

Discussion.

Mr. H. E. STILGOE considered that the Paper was of particular value because it described an attempt—and, so far as he could see, a successful attempt—to provide small installations on cheap lines. The Authors emphasized the absolute necessity of cheapness combined with efficiency. By reason of the large quantity of solids in suspension in Nile water, it was necessary to deal with the matter in a manner in which engineers at home were not so greatly interested, as they were not troubled with the same difficulty. Some time ago he visited the works at Chester, where primary filters were employed; they were of a somewhat different type from those mentioned in the Paper, but were on a similar principle. He noticed that it had been necessary not only to chlorinate the water, but also in one case to deal with it by means of a coagulant. The chlorination appeared to be 1 part per million. That, no doubt, was found to be necessary, and probably did not give any unduly nasty taste to the water; but in dealing with the Thames water 1 part of chlorine in 2 millions was found sufficient, when it was used at all. He had been particularly interested in the subject of washing prefilters, which was a matter of some difficulty, and added greatly to the cost. He presumed that the Nile water presented the same difficulties as were experienced in England. For instance, it was necessary at some seasons of the year to wash the primary filters once in 2 hours, but at other times once in 4 days was sufficient. Such a variation must make a considerable difference in the operating-costs. He noticed the Authors employed in some cases stones ranging in size from 4 inches to 6 inches: he had never used anything as large as that. There was considerable difference of opinion on the point, one maker of filters of that type specifying that the largest medium should pass a mesh 2 inches square and be retained on $1\frac{1}{2}$ inch, and going down the scale to the passing of $\frac{1}{4}$ -inch stone resting on $\frac{1}{10}$ -inch mesh, while another maker of practically the same type of filter stated that the largest gravels should pass $\frac{1}{2}$ -inch and rest on $\frac{1}{4}$ -inch, and the smallest should pass $\frac{1}{8}$ -inch and rest on $\frac{1}{16}$ -inch. It was of the utmost importance, with regard to operating-costs, to arrive at the right size. He had found in one case that a sand which would all pass a screen with square apertures 196 to the square inch, and all be retained on a screen of 900 apertures to the square inch, gave very much better

Mr. Stilgoe. results than a sand which would all pass a screen with 400 apertures, and be retained on a screen with 2,500 to the square inch. By using primary filters it was possible to force the slow sand filters. The ordinary speed of a slow sand filter was $1\frac{1}{4}$ to $1\frac{1}{2}$ gallon per square foot per hour, but in the case he cited the primary filters were being run at 130 gallons, with a view to get out of the slow filters about $4\frac{1}{2}$ to 6 gallons per square foot per hour. If that result could be obtained, the extra cost in the operation of the primary filters would be met by the saving in the cost of operating and cleaning the secondary sand filters. Not only was the slow sand-filter system very expensive, but the filter quickly went out of action at certain seasons of the year when algal growths were prevalent. Before the war, slow sand filters cost £10,000 per acre, and at the present time the cost of construction was nearly £20,000. It was, therefore, of the utmost importance to employ primary filters, in order to save capital expenditure on slow sand filters. In connection with the general methods of operating filters, he had adopted the air-flush method of cleansing. Air at a pressure of 5 lbs. per square inch was turned on to the filter in three "jerks," in order to stir it up, succeeded by flushing and cleansing from beneath by means of a head of water of anything up to 30 feet, according to what was found to be most serviceable in actual operation. He aimed at getting a delivery, to the slow sand beds, of 130 gallons per square foot per hour, from the primary filters, and so far that had been extremely successful. When visiting the extraordinarily efficient Chester filters, he had been surprised at the vast quantity of detritus removed by them from water obtained direct from the river Dee. He felt certain that the adoption of the primary filter would not only reduce the capital cost but also the operating-cost, and at the same time ensure a very satisfactory result.

Mr. Cotterell. Mr. A. P. I. COTTERELL remarked that the title of the Paper was a little misleading. So far as he could see, the only reference to the water-supplies to the smaller provincial towns of Egypt was in the first paragraph, and that was of a general nature. The Paper was of interest as to its special subjects, but with a different heading it might possibly have attracted a wider discussion. He had been impressed many years ago by the smallness of the area of the country compared with the distance covered by the Nile. He believed that the actual cultivated area of Egypt was no larger than the area of Belgium, consisting, with the exception of the delta, of a narrow strip, scarcely more than 10 miles wide, that stretched for 2,000 miles along the valley of the Nile. Obviously, therefore, the towns to which the Authors referred must be upon, or very near to,

the river, and, as the Paper stated, drew their water-supply from it. Mr. Cotterell. It was not to be wondered at, therefore, that the Egyptians in ancient days looked upon the Nile as a god, because it was really the source of their economic life. The late Sir Colin Scott-Moncrieff, Assoc. Inst. C.E., when describing to him the highly-charged character of the Nile water, pointed out the way in which the Egyptians purified the water in some of their towns; and he referred especially to Damietta, where during high Nile the inhabitants gathered the water into their cellars and allowed it to settle for some months. When the water came in it was very turbid and highly coloured, but when it was used it was perfectly clear. Preliminary sedimentation was all-important in dealing with such water. The way in which the Authors had carried through their investigations was in some respects original, but, after all, might be said to be merely an improvement on what others had done before, more particularly the Puech-Chabal system—that of stage filtration, which, he understood, was in use in some parts of Egypt. He had wondered in what way the final design of the Authors' sand filters differed from the gravity type of pressure filter which was now so much used. He had rather expected to hear a discussion on the relative merits of the type of open sand filter most favoured by water-engineers in England and the pressure type of filter so much used in America. The Authors advocated the adoption of series filtration, the first stage being a prefilter or roughing filter and the last a sand filter. The question arose whether any part of the plant could properly be called a filter. It seemed to him that the filters described in the Paper could just as well be defined as strainers. A filter, properly speaking, had bacterial action. The late Mr. Wallis Stoddart, referring to filters, said that one of the great points in any kind of filter was that the bacteria which had to be eliminated from the water attached themselves to the surfaces as the water passed through. He suggested that a strainer which simply strained out the solids in suspension could scarcely be termed a filter. He wished to ask the Authors why, in towns of more than 10,000 population, it was not possible to adopt the ordinary mechanical pressure filter. He believed pressure filters were in use in the city of Alexandria, and he would have thought that that type would have been adopted in many other towns, as being more efficient for the purpose. The discharge of water through the Authors' filters was certainly less rapid than that through the pressure filter, although, as the Authors stated, it was much higher than was usually adopted in the slow sand filter. He did not hold any brief for the pressure filter, but he submitted that, with a coagulant when required, it did form an

Mr. Cotterell. excellent prefilter ; it certainly took away practically the solids in suspension and up to 90 per cent. of the bacteria, and, if followed by slow sand filtration, it was almost a perfect system of filtration and purification. He regretted that the Authors used two standards of measurement, which to those unaccustomed to a quick change from the British to the metrical system, rendered the Paper a little difficult to follow. He was glad to have an opportunity of discussing such a Paper. Investigation of the kind described was valuable to all engineers, especially to those engaged in the construction of waterworks, and incidentally the Authors had evolved an ingenious type of controlling valve, which ought to have a future.

Mr. Coulson. Mr. H. W. COULSON thought the Paper brought out very clearly the fact that the reduction of the suspended matter in the water was a function of the surface-area of the media in the scrubbers and strainers. In the original plant the Authors used stone of 6 inches to 4 inches grading. Assuming those stones to be spheres—which actually they were not—the surface-area for each cubic foot of medium would be approximately 12 square feet. On the same assumption, with $\frac{3}{4}$ -inch and $\frac{1}{2}$ -inch gravel there would be an average area per cubic foot of 87 square feet, with the 47-grain gravel an area would be obtained of about 236 square feet, and the 95-grain gravel would give 480 square feet. In assuming the gravel to be composed of spheres, it was inferred that the void-spaces would be about 25 per cent., but they would actually be nearer 35 or 40 per cent. ; that, however, did not affect the principle of his argument. It was stated that the 6-inch and 4-inch stone in the original plant was replaced by 47-grain gravel in the ultimate plant ; in other words, there had been an increase in surface-area from 12 to 236 square feet per cubic foot of medium. That, he thought, brought out very clearly the vastly increased area upon which the turbid and suspended matter in the water would settle. Dealing in a similar way with the strainers, there was an increase of approximately five-and-a-half times the surface-area in the final plant as compared with the original plant ; and comparing the final scrubbers with the final strainers, the surface-areas of the media per cubic foot was about 236 as compared with 480, or a ratio of 1 to 2. He thought, therefore, that the large suspended matter would be taken out by the scrubber, and probably the strainer would have effect upon the colloidal matter, because of the large surface-area available for action. Engineers had been accustomed to describe rates of filtration as so many gallons per square foot, or so many inches per hour, and those modes of description were quite satisfactory, provided the reference was always to a definite size of medium. But when the size of medium

varied, as was the case in the Paper, that method of description Mr. Coulson. conveyed rather an inadequate conception of what was actually happening in the bed. He was sorry he could not suggest anything to replace it, but he thought that was a subject to which consideration might be given. Mr. Cotterell had referred to the removal of the suspended matter from water, such as was described in the Paper, by closed filters. Without going into the merits of the case, he would point out that in dealing with water having 2,000 parts of suspended matter per million, about 20 lbs. of suspended solids would be precipitated upon the filter-surface per thousand gallons. Working that out over the number of gallons per day, or between successive washes, would show that, because of the thick accumulation upon the filter-surface, pressure filters could not deal satisfactorily with such a water.

Mr. W. PATERSON proposed to confine his remarks to the question Mr. Paterson. of clarification before filtration. It was necessary to visualize the work which the pre-filters had to perform. The plant described by the Authors was rated at 5,300 gallons hourly, and, dealing with water containing 2,500 parts of suspended matter per million, there would be 132 lbs. of dry solids hourly, which was practically 14 tons of thick slurry per day. That was the problem to be faced, and if the Authors had realized it in the first instance, they would have been saved a great deal of trouble. Their first design showed a false floor about 6 inches above the bottom of the sedimentation tank, and these conditions continued up to the semi-final stage, the filters requiring to be washed out every 4 or 5 hours. This strainer floor was then raised to 1 foot 9 inches above the bottom of the tank—in other words, a little elbow-room was given for the sludge to accumulate—and immediately success was obtained. Several speakers had speculated as to whether it was a case of filtration or straining, but he was rather inclined to think it was neither. The real solution of the problem was more efficient sedimentation, and the Authors had obtained this by raising the level of the gravel bed. In his opinion it was not so much that the gravel was active, as the fact that all local flow had been eliminated and satisfactory sedimentation secured. Undoubtedly the gravel performed a most useful secondary function; it became coated with hydrate of alumina and the benefit of surface contact was secured—an essential condition of satisfactory filtration. It was rather unfortunate that the Authors based their comparisons on the results obtained with sedimentation-tanks usually adopted in Egypt, as these tanks were not of the most efficient design. They were long, rectangular, and flat-bottomed, with the water entering at one end and flowing out at the other,

obtained a very illuminating insight into what was happening. In spite of the baffles, the water made a bee-line across the tank. He had the baffles extended, and this resulted in a great improvement. That experience had been embodied in the actual tanks, with most satisfactory results. *Figs. 14*, prepared from actual photographs of the model, taken at 15-minute intervals, showed the action of the tank as originally designed, and as modified in consequence of the experiments. In the series A, 1-4, it would be seen that the coloured water entered on the left and struck a shallow baffle, which, he had imagined, would deflect it and distribute it throughout the whole cross section of the tank. However, the water, as would be seen from No. 2, went immediately below the baffles and directly from one end to the other. Only the edges of the stream were frayed. The water took 1 hour to flow through that experimental tank. He had endeavoured to keep the temperature of the incoming water the same as that of the outgoing. The fact that it was laden with dye might be expected to make it descend, but it actually kept straight across. In the second series (B), with extended baffles, the water passed throughout the whole area of the tank. In No. 2, after the admission of dye had been cut off, a mass of coloured water could be seen moving steadily forward, showing complete displacement by the incoming stream and indicating increase of the retention period and effective use of the whole capacity of the tank. He thought these Figures illustrated the desirability of ensuring that the water was not able to short-circuit through the tank, and in actual practice that had proved to be a satisfactory solution of the problem. The Authors first put in large stones and got improved results, and Mr. Coulson had suggested that that might be due to the surface-area. Mr. Paterson was rather inclined to think that the advantage of placing those stones in the filter arose from the fact that they broke up the local flow and gave the water a chance to settle—in other words, the retention period was increased. Was the 2 per cent. of wash water, referred to by the Authors, 2 per cent. for each strainer or 2 per cent. for the whole plant? If the latter, it meant that the tanks were cleared by a drop of about 3 inches in water-level. That was as difficult to realize as the statement that one segmental arc of the curved tank, apparently about 20 feet long by about 5 feet wide, was effectively sludged by one 4-inch valve opened (as the Authors stated) for a few seconds only. He was rather disappointed that the Authors did not give any information as to the filter which was permanently used on the plant. He feared that the results obtained with their experimental filter (pp. 90-94), very ingeniously arranged to see what was happening through little glass

Mr. Paterson.

Mr. Paterson. windows, would be rather misleading in aiding the formation of any conclusion as to its operation on a practical scale. The Authors had worked out the rate of filter wash at 2 gallons per square foot per minute, but his personal experience was that 10 gallons was much nearer the figure required for the efficient cleaning of a mechanical filter. They explained, however, that the filter was cleansed by a hand-rake on the surface. On a large-scale plant it would be extremely difficult to cleanse a filter by such improvized means. In dealing with a problem such as that discussed in the Paper, the great necessity was clarification before filtration, and he ventured to suggest that the Authors had not indicated the true solution, namely, efficient sedimentation in properly-designed tanks, so that the sludge could be purged out without any difficulty. Immediately gravel was introduced, that gravel had to be cleaned, and it could not be effectively cleansed by a slow back-wash. He wished to express his appreciation of the very candid way in which the Authors had put forward their views and experience. The difficulties were fully realized by him, and he hoped that the discussion would be of help in the solution of the serious problem of purifying highly-sedimented waters.

Mr. Martin. Mr. A. J. MARTIN considered that Mr. Cotterell's remark, that the action of a filter was largely bacterial, was rather misleading. The fact that the work of a water-filter consisted in the removal of bacteria was quite a different matter. A filter, in the true sense of the word, was a strainer, and no apparatus which did not strain the liquid passing through it had any real right to be described as a filter. The thing which had been uppermost in his mind on reading the Paper was thankfulness that in this country, at all events, the water-supplies had not to be obtained from such a source as that described by the Authors. They undoubtedly had a difficult problem to deal with, and he thought they might be congratulated on the success they had achieved. They were also to be thanked for the full and candid way in which they had described their experiments. He believed that in the record of their temporary failures engineers would find quite as much helpful guidance as in their ultimate success. Possibly it was not altogether a wise policy to hurry forward the water into prefilters when dealing with supplies so heavily charged with suspended matter. He could not help thinking that Mr. Paterson was right in saying that the Authors might have done better if they had paid more attention to sedimentation. In speaking of sedimentation, he agreed that the custom of describing tanks as of so many hours capacity was misleading. In connection with another branch of engineering, engineers were accustomed to speak

of a tank of 4, 6, 8, or 24 hours capacity. Such a thing was meaning- Mr. Martin.
 less for practical purposes, unless the shape of the tank was also considered. By using a settling-tank of the same capacity as the Authors used, constructed with some regard to design with the object of giving the best opportunities for solid matter to settle, he thought they would have got much more suspended matter out of the water before it entered the prefilters. In connection with the addition of the coagulant in two doses, he asked whether the Authors had tried adding the whole of the coagulant at a later stage, allowing the suspended matter to settle first by its own weight. The arrangement described was ingenious, but he thought there was a danger, in dealing with problems of the kind, in using improvised plant instead of standard appliances. It was tempting to improvise apparatus to deal with special needs; but the expense was apt to creep up, and it was often found in the end that it would have been better to adopt appliances which had been evolved by years of experience. The Authors described a method of securing a uniform flow through their tanks by means of a conoid spindle rising and falling within an orifice and carried by a float (*Fig. 11*). An identical appliance, known as a "module," had been described¹ by Lieut. (afterwards Sir) Colin Scott-Moncrieff, Assoc. Inst. C.E. It was largely used in Spain for regulating the flow of irrigation water. But Lieut. Scott-Moncrieff made the curious mistake of saying that the apparatus could only be used where there was a free drop from the orifice. A module would, in fact, work better with its orifice entirely submerged. Mr. Martin had used modules of that kind in 1898 to give a constant flow to a set of sewage-filters in Scotland. The quantity dealt with was about 400,000 gallons a day, and there were two modules, with orifices 6 inches in diameter. Those modules required no head beyond that due to the normal rise of the sewage in the tanks. They regulated the flow with absolute exactitude. They were quite automatic, and were the simplest apparatus conceivable.

Mr. WALTER CLEMENCE, referring to the Authors' statement Mr. Clemence.
 that the water to be treated was invariably Nile water, "taken either from canals leading off from the Nile, or direct from the river," remarked that that was a distinction with a very wide difference, and that the Authors appeared to be of opinion that it was easier to clarify and purify the water from the canals than the turbid water of the river itself. He considered that the contrary was the case, and in his experience with the waters of such rivers as the Tigris and Ganges when in flood, better results were obtained if the river

¹ "Irrigation in Southern Europe," London, 1868.

Mr. Clemence. water was passed direct into the filtration-plant than if it was first passed through sedimentation-tanks. The Authors referred to other filtering-installations in Egypt which were supplied with canal water, and stated that the canals formed settling-tanks, that the water was again passed through decanting-basins forming part of the installation, and that the prefilters were large. There was an installation of multiple filters at Port Said where the only source of supply of fresh water was the canal running parallel with the maritime canal. From the point where it left the Nile to Ismailia this canal was 75 miles in length, and from Ismailia to Port Said a further 48 miles. The only water taken from this canal was the 4 million gallons daily which was filtered at Port Said for the supply to the town and ships using the Suez Canal. The fresh-water canal for the greater part of its length was choked with vegetation, the decay of which resulted in a colloidal condition of the water, so that on arrival at Port Said the water had a chalky appearance and was heavily charged with organic matter. In such a condition it could not be clarified by any form of filtration without previous chemical treatment; accordingly, tanks were provided, wherein the water underwent preliminary treatment with permanganate of potash added in the ratio of 1 part per million, that having been found more effective than coagulation with 15 parts per million of sulphate of alumina. After chemical treatment the water was passed through four gravel strainers or roughing filters in series, very similar to those adopted by the Authors in their experiments, and then through prefilters and slow sand filters. The gravel in the primary filters was graded from $\frac{3}{4}$ inch down to "pea gravel" and rested on a false bottom consisting of perforated reinforced-concrete plates. The Authors were mistaken in stating that it was necessary to remove the gravel from the roughing-filters for cleansing. This was effected by passing air at low pressure (2 feet head of water) upwards through the gravel. The water displaced by the air was replaced by raw water admitted from below, and the sand and silt deposited in the gravel was easily removed by means of small sluices at the end of each filter. This method of cleaning the roughing filters by air had been in use at Port Said for 16 years, and a similar installation was in operation at Suez. Many years ago he made experiments with a filter with observation panels, similar to that used by the Authors, and found that it was quite feasible to apply this method of cleaning by air to prefilters in which the medium used was coarse sand; and an installation with prefilters as well as roughing-filters cleaned in this manner had been at work satisfactorily in West Africa for more than 10 years. It was not clear why the Authors had adopted an upward

flow of water through the gravel. That must result in a considerable accumulation of silt on the actual floor of the filter below the false floor on which the gravel rested, and the silt would be difficult to remove. Had the more usual method of a downward flow been adopted, the "stream-line" effect illustrated in *Fig. 4* would have been avoided, and the silt deposited on the gravel would have assisted in clarification. The Authors laid stress on the fact that the object of their experiments was to discover a cheap method of clarifying and purifying the water of the Nile, but no details were given of the cost of construction or of working of any installation which might have been constructed from designs based on their experiments. It would seem that, with any given method of clarifying and purifying a river water, the costs of constructing and working a small installation must be proportionately higher than for a similar installation on a larger scale. There were at the present time many systems of dealing with turbid river waters, and he was of opinion that there was little to choose between them with regard to cost. He had kept a careful record of the working of two installations differing greatly as to type, one a multiple filtration plant dealing with the water of the Ganges in India, the other an installation of pressure filters with settling-tanks, coagulation, and chlorine sterilization, dealing with the water of the Tigris. In both cases the records covered a complete year. The Ganges and the Tigris were both subject to flood for three months in the year, and it was found that, after making due allowance for interest on capital, working-expenses, cost of chemicals, repairs, etc., the cost of purification per million gallons was practically the same in the two cases, while the results of treatment in both cases were excellent. There was also remarkable agreement between the average "life" of the slow sand filters on the one hand and that of the rapid mechanical filters on the other, measured by the height of a column of water passed between cleanings. With the multiple filtration plant and Ganges water the average height of the column was 1,450 feet, and with the pressure filters at Bagdad 1,367 feet. The quantity of water required for washing the latter was 4.69 per cent. of the quantity filtered. He agreed entirely with the Authors in their objection to the use of bleaching-powder for sterilization. At Bagdad and Basra it had been found to be practically useless, owing to rapid deterioration, although various types of package were employed. Chlorine in cylinders was easily transported, and, when it must be used, was readily controlled by many efficient types of apparatus. The Authors were to be congratulated on the careful and methodical way in which they had conducted experiments on the particular water with which

Mr. Clemence

Mr. Clemence. they had to deal, and the Paper was a valuable addition to the existing literature on the subject. Different waters required different treatment ; efficiency and safety were of more importance than cheapness ; and it was perhaps as well that, having concluded their experiments and stated the results, they had omitted questions of costs.

Sir Murdoch Macdonald.

Sir MURDOCH MACDONALD, M.P., observed that plants similar to that described in the Paper had been installed at numerous points on the Suez Canal for the use of troops during the war. If those who had been suddenly entrusted with the duty of providing a clear water-supply for the troops had had the benefit of the experiments dealt with in the Paper before undertaking that work, the information would have been of great value to them. He wished to thank the Authors for the valuable work they had done.

The Authors. The AUTHORS, in reply, explained that the Nile in flood carried a large quantity of solids in suspension, but during Low Nile the quantity fell to 20 parts per million or less, and, therefore, during that season the water could be compared in this respect with river water in England, from the point of view of problems in filtration. The difficulties, then, were not so great, and in order to keep the Paper concise, they had confined it to a description of the experimental work carried out during the flood season. Experimental work was concentrated on the flood water and was not continued over Low Nile at all until satisfactory results had been obtained with the flood water. The last tests carried out were made on the clearer water, and they indicated that a very much higher rate of filtration could be adopted through the prefilters. Even with comparatively clear water, two-stage filtration through gravel was more satisfactory than single-stage filtration. A good effluent was obtained through a single gravel-bed if the correct size of the gravel and the correct rate of filtration were adhered to ; but the length of period between washing was much increased and the quantity of wash water used was reduced by filtering in two stages.

The length of the period between washings depended upon the rate of filtration adopted per square foot of gravel-area, as also, of course, upon the maximum degree of the clarity of the effluent required. The curves shown in *Figs. 6 and 7* (pp. 87 and 88) were taken after the filter had worked 8 hours since the previous wash. Perfect clarification was obtained, but the rate of filtration was rather low. When the Nile was low and its water clear, it was possible to double or treble the rate of filtration without increasing the number of washings. This was not a direct answer to the point which Mr. Stilgoe had raised, but the Authors had not continued the experiments during Low Nile with a view to find out how long the clarifier could

run at a constant rate of filtration without being washed. *Fig. 8* The Authors. showed that by two-stage filtration, and with the filters divided into compartments which could be washed separately, it was possible to maintain good clarification continuously at a rate of filtration approximately double that shown on the previous Figures. A mechanical arrangement was devised for operating the valves in sequence at intervals of 1 hour. It would be noticed that the 4-inch and 6-inch stones were used only during the earlier tests, and were discarded entirely at an early stage in the experimental work. The Authors attempted to assist the cleansing of one of the compartments of the strainers with an air-flush at pressures ranging from 3 to 10 lbs. per square inch. The air was admitted into the space between the gravel and the floor by means of a manifold of perforated pipes just below the false floor. That compartment did not show appreciably superior results with regard to the washing, compared with the other compartments which were working at the same time, and which were washed simply by a downward flush of water only. There was definitely insufficient difference to warrant the use of the compressed air. The Authors adopted the ratio of 1 part of free chlorine per million of water because there was then no doubt whatever that the water would be absolutely sterilized, since it entered the chlorination tanks absolutely clear from the clarifier. The object of the test was to see whether it was possible to eliminate the taste entirely by simple storage as described. If it was possible to do that with 1 part per million of chlorine it would certainly be possible to do so with less. The results were entirely satisfactory. There was no taste of chlorine in the water, and the chemical tests for chlorine gave a negative result. It was thereby proved possible to obtain a clean and sterile water by simply using the clarifier and chlorinator as described, and eliminating sand filtration altogether.

With regard to Mr. Cotterell's remarks, during Low Nile the Damietta branch of the river was closed every year with an earthen dam several miles away from the town, and therefore the river-channel from the sea up to the dam became filled with sea-water. During that season there was no fresh water at all within easy range of the town. The specially-made reservoirs beneath the houses were used for storage rather than for purification. In the days of the Romans the reservoirs might have been filled direct from the Nile, but now they were filled almost entirely from surface subsoil water collected when the Nile was high and the ground was saturated under rice-cultivation. Collected in that way, the water, though still turbid, was not nearly so highly charged with silt as was the Nile water; and after 3 months' storage it was fairly clear, though

The Authors. still cloudy if observed through a 3-foot turbidity tube. It was a very bad water from the bacterial standpoint, being invariably highly polluted with sewage. The town now owned water-purification works consisting of settling-tanks and mechanical filters. The filters were of the open gravity type, working up to a rate of filtration of 13 feet (81 gallons per square foot) per hour. They were fed with water from settling-tanks of 8-hour pumping-capacity. A large storage-tank kept the filters supplied for the period during which Damietta was shut off from the Nile supply. A similar type of purification works was in use in four other towns besides Cairo, Alexandria, and Damietta, all under municipal control. Three or four further schemes had been prepared for other towns, and some of them were in course of execution. In certain places, where a favourable site was possible, slow sand filters had recently been installed in Egypt; but as a rule, unless local conditions favoured them, their initial cost was too high. The rapid sand filter-plants of the type described gave excellent results if the plant was properly worked and managed. If it were badly managed, the effluent from the filters immediately suffered in quality; the rapid rate of filtration rendered that inevitable. It had been very difficult to find men of Egyptian nationality sufficiently reliable to supervise those plants. The object of the Egyptian Government, in affording facilities for the experimental work described, was to find, if possible, a method by which the first cost of rapid sand filtration-installations, including the settling-tanks, would be reduced; also to obtain a plant which might be expected to give a fair effluent under poor supervision. The Authors did not claim originality in their methods, except only perhaps in the manner in which they had laid bare their failures; and they accordingly much appreciated the kind way in which members had commented on that feature of the Paper. That the work done had led to an improvement in what others had done before was the most that they could have hoped to attain.

The Puech-Chabal system was excellent and one of the best known of prefilter systems, but there were others to which the final plant evolved by the Authors had quite as close a resemblance. Their sand filter differed only from other types of rapid sand filters in the design of the false floor, which was comparatively cheap to make; none of the fittings to the sand filter was expensive, so that the filter could be made of large area, to give a low rate of filtration, without undue cost. The sand filters must not, however, be considered by themselves. The water reaching the sand filters was always perfectly clear and much purified by the prefiltering treatment described. The combination of efficient prefiltration and low

rate of filtration through the final sand-bed rendered an unreliable foreman in charge a less dangerous person than would otherwise be the case. If it were known that the works would be managed by a reliable man, the rate of filtration might well be increased, with the consequent further saving in first cost and without any danger of a poor effluent. The Authors agreed with Mr. Coulson that the results obtained showed quite definitely that the surface area of the media was the important factor, though they had never worked it out in the illuminating manner which he described. The figures and diagrams given in the Paper had been chosen as fairly representative of the several thousand observations taken. Mr. Paterson considered the results obtained were principally due to sedimentation, and he had taken exception to the design of the sedimentation-tanks to which the Authors referred in comparing results. The Authors held no brief for those tanks, but Mr. Paterson's description of their construction was not quite correct. There was definitely some local flow, but they were not nearly so inefficient as Mr. Paterson thought. Mr. Paterson's figures illustrating local flow were of the greatest interest, and the Authors did not wish to deprecate the serious results of local flow, which Mr. Paterson had ably demonstrated. In order to gauge the efficiency of existing settling-tanks of the continuous-flow type, as was the case of those in question, the most satisfactory way was to stop the flow into the tank and allow the water to remain absolutely quiescent for the period which it would take to fill. That gave the figure for 100-per-cent. efficiency of the tank. The Cotton Research Board of the Ministry of Agriculture made some interesting tests in 1921 on the rate of deposition of solid matter in suspension in still water from the Nile. The mechanical analysis of the solids was made by measuring the grains under a microscope. The solids were then classified as follows:—

Coarse sand 1·00 to 0·20 millimetre diameter.

Fine sand 0·20 to 0·04 millimetre diameter.

Silt and clay less than 0·04 millimetre diameter.

A sample of water taken from the head of the Menufia canal at the Delta barrage yielded: coarse sand 14, fine sand 198, and silt and clay 1,923 parts per million, giving a total of solids in suspension of 2,135 parts per million. The coarse and fine sand settled out from suspension through a distance of 25 centimetres in the course of about 2 minutes. It required about 3 days for the silt and clay to settle through 50 centimetres, and even then the solution was not absolutely clear. The small quantity of matter remaining in suspension after 3 days was colloidal. It could be considered as being

The Authors permanently in suspension. Thus only 10 per cent. of the total would settle out at once, and the remainder would take 3 days, with the exception of the finest particles, which remained permanently in suspension. When the river was lower, the speed of the current was not so high, and the ratio of sand to the total solids carried in suspension was much below 10 per cent. The results obtained by the Authors' plant, working without alum (*Fig. 7*), showed that the final effluent from the last strainer was 25 parts per million, as compared with 45 parts per million in the river water, a reduction of 45 per cent. In another test on river water containing 130 parts per million, the final effluent gave 56 parts per million, a reduction of 57 per cent. The capacity of the plant, including the space occupied by the gravel itself, was $2\frac{1}{2}$ hours pumping-capacity, as compared with 3 days in the figures of the Cotton Research Board. The quantity removed before the gravel filters were reached was 7 parts per million, or about 5 per cent., which represented the heavy matter in suspension. The foregoing figures, compared with those furnished by the Cotton Control Board, indicated very clearly that surface tension on the gravel, as explained by Mr. Coulson, and not sedimentation as maintained by Mr. Paterson, was the principal cause of the results attained. When the plant was worked with alum, the whole of the sediment was removed, the surface tension of the gravel filters being aided by the alum. Also in coagulation the settling-tank did more work, but the process was the same. The Authors contended that that process was logical. Water coming from the river was charged with sediment, some of which would settle at once, and some would not. The heavy particles dropped straight to the floor of the settling-tank and gave no more trouble. The fine particles were trapped by the gravel. Then one single back-wash of water cleared the whole away. Mr. Paterson thought that the Authors had only gradually realized the quantity of solid matter they had to deal with. The point was only of importance in that it affected the argument. The Authors had too long an experience of the Nile to minimize the quantity of silt it carried. The figure of 132 lbs. of dry silt per 5,300 gallons, which Mr. Paterson gave, was correct. The empirical figure of 14 tons of thick slurry was much too high, because, when Nile silt deposited, it packed very tightly. The word "slurry" did not convey the right impression. The Authors, when designing the plant, had expected that during high Nile it would have to be flushed out every 4 hours. It was not known how much water would be required to stand above the gravel, in order to flush, and what minimum depth of gravel would be required. The false floor was therefore kept low. As stated in the Paper, the

results were good if the gravel was flushed after working 4 or 5 hours, and success at that point had been attained by successively reducing the rate of filtration and the size of the gravel. This was before the floor was raised. The changes were made step by step, and every step in this direction proved advantageous. The raising of the floor was one of the changes made in the last step, and was rendered advisable owing to the sediment almost filling the space below the gravel when it was attempted to run the plant for more than 5 hours. For the first few hours the plant worked well, and then the quality of the filtrate deteriorated quickly because the sediment had filled the 6-inch space and was being carried up into the gravel and into the stones below the gravel, which became very foul and would not wash clean. The 2 per cent. of wash water used referred to the scrubbers and strainers. Normally a drop of 10 centimetres was sufficient, but for 2 months in the year 10 to 15 centimetres was required. The area of the scrubbers and strainers combined was 25.6 square metres, and a drop of 15 centimetres, therefore, represented 3.84 cubic metres. At a flow of 24 cubic metres per hour for 8 hours, 3.84 cubic metres represented 2 per cent. The settling-tank was washed out once a week during these 2 months. The floor was formed of concrete laid flat as shown in the section, but the surface was rendered to give a slope to the two wash-out valves. This slope was not sufficient, and the tank had to be run out in jerks, until nearly empty, in order to wash it. No. 1 scrubber, when used as a settling-tank, had to be similarly treated. This added just over $1\frac{1}{2}$ per cent. to the quantity of wash-water used. The total for the clarifier was, therefore, 3.5 per cent. maximum for the two worst months in the year, and on a more recently constructed plant the quantity had been considerably reduced by giving a steep fall to the floors. The plant was situated on a hill and the wash-out pipes were brought to a single pipe which was laid down the hill and terminated with a throat piece. A sluice-valve was also provided, but was used only for some experimental work. That arrangement was adopted so as to get a big back-wash head, permitting the use of comparatively small pipes and valves. On many sites topographical conditions would allow of a similar arrangement. In order to convince a friendly critic that, when a tail pipe was impossible, an equally efficient wash could be obtained by using larger valves, a 6-inch valve was put into one of the strainer compartments, with a separate discharge. The actual velocity of wash was obtained by taking with a stop-watch the time which the water took to fall 10 centimetres in each compartment. Observations also were taken through the 3-inch inlet-pipe, which was a vertical pipe passing

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The Authors. through the gravel and extending from the surface of the water to below the false floor. As soon as the wash-out valve was opened, the water below the gravel ran away much faster than the water could get through the gravel which was choked with sediment. The result was that the space below the false floor was nearly empty of water before the water on top of the gravel had begun to fall appreciably. Water could be heard streaming through the gravel on to the floor, with a sound like a tropical rainstorm, growing rapidly faster until it gained on the discharge from the valve and water could again be seen, appearing at the bottom of the observation pipe, where it remained fluctuating in level. The Authors did not find the experiments on the experimental sand filter to be misleading. They did not differ in that respect from Mr. Paterson's model sedimentation-tank. It was necessary to follow them up with tests on a practical filter. The steel filter constructed was approximately 19 feet in diameter, and was divided along a diameter into two entirely separate units with separate controllers and fittings. Two distinct tests could thus be carried out at the same time and with the same water. The filters were mounted so as to form the roof of a circular filtered-water reservoir. The reservoir was provided with calibrated water-gauges. The filters were washed by a centrifugal pump drawing from that reservoir. The quantity of wash-water used was obtained by direct measurement read off the gauges. Gauges were also fitted to the filter itself, to determine the filter heads. The quantity of wash-water required was very much less than that needed for many mechanical filters, but the water coming from the clarifier was absolutely clear—so clear that passing it through the sand-bed made no difference in its appearance. There was no doubt that that made a great difference to the quantity of wash-water required and the rate at which it had to be applied. Another factor was the type of false floor employed, which gave a very even distribution of the wash-water over the whole area of the filter. The Authors did not contend that a garden rake was the best implement to use when washing a filter. If the rate of wash was increased, it was quite unnecessary to rake at all. With the low rate of washing mentioned, raking was desirable, but it was only necessary to rake the surface. Mechanical rakes with prongs only 4 inches long were much lighter and cheaper both to make and to operate than were the usual deep raking types or, alternatively, agitating the sand with compressed air. The method of washing with water alone, without the aid of rakes or compressed air, had been used in America and was not novel. The Authors did not agree with Mr. Martin that they hurried the water too quickly through the settling-tank. When the Nile was in flood the settling-

tank, with No. 1 scrubber, was about the correct size for the final flow decided upon; in addition when the river was clearer, it was found unnecessarily large; and tests omitting the central tank altogether had given excellent results. Numerous experiments had been made during high Nile on that central settling-tank, the most interesting of which was the suspension of small splines of wood 4 feet long by 1 inch by $\frac{1}{4}$ inch in cross section, spaced 2 inches apart, on frames which held them suspended vertically in the water. They were intended not only to prevent local flow, but also to assist the deposition of the silt by surface tension. Six frames were placed in the settling-tank, but they made no difference whatever to the efficiency of the tank in so far as could be measured with an ordinary turbidity tube. It was found that the position of the inlet was important. The fact that the tanks were circular, with rough walls, probably tended to destroy local flow. The tests made with baffles of various kinds gave no appreciable result, good or bad, and for that reason were not alluded to in the Paper. The filters to which Mr. Clements referred were under the sole control of the Suez Canal Company, and the Authors were not responsible for them in any way. The Authors referred to similar filters at Ismailia, also belonging to the Canal Company. They regretted the error they had made with regard to the usual method of washing that type of filter. They adopted the upward flow through gravel in order to wash without the aid of compressed air, rakes, or an artificial head of water of any sort. With regard to the treatment of canal water as compared with river water, the waterworks of two large provincial towns, consisting of settling-tanks and mechanical filters, were on canals, and those of three other towns were on the river. The Authors' experience with these five similar plants had led them to the opposite view to that which Mr. Cotterell took. The canals in question were all important irrigation-canals, and were kept reasonably clean. The sweet-water canal from Ismailia to Port Said was of more than ample cross section for the purpose it served, and it was consequently not kept free from weed, which might explain the two opposing experiences. The Authors thought that the plant they described differed somewhat from those referred to by Sir Murdoch Macdonald.

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