeline from Dalmarnock to Shieldhall must surely be the oldest operational sludge pumping main of comparable length in the UK, if not in the world. On a visit to Glasgow in 1971 its record of trouble-free service for well over 50 years was most impressive. The sludge conveyed by this main is raw but there has never been any difficulty with deposition of grease on the pipe wall.

121. Many other existing raw sludge pumping mains work satisfactorily without evidence of grease deposition, but in view of the potential importance of any build-up in the long mains proposed in this scheme a questionnaire was circulated at the start to each of the 49 authorities concerned, asking whether they had ever experienced trouble with the existing sludge mains at their sewage treatment works. Most of

the replies received were negative, but a few authorities reported considerable difficulties. In one case a sludge main had become completely blocked by grease after four years of operation and in another a 300 mm dia. main had been reduced to an effective bore of about 75 mm after a few years. A sample of the deposit from the latter pipeline was obtained and analysis confirmed that the deposit consisted largely of grease.

122. There appears to be no way of reliably predicting whether grease deposition will or will not occur in any particular raw sludge main. For this reason it was decided that facilities for pigging should be provided on this scheme. The provision of a mortar lining to the pipes was considered to be an economical precaution against any ill effects which might result from the removal of the bitumen lining during pigging. Out of four long sludge pumping mains inspected in the USA, three are pigged regularly.

123. Returning to the problem of smell, it is thought that the elevated sludge reception tank at Shieldhall is open but in this case it is proposed to cover the sludge storage tanks and to provide air filters. Manchester Corporation's ships are already equipped with activated carbon filters on the air outlets used during loading.

124. Mr Hughes questioned whether it was essential to pump in the turbulent range. The decision was dictated by the topography and the widely varying viscosity of the sludges to be pumped. Reference to the typical pumping main section in Fig. 7 shows that if air valves were provided and the outlet left open between pumping cycles two thirds of the main could drain by gravity. This would lead to unacceptable pressure fluctuations when pumping was restarted. If relatively viscous sludges had to be conveyed, the head required would not be reduced significantly by pumping in the laminar range—a point which is shown by the upper curves in Fig. 4. Different considerations no doubt apply in the case of the GLC mains mentioned by Mr Hughes. The sludges conveyed are wetter and the pumping main routes either flat or uphill.

125. At the start of the investigation we looked carefully at the merits of twin pipelines but soon became disenchanted with the idea. The benefits of having a second main available proved, on detailed examination, to be totally insufficient to justify the substantial additional cost. On the question of pipe material, ductile iron is not more expensive than grey iron of the required pressure capability. There does not appear to be any evidence that ductile iron is less resistant to external corrosion than grey iron, and the provision of additional protection where required in corrosive soils is a straightforward matter. If present manufacturing trends continue, with ductile iron making up an increasing proportion of total output, it seems possible that there will soon be no choice in the matter.

126. Mr Lupton carried out all the analyses of surge problems associated with the scheme. In drawing attention to the logarithmic scale of potential in Fig. 10 he has, with characteristic modesty, omitted to mention that he himself developed this novel device during the course of the investigation.

127. The selection of an appropriate discount rate for present worth calculations is anything but straightforward and a range of figures from 6% to 12% was covered in the economic analysis. Mr Lupton argues strongly in favour of a rate at the lower end of that range. In 1967 the Government suggested that a test discount rate of 8% should be adopted for projects in the public sector, this figure being intended to represent the minimum rate of return to be expected on marginal low-risk projects undertaken for commercial reasons; more recently this test rate of discount has been raised to 10%. Further guidance relating more particularly to the field of water pollution control will, it is hoped, be provided in due course by the steering group set up by the Department of the Environment to study the economic and financial objectives of the new water authorities.

128. Mr Oakley and Mr Bacon both referred to the wide variation in sludge outputs from the major sewage treatment works. In each case the sludge output was assessed by the authority themselves. When the extent of the differences became

DISCUSSION

apparent the derivation of the figures was discussed in detail with each of the authorities. Although the methods of measurement used were clearly all subject to some degree of error they could not account for the wide difference in sludge production, neither could socio-economic factors which appeared not to vary greatly in the drainage areas as a whole. It was eventually concluded that the figures represented the best estimates which could be made and that the differences between the outputs of the major works were real. These works produce about 80% of the total sludge quantity to be dealt with in the scheme.

129. Digestion of sludge before conveyance through the pipelines would certainly be helpful in reducing gassing and also in reducing the amount of grease present in the sludge. However, at the time that the investigations were begun, considerable difficulties were being experienced with the persistent failure of digestion at Manchester Corporation's Davyhulme works. This works produces a much larger quantity of sludge than any of the other sewage treatment works catered for and the incident highlighted the inadvisability of basing any design on the assumption that raw sludge would not have to be conveyed. The Consortium accordingly decided at an early stage that the pipeline scheme must be capable of catering for both raw and digested sludges.

130. Both Mr Truscott and Mr Oakley referred to questions associated with the final disposal of sludge at sea. The results of the study on sludge disposal in Liverpool Bay³ provide encouraging evidence of the ability of this part of the sea to absorb substantial quantities of sludge without apparent ill-effect on fisheries or amenity. The disposal of similar quantities of sludge on land in south Lancashire and north Cheshire would pose considerable problems. Indeed, the Ministry of Agriculture at one stage approached the Consortium enquiring whether up to 500 000 tonnes per annum of farm wastes originating in this area could be accepted into the pipeline system.

131. **Mr Ainsworth's** plea for the removal of screenings from the sewage flow was echoed by several other speakers, and we can only agree wholeheartedly. The development of improved methods of screenings disposal, particularly on the Continent, appears to offer considerable promise in this respect.

132. With regard to **Mr McGeachie's** comments on the two curves in Fig. 5, the first sludge passing through the pump at the start of a pumping test did not reach tapping no. 2 until at least 2 minutes after start-up, although the first pressure wave arrived after about $2\frac{1}{2}$ seconds as shown by Fig. 6. The similarity of the two curves in Fig. 5 therefore indicated the absence of any significant thixotropic effect. The pressure peak occurring during the first 10 seconds after start-up resulted from the usual dynamic effects in the test circuit and was unrelated to thixotropy.

133. Mr McGeachie is correct in saying that the case for adopting turbulent flow is not fully explained in the Paper. One consequence of attempting to condense the results of such an investigation into the space of a few thousand words is that complex matters are made to look straightforward. The line of reasoning suggested by Mr McGeachie is broadly correct.⁴

134. With reference to the use or otherwise of centrifugal pumps, Mr Greer mentioned the stringy material produced by comminutors, and Mr Truscott asked whether an increase in the size of pumping plant had any effect on the choice of centrifugal pumps for a duty of this nature, bearing in mind the screening that may be carried out. Several people have had experience of quite large centrifugal pumps choking because of stringy material. Those pumps were liable to choke because they were high efficiency units with very good flow conditions into the impellers. The stringy material becomes wrapped around the impeller blades of such units, there being no turbulence to wash it away; hence the preference for the reciprocating type of pump in all sizes. Even they have their problems, of course. Special attention has to be paid to the design of the valves, and the valve chests have to be cleaned out regularly. Another factor affecting the choice of unit in primary pumping stations is

that if a pipeline begins to choke, thus increasing the head, the output of centrifugal pumps would be reduced and further choking encouraged. Within limits, the output from a reciprocating pump remains constant irrespective of head.

135. Mr Greer queried the use of only two pumps in many of the pumping stations with low load factors. Reciprocating pumps are expensive, both in themselves and in the amount of floor space they occupy, and it is therefore desirable to limit the amount of standby to that which is essential for continuity of operation. In this case the units in several of the pumping stations would be identical, making it worthwhile to keep spare parts in stock. Planned maintenance is essential and must be carried out regularly. The fact that stations are unmanned need not reduce the effectiveness of maintenance procedures, particularly where the existence of considerable numbers of pumping stations makes it feasible to have mobile gangs specializing in this work.

References

1. DAINY S. H. *et al.* Design of extensions to the Beckton sewage treatment works of the Greater London Council. *Proc. Instn Civ. Engrs*, 1972, **51**, Apr., 657–688.
2. MCGEACHIE G. *The rheological characteristics of sewage sludges—related to the pumping of such sludges through long pipelines.* MSc thesis, Strathclyde University, 1970.
3. BEST R. *et al.* Effect of sewage sludge on the marine environment: a case study in Liverpool Bay. *Proc. Instn Civ. Engrs*, Part 2, 1973, **55**, Mar., 43–66.
4. SLUDGE DISPOSAL CONSORTIUM. *Report on sludge pipeline scheme.* Binnie and Partners, London, 1971.