Paper No. 6328

Tehran water supply: water treatment and chemical manufacturing †

by

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Discussion

Mr A. H. Dilmaghani, presenting the Paper in the absence of Mr Meykadeh, who had just retired from his post as Managing Director, said that the Tehran water supply project provided an example of what could be achieved by close international collaboration; it had brought about vast changes in the standard of living of the inhabitants of Tehran and it had encouraged authorities and municipalities throughout Iran to do something similar for the potable water supplies of towns all over the country.

117. He explained a few of the problems which had been encountered during the three years' operation of the plant.

118. The ferric chloride injection pumps had given trouble owing to rapid wear of the various parts, and also it was quite certain now that at moderate temperatures coagulation and floc formation took place immediately after the addition of ferric chloride. Therefore, provision should be made for the injection of the ferric chloride to each accelerator, whereas in cold weather injection had to be made in the raw-water inlet chamber.

119. High silt content of water, which had not been experienced during the preliminary research work had also created a problem. In some cases, for a short time, there had been 30,000 p.p.m. of silt in the water, and it was almost impossible to treat it with present arrangements. However, with lower concentrations of silt, the addition of alkali had improved coagulation and functioning of the accelerators. The addition of alkali also had the advantage of reducing the total number of organisms in the water, which apparently could not survive at higher pH-values.

120. Automatic control of raw-water flow rate had been abandoned owing to lack of communications between the treatment plant and various points on the raw water aqueduct. Operation of the plant with a constant raw-water flow in proportion to average consumption rates eliminated the constant movement of operators in putting into service the relevant number of accelerators and filters, or taking them out of service in accordance with the rate at which raw water reached the treatment plant.

121. In the electrolysis plant corrosion of the ebomite lining of the cells and short circuits on the cell covers had occurred frequently. That had been compensated by the delivery of new cell bodies by the manufacturer.

122. Electrical switch gear, rectifiers, and transformers required constant supervision.

123. The temperature of the brine feeding the electrolysis plant was lower than normally required and had now been adjusted by modifications to the brine heater. That heater had originally been foreseen to warm up raw brine before treatment, and now was used to adjust the temperature of the treated brine.

124. In the ferric chloride manufacturing plant, capacity had been reduced because of

† Proc. Instn civ. Engrs, vol. 11, p. 385 (Dec. 1958).

frequent stoppage of the plant to clean out the scrap-dissolution tanks. A considerable amount of slime and sludge caused by insoluble material in the scrap used in the process accumulated in those tanks. However, steps had been taken to increase the capacity of the finished product to cope with high consumption of ferric chloride during flood periods and to compensate for the reduction in capacity.

Mr H. H. Dixon (Partner, Howard Humphreys & Sons) said it must be very seldom that so large a scheme was undertaken right from the intake to the consumer.

126. The units used in the Paper were mostly given in metric measure, and a conversion table was provided giving them British measures. However, he suggested that in Papers delivered to the Institution in London, although the work was carried out abroad, the main features should be in British measures which were normally used and the conversion should be into metres.

127. The quantities involved were very large—from 50 m.g.d. as designed to a future consumption of 77 m.g.d. There must have been many difficulties, but they had all been overcome and the work had been completed very quickly, even compared with much smaller works.

128. The connected production of chemicals was a novel idea, but it appeared to have been fully justified by the high cost of the equivalent traditional reagents, and the ready availability of cheap scrap iron and common salt.

129. On the operation of the filters, there appeared to be no central control panel in which the loss of head was indicated. Had that created a difficulty in the choice of filter to be washed? There were now forty filters and there were to be sixty-four. Did it mean that the attendant had to choose a filter from experience, or were they all washed as a matter of routine? Between the flood conditions and the dry-weather conditions there must be an enormous range in the quality of the raw water.

130. The silt load and the bed load were very large in times of flood. There was a reference to the construction of an impounding reservoir higher up the river and it had been suggested that excavated material might be contributing to the silt load. What would happen to the reservoir when it was completed? What allowance had been made for silt capacity, or what other steps had been taken to deal with the silt problem?

131. It was noteworthy that about 25% of the water was calculated to be used for irrigation. Metering to all consumers had been adopted, and that presumably prevented very much higher quantities from being used through lawn sprinklers and hoses being left on all night. Had the capital cost of the individual metering been justified by the results achieved in keeping down to a reasonable level the water used? The range was said to be from 15 to 66 g.h.d. with an average of 55 g.h.d. He thought that 66 g.h.d. might prove to be low.

132. He was not surprised that the estimated population for 1980 had already been reached, because the population increase from 1931 to 1946 was 7.6% compound interest whereas the 1946–1980 estimate was only 1.3%, or for Greater Tehran 3%. There seemed to be a reasonable explanation why the larger population had already been reached. That was common experience in urbanization all over Africa; people had flocked to such places as Khartoum, Nairobi, Dar es Salaam, and Kampala.

133. The losses in fittings in the pipeline were 11%. Could that be checked and confirmed? It was very high.

134. On testing, all reservoirs had leaked. What had been the main causes of the leakage and what steps had been taken to rectify it, and how had the testing water been paid for?

135. The period of maintenance of 2 years was unusual. Was there any particular advantage over the normal 1 year?

136. The metering must have given very good information about the distribution of flow, and he wished to know how the various meters agreed from the intake, treatment works, and service reservoirs right up to the consumers to see where the losses, if any, occurred. That information would be helpful to engineers generally.

Mr R. W. Aitken (Director, Candy Filter Co. Ltd) said he was very interested in the details of the treatment plant and particularly in the differences between what had been done and how it was normally done in Britain.

138. It would be interesting to have more information about the quality of the water. The astronomical figures for the raw water had been given, but what were the suspended solids or turbidity figures after settlement and after filtration?

139. An alkali had had to be used with the coagulant. What was the range of pH-values obtained through the plant? From the dosage figures given for the coagulant, it appeared that the water was an easy one to coagulate.

140. The raw water was treated in accelerators which were a high performance type of tank. The designed vertical flows were given as 21 ft/hour under normal flow. These were very high figures and indicated that the water must be easy to settle. Velocities of this order were normally only applicable to reasonably warm waters with a low viscosity which would permit a high settling rate. What were the ranges of temperature throughout the year?

141. The water level in the filter was about 3 m above the water level in the clear water tank. The head loss across the sand was restricted to 1 m. This meant that about 33% of the head available was used for filtering. Rough scaling on the diagram showed that the maximum possible head across the sand bed was about 2 m. Why was the head loss limited to 1 m? Was it because, using a relatively coarse media, one would expect a considerable penetration with relatively low head losses? In Britain filters were normally designed to fail safe; the limiting head loss was reached before penetration was such as to bring suspended matter through the filter.

142. It was stated that no packing medium, only sand, was used in the filter. Mr Aitken did not like filters which had no packing medium. Unless the nozzles were very closely spaced—they were in fact at about 4½-in. centres—something was needed to distribute the water between the individual points of entry to give uniform flow through the sand. In this case it would seem that the bottom sand was merely fulfilling a function which could be done better by a packing medium consisting of gravel and coarse sand.

143. What was the routine for filter washing? Was it on a time basis or on reaching a certain head loss? What was the time taken to reach the 1 m head loss.

144. The wash-water channel was above the normal water level in the filter and was not drained down. The quantity of water used for washing a filter was 150 sq. in. He calculated that the quantity of water remaining above the filter bed after washing was 50 sq. m, which meant that one-third of the water used for washing was left on top. Unless all the dirt in the water had been displaced at an early stage in the wash-water operation, a considerable quantity of dirt would go back into the filter bed.

145. The washwater from the filter was not run to waste but was all put back untreated into the inlet of the settling tanks. Were there any difficulties in this? In tropical countries, or where the water temperature was relatively high, septic conditions could occur in the decomposing organic matter removed in a filter and odour develop in the washwater. Was anything like that noticed in this case?

Mr G. A. R. Sheppard (Partner, Messrs Binnie, Deacon and Gourley, Consulting Engineers) referred to the unit costs of the chemical plant given in § 105. The chlorine plant was given as £123,000 per tonne and the production rate was 2.1 tonnes/day. That came to £258,000. The ferric chloride plant was given as £6,050 per tonne. At 3.2 tonnes/day that came to £19,400. That added up to £277,400, whereas § 97 gave the total cost of the chemical plant as £211,000. Where had the odd £66,000 come from?

147. Mr Sheppard himself was interested in a scheme having about 16 miles of raw-water pipeline. He had been considerably worried about the troubles that might eventually come through loss of carrying capacity and so on unless very considerable settling was allowed at the inlet end. At Tehran it was 7½ min whereas he would have

expected at least 30 min. Had the short settling time produced any disadvantages in practice?

148. What had led the Authors to select the filtering rate of 100 gal/sq. ft/hour? That was normal British practice. Recently in America rates up to 150 gal/sq. ft/hour had been used for water which had had good pretreatment.

149. Was the size of the sand dictated by availability? The grain size used was 1–1.4 mm as against 0.5 to just over 1 mm normally specified in Britain. Was the rate of filtration in any way dictated by the sand available? Was the very low loss of head used before the filters were washed dictated by the availability of sand?

150. For a plant of such a size being built in two stages, the size of the filter units was rather small for 1½ m.g.d. In America anything up to 2–2½ m.g.d. units were used. Construction in the bigger units would have been more economical and easier to run and there would have been fewer filter washing operations to conduct during the day.

151. It was a criticism of siphon-operated control plants that owing to the reduction of pressure on the base of the sand there was a release of oxygen, causing bubbles in the filter bed. Had that occurred on the beds used for siphon operation?

152. In the description of the siphon operation there appeared to be a misprint in § 19. The R should follow § 20.

153. The capacity of the treated-water tank, which was only 15 min, seemed small either as a chlorine contact tank or as a balancing tank between the filtering rate and the pumping rate. Mr Sheppard had been severely criticized in the past when he had provided an hour. He had been told by the engineer who had had to operate the plant that although theoretically it was all right it did not work out in practice. Mr Dilmaghani would be able to comment on the point from his experience. If the tank was to be used as a contact tank, as was conventional in Britain, then 15 min seemed a very short period.

154. Was the failing disk expected to fail at reasonably frequent intervals or was it something which it was assumed would never happen? How complicated and expensive was it to replace? If it was going to happen very often a conventional weight-loaded valve might have served the same purpose.

155. A Diesel-engine speed of 375 r.p.m. had been chosen. That was exceptionally low for modern plant. He would have expected at least the next synchronous speed of 750 r.p.m. to be used for an economic plant. Would the Authors give their reasons for selecting the very low speed plant? He appreciated that the slower plant was more reliable and that Tehran was not a very easy place to get to for urgent repairs.

Mr F. E. Warner (Partner, Cremer and Warner, Consulting Chemical Engineers) said that the Paper argued that the preliminary results of coagulation showed the advantage of the ferric chloride system, and from that there followed logically a scheme for the combined production of ferric chloride plus chlorine for sterilization although the alternatives were considered of other coagulants and the use of ozonization for sterilization. The undertakers had had to build what was almost the first chemical plant in the country.

157. The Anglo-Iranian Oil Company, when they conducted the nearest thing to large-scale chemical manufacturing, had located it in the obvious place, on the sea in the south. It was a natural advantage. Tehran was rather an artificial capital, but in the water undertaking all the disadvantages had been overcome successfully. In time process manufacture would return to the south and big industrial centres would develop in the south and south-west. It might then be economical to ship chlorine to the capital. But at present the plant justified itself.

158. Caustic soda, chlorine, and ferric chloride were three of the most corrosive and toxic materials known to the chemical industry. In spite of that, the whole of the plant was up to the standard of a water undertaker and not the standard of a chemical manufacturer. A chemical manufacturer often adopted considerably lower standards of housekeeping than did a water undertaker, but the general appearance of the outside of the buildings, the garden layout, and the inside of the chemical manufacturing plant was good.

159. There had been difficulties of corrosion of the linings of the cells and short-circuiting across the covers, and there had been inevitable alterations to be carried out on the chemical plant because the wide temperature variation was not fully realized. It was a very big temperature variation from 20° of frost to 90°F in summer.

160. The locally available rock salt contained 4% of gypsum, which had to be removed in the purification plant. The purification plant was subject to wide temperature fluctuations, and perhaps not sufficient allowance had been made to keep reasonably constant temperatures in those sections of the plant to get proper precipitation.

161. There should not be any shortage of scrap iron because Tehran must be one of the over-motored cities of the world—there were more taxicabs than in London—and there must have been plenty of bent bumpers. Perhaps that was why there was so much sludge in the ferric chloride plant. This plant justified itself. It was not completely in balance, because hydrogen was going to waste; but if all the hydrogen was used by combining it with the chlorine there would not be any chlorine available for the other manufactures.

Mr H. R. Lupton (Consulting Engineer), who had been concerned with the prevention of waterhammer in the delivery mains from the main pumps, said that the bifurcation of the main had added to the interest of the surge problem. The system could have been protected by means of an air-cushion at the pumping station alone, but at Tehran the use of a water-feed, through a reflux-valve, from a tank at a high point, allowed a great reduction in the size and cost of the air-cushion.

163. Mr Sheppard had questioned the use of failing disks. The main pumps delivered into service reservoirs through float-controlled valves, rise in pressure caused by throttling automatically tripping the pumps at a preset level. So long as these valves worked smoothly there would be no trouble: if, however, a valve were to stick and then complete its closure suddenly there would be a dangerous rise of pressure in the pipe. A conventional relief valve would take care of this, but it was much cheaper to fit a disk, blocking an escape orifice, and retained by small brass studs of such strength as would break before the pressure reached a dangerous level. The disks were a provision against a very unlikely occurrence, and the saving of the cost of relief valves was undoubtedly justified.

164. Mr Lupton was interested in the decision to use electric-motor drive for the main pumps, which could alternatively have been driven directly by Diesel engines (about 350 w.h.p. was involved) through step-up gears. The electric power had to be generated on the site and it had presumably been decided that the 12–14% loss entailed by double conversion of energy—mechanical-electric-mechanical—was worth while. The use of an electric motor, of course, gave more flexibility in the layout of a station, but this flexibility was offset by the use of A.C. motors driven from a constant frequency generating plant, since the pump speed could not then be efficiently varied to suit the various outputs. How did the Authors justify this lowering of efficiency to an extent which was the equivalent of about £1,000 in oil value for one pump running continuously at full load throughout a year?

165. It seemed not unlikely that the low speed (375 r.p.m.) of the Diesel engines in the generating plant was largely responsible for the very low maintenance costs so far incurred. In Britain, the cost of routine maintenance and servicing of Diesel engines (excluding repairs) was often taken at about 28% of the cost of fuel. Since fuel in Tehran cost about half as much as in Britain, the corresponding percentage given in the Paper—17½%—was very low indeed.

166. Could the Authors give particulars of the “toothed valve” used for preventing separation in the incoming main?

Mr G. Knowles (Principal Scientific Officer, Water Pollution Research Laboratory, D.S.I.R.) said that the first task in the preliminary laboratory and pilot-scale plant work had been to find out whether a coagulant was necessary at all. That had been quickly apparent. The samples of the raw water had contained appreciable amounts of very

fine suspended material and also colloidal material which could not have been removed in settling basins.

168. The next major question had been which coagulant would be best. It was particularly essential to know in this case because the equipment for making the solutions and for storage varied with the coagulant and there might have been difficulty in obtaining or making a special chemical in Iran.

169. Fig. 12 showed results typical of hundreds of metering tests which were made in the laboratory. It showed the size of floc and the pH value after the coagulant had been added. Curve 1 was aluminoferric. It had a very narrow pH range. The other pH values were artificially obtained. The curves, typical of so many experiments, gave a short-list of coagulants. No. 1 in Fig. 12 was aluminoferric (aluminium sulphate). No. 2 was aluminoferric with activated sodium silicate. No. 5 was sodium aluminate with activated sodium silicate. No. 4 was ferric chloride.

170. They went on from that short-list to try the coagulants in the pilot-scale plant. Of the three coagulants only the ferric chloride was completely satisfactory. A good sludge blanket was obtained with one of the others, but the sand filter, if the sand was of about 0.7 mm dia., blocked much too rapidly. There was also a horizontal flow pilot-scale plant, and in it the ferric chloride again proved to be the only completely satisfactory coagulant.

171. The treated water had been used for residual iron, and had always shown less than 0.05 p.p.m., so there was no danger of causing stains on wash-hand basins. Tests in the laboratory had indicated that ferric sulphate would be as good as ferric chloride, but ferric chloride had been finally chosen.

172. Besides selecting the coagulant, the pilot-scale test had given other information of some value, such as likely loss of water in the sludge, how much chlorine would be required to obtain satisfactory concentration lasting for several hours, and whether it would be necessary to raise the pH of the final water to prevent corrosion, and, very important, taste and odour tests were made on the final treated sterilized water.

173. The suspended solids encountered were very much higher than the maximum obtained in the pilot-scale tests, which had been 1,000 p.p.m. How did the dosage of chlorine required for the plant to give a satisfactory residual compare with that used in the pilot-scale tests? The raw water required about 0.3 p.p.m. to satisfy the chlorine demand.

174. Since the pilot-scale tests showed that corrosion would be unlikely to occur but that the water was on the borderline of corrosion, how had the plant and the distribution system fared?

Dr S. G. Burgess (Scientific Adviser to the London County Council) said that it was most praiseworthy that the Authors were able to manufacture the coagulants necessary for the treatment cheaper than the cost of importing them, but even if it had been slightly more expensive to do so it would have been well worth while from public health considerations to make a works in such a location completely self-contained.

176. The same thing applied to using a local rock salt of a not very good quality in preference to a better rock salt than could be obtained from the evaporation of sea water. It might be some consolation that there were very many rock salts available which were very much worse than the one used.

177. In § 24 of the Paper it was stated that sterilization by means of ozone was rejected on grounds of capital expenditure and operating cost. But this had been a very wise decision on other grounds. There were very many ingenious ways of destroying bacteria, including ultrasonic methods of shaking them to pieces, but chlorine was the only one that gave a stable residual in the water that would sterilise the pipelines and was useful when it came to the service pipes. In the circumstance on that consideration alone the use of chlorine was an extremely wise choice.

178. In § 110 (iii) 2 p.p.m. of chlorine was mentioned. Was 2 p.p.m. the normal dose given to the raw water and was that sufficient to achieve breakpoint chlorination?

FIG. 12.—INFLUENCE OF pH-VALUE ON FLOC SIZE IN LABORATORY TESTS ON WATER FROM RIVER KARAJ. TEMPERATURE 12°C
(Printed by courtesy of The Institution of Water Engineers from J. Instn Wat. Engrs, vol. 5, 1951, p. 289.)

KEY

1. Coagulant: aluminoferric (30 p.p.m.)
2. " aluminoferric (15 p.p.m.) with colloidal silica (6 p.p.m.)
3. " ferrous sulphate (20 p.p.m. FeSO_4)
4. " ferric chloride (10 p.p.m. FeCl_3)
5. " sodium aluminate (5 p.p.m.) with colloidal silica (5 p.p.m.)

Arrows indicate pH-value with no addition of acid or alkali before coagulant. Hydrochloric acid or sodium carbonate (calcium hydroxide for ferrous sulphate) was added 15 sec before coagulant to obtain the various pH-values.

It would be very interesting to know the composition of the raw water and its bacteriological state.

179. Turbidity varied from 553 to 11,600 p.p.m. Dr Burgess thought of turbidity as something less than 5 p.p.m. that could not be measured by normal methods. In fact, 11,000 p.p.m. was very nearly diluted slurry. That the water could be cleared up with 7–25 p.p.m. of ferric chloride and purified in the plant indicated that the plant was very efficient.

Mr A. A. Chapman (Engineer and Manager, Medway Water Board) said that the use of accelerators prior to filtration was fairly commonplace in Britain. They were used extensively in lime softening plant and for clarification of the raw water. In the latter application they tended to be temperamental, their effective operation being dependent on the formation of a sludge blanket. The Authors had stated that turbidity varied between a little more than 500 p.p.m. to 11,000 p.p.m., and he suspected that the variation took place violently. What difficulties had the Authors experienced in the operation of the plant in maintaining an adequate sludge blanket and preventing it carrying over to the filters?

181. The use of a variable speed motor for the accelerator impeller drive was not common practice in Britain. Was that a special requirement of the specification or was it standard practice with the continental licensees of that type of plant? In an accelerator installation with which Mr Chapman had been associated, he had been

instrumental in installing variable-speed drive for that very purpose—against the advice of the licensees of the equipment—and it had proved valuable in practice.

182. The filters had been enclosed and provision had been made for enclosing the tops of the accelerators but the latter enclosure had not been done. There was an advantage in covering the filters, but he doubted if the cost was justified under normal circumstances in Britain, where the range of temperature was not as great as in Tehran. It would be relatively cheaper to cover the accelerators than had been the case with the filters, and such provision would have reduced the risk of floc carry over, which could be considerable in a high wind, particularly with large accelerators. It would be interesting to know if experience in Tehran would now favour covered accelerators.

183. A false floor made of asbestos sheets had been used for the filter bottoms. That type of filter bottom had not been used in Britain. Had it proved entirely satisfactory? The design might facilitate construction and maintenance, but it introduced difficulties with bedding the asbestos sheets and prevention of fracture of the sheets. It might be that the advantages of simplicity could be outweighed by disadvantages.

184. Part of the treated-water tanks were located below the filters. Mr Chapman had had experience of that type of layout and did not like it. It added difficulties in the construction of the filter and slowed up the construction. What were the Authors' views on such a layout?

185. The control of the rate of flow through the works was apparently done by the filter rate setting with a secondary control from the level in the treated-water tank operating the main inlet valve. He gathered that it had not proved entirely satisfactory. It was better to control the rate of input to the works and then by mechanical or mechano-electrical means control the rest of the installation to follow the pattern of the flow into the works. It would have been relatively simple to have done that at Tehran. He understood that some alteration had already been effected.

186. The treated-water tank was stated to have a capacity of only 15-min retention at ultimate output. That seemed alarmingly small. The whole control of the works would have been greatly simplified if the size of the treated water tank had been enlarged to what in normal practice in Britain would have been at least 1 hour.

187. All the electrical equipment used nowadays in water works was extremely reliable, and he was surprised to hear that the equipment required constant supervision and maintenance.

Mr Herbert Addison asked for the views of the consumers of the water supplied by the installation. There were two kinds of consumers, those who presumably had to pay for the water because it was metered and those who drew it free of charge from standpipes. Some of those latter users might not have been accustomed to water of such purity, and so far from appreciating the purity they might have thought that the water was lacking in body. Had there been any complaints on that score? Alternatively, had the users of water from standpipes appreciated the advantage of the improved supply so much that they had put a strain on the resources of the installation?

189. Was the total revenue likely to balance the very heavy expenditure of about £10 million on the plant? He thought that the cost of delivering the water was 11d. per 1,000 gallons. The charge to the consumers must be higher than that. Did they regard it as excessively high?

Mr Bernard Whitteron (Partner, Howard Humphreys & Sons) said that silt removal was proving a troublesome factor in operation. Whereas in the experimental work over 2 years described in Mr Knowles' Paper¹ there had been variations of 1,000–3,000 p.p.m. of suspended solids, as much as 30,000 p.p.m. had now been reported. If the increased silt load was mainly due to the excavated material deposited in the stream the representations to stop it should be unanswerable.

191. Maximum figures of suspended matter given by Reid² were, for the Irrawaddy, 10,000 p.p.m., the Nile 4,000 p.p.m., the Hooghly 3,600 p.p.m., and the Jumnah 4,000 p.p.m. Tehran exceeded all those and such concentrations must present particular

difficulty. A further case reported by Smethurst and Hardy³ gave 10,000 p.p.m. as a normal maximum of Tigris water, but there had been an exceptional occurrence of 47,200 p.p.m.

192. The delay entailed in making silt analyses normally imposed a restriction on obtaining satisfactory records. Was any method of quick estimation of wet silt used, and if so, had a reasonably reliable conversion factor been established?

193. Might not the whole plant with advantage have been sited near the intake where the silt disposal appeared to present no problem?

194. The temperature variation of the river water was extreme. He thought that would give rise to some operating difficulty, particularly in filter washing.

195. Mr Whitterton had frequently pressed the advantage of electrolytic sodium hypochlorite solution, but presumably that had been ruled out because of the need for ferric chloride. Although the cost of chlorine was only slightly less than the imported material the advantage of using only local materials was immense. There were often delays in the delivery of chlorine, and use of local supplies eliminated risks and worry in this respect.

196. Ferric chloride was not often used in Britain because it was such a difficult chemical to handle. Would the cost advantage be very much altered if the plant was scaled down to one-tenth the size?

Mr D. F. G. Larkman (Civil Engineer, The Paterson Engineering Co. Ltd) said that, on the River Mersey, accelerators had been installed as clarifiers, and the rise rate which had been used was 2–2½ metres/hour. A rate of 6·5 metres/hour seemed rather high. Softeners using rise rates of 5–6 metres/hour had been installed, but even 6 metres/hour was very high for a softener. Was there, with a rise rate of that order, any carry over of the sludge bed through which the incoming raw water passed before being collected?

198. Unless a clarifier was designed for the particular water with which it was to be used it would be temperamental. There was considerable difference of opinion about the design of clarifiers.

199. An important feature of the scheme was the type of collection. Water was collected in radial launders through orifices below the top surface of the water. That was an advantage where there were extreme conditions of temperature. At very low temperatures with ice forming water could be drawn from below the top surface. Had the Authors had any trouble during very cold conditions, and if so, how had they overcome it?

The following contributions were submitted in writing.

Mr George Smethurst (Senior Engineer, Messrs Binnie, Deacon & Gourley, Consulting Engineers) asked if the high rate of upward flow in the accelerators led to trouble when the river water became really turbid. Upward-flow tanks tended to be smaller in cubic capacity than horizontal-flow tanks and it had been his experience in the Middle East that when the rivers were really turbid upward-flow tanks behaved rather badly. Admittedly his experience had not been gained on accelerators, but he imagined that they might be afflicted similarly by reason of their relatively small volume. He believed there was a critical value of the suspended-solids content of the water being treated, below which the upward-flow tank held many advantages, and above which it tended to fail. Naturally this critical figure would vary from river to river, because of different types of suspended matter, and he doubted if failure would ever occur in Great Britain where turbidities were infinitely lower than peak values registered in the Middle East.

201. Sudden failure of upward-flow basins had occurred in Baghdad from time to time, and this condition had been cured by building a small horizontal-flow basin of roughly one hour nominal retention capacity in front of the upward-flow basins. It

was worth mentioning that on the old works at Mosul a small preliminary horizontal-flow basin had extracted an enormous proportion of the suspended solids; the time might come when some similar expedient might have to be adopted elsewhere if conditions required it.

202. The Authors had achieved excellent results. It appeared that the costs were rather lower than would have to be paid for comparable work in the United Kingdom and were probably similar to those ruling in Iraq. From the photographs, however, and from his own knowledge of the Middle East, it was evident that the workmanship achieved in Iran was better than was obtainable from local firms in Iraq, and the cost of the finished plant in relation to its quality seemed to be very satisfactory.

203. The continuous loss of head across the filters between the settled-water channel and the level in the pure-water basin seemed to be rather high, even compared with module-controlled filters, and again he thought that the type of filter installed latterly at Baghdad had advantages. Had any trouble been experienced in practice because of untimely leakage at the air inlets controlling the siphons, and what indication would be given to the operator if such leakage took place and reduced the flow through any particular filter?

204. He also noted the relatively small difference in cost of making the chlorine on site and importing it and wondered if the cost of maintenance of the plant was showing any tendency to rise and thus reversing the balance in favour of importation? However, price was of secondary importance because World affairs had been known to upset chlorine deliveries to the Middle East and it was wise to be in a completely independent position.

The Authors, in reply, felt sure that British Engineers were now familiar with the use of the metric system on overseas projects (§ 126), and hoped that the tables included in the Paper would facilitate rapid conversion to British units.

206. They thanked Mr Sheppard for pointing out (§ 152) the misprints in §§ 19 and 20.

207. The composition of the raw water (§§ 129, 178) had been summarized in Fig. 2 of Paper No. 6327 and in greater detail by Knowles¹.

208. Further information, obtained since the designs were prepared, had been given by Mr Dilmaghani (§ 119). During the year ending March 1959 the bacteriological count had varied between a minimum of 60,000 and a maximum of 5,000,000. The highest M.P.N. (most probable number) of coliforms had been 10,000 and the minimum 3,000.

209. Conditions in the reservoir to be formed by the dam now under construction in the upper Karaj Valley lay outside the Authors' direct responsibility. They were, however, able to state that considerable dead storage had been provided and that no other special steps had been taken to deal with silt (§ 130).

210. The total head loss (§ 133) in the pipeline was 86.75 m of which 5.70 m was lost in valves and fittings, and 2.80 m at the inlet and outlet chambers.

211. The retention time (§ 147) of 7½ min (§ 24 of Paper No. 6327) provided for settlement of the coarser solids, first to protect the bitumen lining in the raw-water pipes, since the operating velocity was 1.85 m/sec (6.1 ft/sec), and secondly, to obviate settlement and banking of heavy solids which could not be removed from the settling tanks by normal means. An extension of the retention time in the detritus tanks would have increased the percentage settled, but the additional expense involved would not have produced a compensating saving at the treatment plant. If the high silt content persisted, the bulk storage of raw water as referred to in § 88 was considered to be preferable.

212. The pipeline had been in operation for 3 years with no noticeable loss in carrying capacity. No deterioration had been observed in the pipe lining.

213. The control valves (§ 185) on the outlet to the raw-water main, referred to in § 29 of Paper No. 6327, would probably have been better described as sleeve valves with triangular ports, rather than "toothed" valves (§ 166). Each valve consisted essentially

of a vertical cylinder with two rows each of six tooth-shaped ports set at equal spacing around its circumference. A sleeve with similar ports in the same vertical alignment slid within the cylinder. In the lowest position the sleeve closed the cylinder ports, while in the highest position the ports of both cylinder and sleeve coincided to permit full flow from outside to inside the cylinder. The ports were shaped to limit the rate of opening or closing when the sleeve was in the low position of travel.

214. This type of valve overcame the vibrations and pulsations caused by unbalanced forces when a column of water flowing at high velocity passed through a partially closed sluice valve.

215. Measurement of the residual head on the upstream side of the valve provided a means of assessing the flow in the pipeline. The valve was, therefore, also used to control the rate of flow of raw water to the gravity conduit and to the treatment plant.

216. The "toothed" valves on the outlet to the 40-in. raw-water main provided the primary control. The additional control derived from the falling water level in the treated-water tank was, therefore, confined to narrow limits.

217. The possibility of siting the treatment plant near the river intake (§ 193) had been considered during the planning stages, but rejected in favour of the better accessibility and closer control made possible by location on the outskirts of the city.

218. Instrument panels in the treatment plant provided continuous records of water levels in all service reservoirs and consumption in each of the six distribution areas. The quantity treated could, therefore, be closely related to consumption and need. This would not have been possible so readily had the treatment works been located near the intake from the river.

219. The turbidity (§ 138) of the settled water was about 7 p.p.m. (silica scale) and of the filtered 2 p.p.m. The pH-value (§ 139) of the raw water ranged from 7.5 to 8.6, reducing with the addition of FeCl_3 . After chlorination the pH-value of the treated water was between 7.5 and 8. Speaking generally the water was easy to coagulate. No simple or quick method of estimation of wet silt (§ 192) had been used in the plant.

220. From Fig. 2 of Paper No. 6237 it would be seen that the flood period with high silt content occurred in the warmer weather of early summer. Had it occurred in mid-winter when the temperature of the water was about 1°C (§ 140), or had it persisted into August when consumption was at a peak, it was possible that more difficulties would have been experienced in an accelator operating at high upward velocity (§§ 197, 200). Even so the exceptional high silt content of the raw water which had been experienced during the first 3 years of operation, and which had been commented upon by a number of speakers, had made it necessary to reduce for short periods the rate of flow through the accelators. To overcome this, provision had been made for a large settling basin for raw water as referred to in § 88.

221. Otherwise this high velocity had raised no operational difficulties in maintaining an adequate sludge blanket, and no special measures had been necessary to prevent carry-over of floc to the filters. Probably the limit of silt content at the designed maximum upward rate of flow was of the order of 8,000 p.p.m., but above 4,000 p.p.m. extra attention and care had to be given to the operation.

222. Carry-over to the filters had occurred when the FeCl_3 was added in the raw-water channel, for floc formed very rapidly and was broken up in the inlet to the accelators. Adding the chemical direct into the accelator had eliminated this trouble.

223. With the rapidly changing quality of water the use of variable-speed motors (§ 181) to operate the accelator impellers provided the required flexibility in operation.

224. Although provision had been made in the design for covering the accelators (§ 182), this had not been necessary, for the expected troubles from high dust-laden winds disturbing the sludge blanket had not been experienced. There had been some icing of the water surface of the accelators, but operation of the plant had not been affected.

225. The normal temperature range of the water was from 1°C to 25°C , but since the Paper was presented a short period of intense cold had resulted in the formation of frazil ice at the river intake.

226. The unit size of the filters (§§ 148, 150) had not been stipulated in the original specification, but the use of side weirs and a central channel for collection of filtered water and distribution of air and wash water had imposed a limit on the width and length.

227. The rate of filtration and of backwashing closely followed the specification, which had been based on the pilot experiments and followed general practice at the time when the plant was designed. The Authors believed that, although higher rates were used in the U.S.A., general practice there was much the same as in the United Kingdom.

228. Each filter had a control cubicle at which loss of head (§ 129) and rate of filtration were measured. There were two lamps on each cubicle, one green and the other yellow; as soon as head loss reached 1 m the yellow light flashed to indicate that backwashing was required, thus avoiding the need to keep a constant watch on individual filters.

229. In operation it had been found that the period between backwashing, utilizing the full head loss available, was 5–6 days, but at the end of the filter run there was a tendency for negative pressure to develop in the collecting channel releasing dissolved oxygen (§ 151). An arbitrary limit of 1 m (§ 141) had, therefore, been fixed to provide the margin described by one speaker as “fail-safe”. The interval between filter-washing (§ 143) was not normally allowed to exceed 3 days.

230. The actual head loss was 1.82 m from normal top water level in the filter to water level in the filtered water outlet chamber (E in Figure 6) with a further head loss of 1.48 m to the top water level in the treated-water tank.

231. The grading of the crushed quartz sand (§§ 142, 149) used in the filter was determined by the manufacturers of the plant and had given satisfactory results.

232. There had been no difficulty in flushing the silt away from the top of the filter, the maximum travel being only 2.4 m. With a sludge, mainly inorganic in character, there would, in the Authors' view, be no disadvantage if a little silt settled back on the top of the filter (§§ 144, 145).

233. Since the filters were not drained down, the actual net additional quantity left after backwashing was 7.5 m³. The contents from the top of the sand to the washwater weir level was 30 m³.

234. There had been no evidence of septic conditions or smell as a result of returning the wash water to the inlet of the settling tank.

235. The false floor (§ 183) consisted of asbestos-cement sheets and precast concrete beams bolted down against uplift during backwashing. There was no inherent fault in the design, but the extra care needed in erection balanced the simplicity of the arrangement to some extent.

236. The cracked plate and broken nozzles which had to be replaced were regarded by the Authors as unfortunate teething troubles. The failure had been, in all probability, due to the speed with which the erection had had to be completed to meet the appointed opening date.

237. Since air was admitted to the top of the siphon during the whole period of filtering, there was some tolerance for leaking joints (§ 203). If an appreciable air leak occurred, the filtering rate would be correspondingly reduced and this would immediately be revealed by the rate of flow indicator.

238. The Authors agreed that the volume of the treated-water tank (§ 153) could, with advantage, have been made larger, although after more than 3 years of operation, during which samples for bacteriological analysis had been taken regularly from every part of the plant and from the distribution grid system, standpipes, and consumers taps, it had been found that the contact time was sufficient.

239. In their bacteriological laboratory the Tehran Water Board were following the American standard method of testing, which provided for only 10% of the samples collected to give positive results. Over the past year ending March 1959, positive results had been obtained from 7.3% of samples, which was well within the 10% allowed.

240. No difficulty had been experienced in balancing filtration and pumping rates.

241. The treated-water tank had been located in a natural depression (§ 184). The filters would have had to be designed to span this and complications in the design could not, therefore, have been avoided in any case. Moreover, the natural ground provided good foundation conditions and the Authors believed that in this case an overall saving in cost had been achieved. They agreed that for a level site the form of construction adopted might have been different.

242. Figures for chlorine dosage given in §§ 110 and 115 were higher than the actual quantities used in practice (§ 178). These closely coincided with the pilot-plant tests carried out by Mr Knowles (§§ 167–174). Using 0.6 p.p.m. a residual of 0.3 p.p.m. was obtained at the outlet from the plant, and constant sampling had shown that there was always residual chlorine in the remote parts of the distribution system.

243. No corrosion had so far been found either in the treatment plant or the distribution system (§ 174). The pilot experiments had shown that the quality of the treated water was marginal in respect of corrosion and provision had, therefore, been made for the addition of an alkali. This had been referred to by Mr Dilmaghani in § 119 as having the added benefits of improving coagulation and reducing the bacteriological count in the settled water.

244. The specification called for Diesel engines having a maximum speed of 750 r.p.m., the manufacturers being given the option of offering alternatives. Machines of 375 r.p.m. (§§ 155, 165) had been offered in the accepted tender.

245. Mr Lupton had queried (§ 164) the decision to use electric-motor drive for the main pumps. Power requirements were widely distributed over the site and distribution could only have been made satisfactorily at high tension. This had determined the use of A.C. current. Allowing for the reduction in steady base load on the main generating plant (see Table 1, § 76) which would have resulted from the introduction of direct Diesel-engine drive to the pumps, the comparative loss in efficiency was probably nearer 8% than the 12–14% quoted by Mr Lupton. The pumps were not running continuously throughout the year, and after allowing for this and for the extra labour required for operation of dispersed power units the equivalent annual cost was about £650. Against this could be offset a saving in capital cost of plant and building work.

246. In addition, the exhaust gases from the main engines were utilized in waste-heat boilers, supplemented by direct oil firing, for space heating in the administration block. The heat contributed to the system by the pumping load on the main engines contributed more to the overall efficiency than was lost by the mechanical-electrical-mechanical power conversion.

247. In the summary of generating cost in § 111 the allowance made for plant maintenance plus labour represented 24% of the fuel cost. On the same basis the value of the spares shipped with the plant represented a similar percentage addition to maintenance costs.

248. The provisions made for operating labour allowed for normal servicing such as decarbonizing, etc.

249. Since labour charges and fuel costs in Iran are substantially lower than in the United Kingdom, it was probable that the relation between maintenance and fuel costs would be comparable in both countries.

250. Mr Lupton had, in § 163, replied to Mr Sheppard's query (§ 154) about the failing disks at the reservoir intakes. Replacement was a simple operation which had so far only once proved to be necessary.

251. The main difficulties experienced in constructing the reservoirs (§ 134) had been in obtaining a sufficiently dry concrete and in sealing the joints between slabs on the sloping sections of the reservoir floors. Cracks had been cut back and treated satisfactorily with waterproof cement and a suitable proprietary jointing material had been found with which to seal the slab joints. Water for testing the reservoirs had been supplied by the Board.

252. The Board adopted their own method of assessing charges prior to the installation of meters (§ 131), based on the size of connexion, which in turn was determined by

the size of the building, number of occupants, and area of the plot. Since the general installation of meters there had been an appreciable drop in consumption, but insufficient time had elapsed for a reliable assessment to be made of the savings. In the Author's opinion the cost of maintenance was a much more important factor than the initial capital cost when selecting the type of meter to be adopted.

253. Reference to seasonal water consumption had been made in § 82 of Paper 6327. In extensions to the distribution system a peak summer demand of 82.5 g.h.d. was being provided for in high-class residential areas (§ 131).

254. Although reasonable agreement had been obtained between the meter readings at the intake and at the treatment works (§ 136), the limits of accuracy of the meters did not permit a reliable estimate of losses to be made by this means. In the distribution system the installation of meters had not been completed, and it was, therefore, not yet possible to attempt to estimate the losses between treatment and consumer.

255. The consumers appeared to be entirely satisfied with the water now supplied to them (§ 188), and there had been no complaints about lack of body or presence of chlorine. The inhabitants of the poorer quarters of the city had appreciated the stand-pipe service, but this meant carrying water to their houses, and they were now demanding metered connexions. During a recent 9-month period, only 2 million of a total of 23 million m³ distributed had been taken through standpipes.

256. Total revenue (§ 189) was designed to balance expenditure, and consumers did not regard the charge for water (equivalent to 26d/1,000 gal) as excessive.

257. In the case of the chemical manufacturing plant a substantial part of the erection charges had been paid in local currency, and this accounted for the apparent discrepancy in unit costs referred to by Mr Sheppard (§ 146). By combining the sterling and rial costs in § 97 (g) a total of £412,100 was reached for plant and buildings. Taking the equivalent figures from § 105 of £189,000 × 2.1 plus £7,050 × 3.2 the total cost came to £419,460. The small difference between these two figures arose because the unit-cost rates quoted in § 105 included an allowance for chlorine and ferric chloride cylinders and drums, allocated under item (h) in § 97.

258. As recorded in § 91 of the Paper there had been some trouble with temperature control (§ 160) during the initial operating stages of the chemical manufacturing plant. Mr Dilmaghani had commented on this in § 123.

259. The reference to constant supervision of electrical gear in § 122 applied only to the electrical equipment of the chemical manufacturing plant. Although air conditioning had been installed and a positive pressure maintained in the switchgear building, some chlorine sniff gases had got in at times and caused corrosion.

260. The cost of chlorine manufacture (§§ 157, 204) was not rising and there was no reason to suppose that there would be any future reversal of policy in favour of importation or of manufacture elsewhere in Iran. There were deposits of good rock salt in the country, but the price was two to three times that of the rock salt obtained from the quarry owned by the Tehran Water Board, who, therefore, preferred to use material of lower quality on economic grounds.

261. In view of the vital importance of maintaining supplies of chemicals it would still have been advantageous to have produced these locally even had the plant been reduced to 1/10th its size. This did not necessarily apply elsewhere, and the Authors regretted that they could not give a clear answer to Mr Whitteron's question (§ 196) without making an economic study of each specific case.

262. Mr Dixon had asked (§ 135) about the 2-year maintenance period. This had been introduced for two main reasons; first, as could be seen from Fig. 7, some sections of the project had been completed 9 to 12 months before commissioning, and secondly because the whole system had had to be started up from scratch and time had had to elapse before consumption built up to a figure which allowed a reasonably full-scale test on the plant.

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