

Discussion.

Mr. ROGER T. SMITH congratulated the Author on his share of Mr. Smith. the courage required to introduce, first, a completely electrically-worked and controlled pumping-plant, and secondly, the mercury-arc rectifier instead of the motor generator, in order to increase the efficiency of that working. He expressed his appreciation of the extreme clarity of the Author's description of what was rather a complicated form of electrical control. A risk had certainly been taken in choosing the principle of working and controlling the booster pumps electrically, which was a new application; but no risk whatever had been taken in working out and providing for the safeguards, and for what might be called the calibrating apparatus which was provided to ensure success when the working was made fully automatic. Was the station now worked entirely automatically? The Author's claim that the apparatus was "fool-proof" was probably justified, and the happy result of the work was shown by the fact that 60 per cent. of the cost of the pumping-main, which would otherwise have been required in order to do the same work, had been saved by the boosting-apparatus. Generally, the Paper concerned the use of electrically-driven centrifugal pumps, which, he thought, had always been a success wherever they had been used. They had been especially successful when used as multi-stage turbine pumps for the supply of hydraulic power at 750 or 800 lbs. per square inch pressure in docks for working hydraulic apparatus. The latest of those installations had just been started in Cardiff docks, and was running very successfully. The booster pumps at Monte Video worked, of necessity, on the rising part of the pressure—quantity pump-curve, always a difficult thing to do, and wanting careful regulation. What was the maximum velocity of water in the pipes beyond the boosters? The Author spoke (p. 134) of making the slope of the quantity—head curve of the pump steeper. Could that be done simply by altering the design of the impellers, or were further changes necessary? Also, was the added head entirely absorbed in the increased friction in the pipe, or would the head of the supply be increased? The Author referred (p. 132) to numerous mechanical and hydraulic methods tried for obtaining the desired control; had he considered an electrically-driven hydraulic variable-speed gear for the working of

- Mr. Smith.** the pumps? For instance, in such a gear as that invented by Dr. H. S. Hele-Shaw, M.Inst. C.E., the venturi pressure-tube, either working direct or through a separate relay, would only have to move the floating eccentric ring of the pump one way or the other. Also, the 6,000-volt supply could have been applied direct to the motor and thus save transformer losses. He was not suggesting that the way in which the matter had been worked out was not the best, but he was interested to know if the simple method of using the infinitely variable speed gear had been considered, and, if so, why it had been rejected.
- Mr. Lupton.** Mr. H. R. LUPTON remarked that two points presented themselves to him, as a pump-maker, for discussion. One was the pump regulation. The Author stated that the pumps themselves were standard. When pumping through a long main, in which the head was almost entirely due to friction, the pumping head was proportional to the square of the quantity. That, he thought, was very nearly an ideal characteristic for a centrifugal pump to work against, because the ratio of the quantity to the square root of the head was constant, and the variation in both quantity and head was entirely done, in the instance under discussion, by speed. Therefore the pumps were working under almost ideal conditions for retaining maximum efficiency. He was rather surprised at Mr. Smith's claim that they were working on the rising part of the characteristic, for that very reason. Mr. Lupton thought they were working on the successive peaks of the efficiency curves for the different speeds. That was done at the expense of a certain efficiency in the electrical equipment. But if those pumps had not been absolutely standard, but had been made with nearly radial vanes, so that the head—quantity characteristic did not fall, but rose slightly, which it could be made to do, would not some of the regulation which had actually been done, perfectly successfully, by electrical means, have been possible by hydraulic means? He was rather diffident about mentioning his second point, since it concerned an electrical problem, and he was not an electrician. He thought the motor characteristic itself could have been used perhaps slightly more than it had been for regulation, independently altogether of venturi meters. In the case of plants B, C, and D, he gathered that the motors were shunt wound, but with plant A the motor was of a differentially-wound compound type which had, of course, a slightly rising characteristic with increasing torque. He had attempted with very rough experimental apparatus to see what sort of regulation could be got on the motor alone. He had put some series coils on a shunt-wound motor and had made it drive an ordinary pump. He had increased

the resistance in the shunt circuit until the latter was in reasonable proportion to the series windings which were opposing the shunt windings. Supposing the motor could be wound so that its torque was proportional to the square of the speed, the torques of both pump and motor would correspond to one another, and a considerable range of speed might be obtained before one overbalanced the other. Thus it could be anticipated that wide variation in delivery head would be obtained before torque balance would be re-established, even after a comparatively small initial variation in pump torque. The experimental plant ran quite steadily until the series ampere-turns rose to a certain proportion, which calculation would indicate to be about one-quarter of the shunt ampere-turns. After that point the plant became rather unstable. The speed characteristic rose rapidly, as was required, but a good deal of surging and sparking occurred. In spite of all that, however, a variation was obtained by merely opening the pump-delivery throttle-valve. While the delivery increased from 45 to 80 gallons per minute, the speed rose from 1,750 to 1,800 r.p.m., and the head from 50 to 55 feet. He did not claim that the results were good; the efficiencies were very poor indeed; but he thought it might be possible, by working somewhere near that critical value of the ratio of the shunt to the series coils, to get a fair variation. He did not claim that it could possibly be sufficient for the case which the Author had put, but it might easily be sufficient in other cases, especially where the pump was delivering against a static head instead of delivering downhill. He asked whether the Author had any figures showing how much regulation might have been obtained by the motors themselves being contra-compound wound without the help of any venturi-meter control at all.

Mr. A. C. ANDERSON was struck by the extraordinary ingenuity with which the Author had tackled the problem; but he doubted whether it had really been necessary to put in so much automatic apparatus. It seemed to him that the saving which had been obtained by using boosting-apparatus might possibly have been rendered even greater had simpler plant been employed. It appeared that attendants were always in the pumping-station, and it was mentioned that the hand appliances had been of great service in making the various adjustments. The same point of view was also emphasized on p. 142, where it was stated: "the former method [by hand] is of considerable importance, as it is relied upon to replace the automatic method." Apparently, also, the largest pump was not yet operated automatically. From the Author's description (p. 144) he gathered that the mercury tube was complicated, and

Mr. Lupton.

Mr. Anderson.

Mr. Anderson. reference was made to leakage of the mercury ; it was stated also that in case of such a leak the motor could not start, and that no boosting could be effected until the defect was remedied. How often had that leakage occurred ? Apparently it had happened fairly frequently during the night. In connection with the larger pump, it was said that the attendant always operated a switch when the time came to accelerate the speed of the pumps. No doubt the Author had considered all those matters, but it seemed that ordinary rotary converters, over-excited so as to correct the power-factor, and combined with hand-controlled variable-speed direct-current motors coupled to ordinary pumps, would have been the best equipment. He was not quite satisfied as to why the station had been designed with the aim of making it entirely automatic. He imagined that a good deal of expensive experimental work had had to be done. The rotary converter, too, he thought, had distinct advantages over the mercury rectifier. It was mentioned that the only trouble which had been experienced so far was an irregular action in some of the bulbs. He thought perhaps a more important point was that the bulbs were delicate. Some of them had broken in transit, and two appeared to have lost their vacuum. He did not wish to be accused of being an enemy to progress, but he thought that in some instances automatic apparatus, especially on a fairly large scale, could be much overdone.

Mr.
Ackermann.

Mr. A. S. E. ACKERMANN said he would like to congratulate, not only the Author, but also the Author's clients. It was not often engineers had clients who were so enterprising as to accept what their engineer recommended in so whole-hearted a manner as they had done in this case. The only point of criticism he had to make was that the centrifugal pumps delivered at right-angles into the main. He would have liked to see some method of overcoming the loss of head due to pumping into a main at right-angles, especially where the sizes of the two were so nearly alike. On p. 135 some slight information was given concerning the capacities of the mains. It was not often that precise information could be obtained of hydraulic experiments with pipes 18 and 24 inches in diameter, and 12 miles long ; he therefore asked the Author to give the whole of the data he had obtained in that connection.

Sir John Snell,

Sir JOHN SNELL remarked that some years ago he made an investigation into the corrosion of the water-pipes in Monte Video, which had been caused by leakages from the electric tramway system in that city. He thought, therefore, that the directors of the water-works company were the more to be congratulated on their broad-mindedness, in view of the application of electricity which they

had made in their boosting-station. There was nothing really to criticize in the Paper from the electrical engineering point of view. The selection of the apparatus, the method of control, and generally the application of the electrical plant to this method of boosting, seemed to him to call for nothing but congratulation. There was one matter which was of great interest to suppliers of water from the economic point of view. The Author showed that the capital saved by the method which he had adopted, as compared with the cost of supplying the otherwise necessary mains for the same conditions of water-supply, was £190,000. Having regard to the value of money in Monte Video, he supposed that might be taken as equivalent to about £16,000 a year. It would have helped if the Author could have given a balance-sheet of the annual working-cost, which he must now know, of the boosting-station, including the cost of energy, the depreciation on the boosting-station itself, the cost of repairs and maintenance, and any other overhead charges which might apply, and also if he could have shown in figures what was the net annual saving as compared with the saved capital charges upon the otherwise additional cost of the pipe system. Sir John Snell knew little about the economics of water-supply, but he presumed that with the growing population, and with the growing consumption of water per head of population which was now taking place, there must be a constant requirement upon waterworks engineers to increase their mains, especially their feeder mains; and it might be that the application of a boosting-station of the kind described that evening would save a very considerable capital outlay. If it did, and having regard to the hours during which the extra pressure of water would be required for industrial purposes, he suggested that, worked in conjunction with a general electricity supply, it would have a double effect: it would tend to improve the load-factor of the water-supply (and improvement of the load-factor in any class of business made for economy), and it would most emphatically tend to improve the load-factor of the electricity supply. On those grounds, if the Author could give the information for which he had just asked, it might have an effect on the policy of waterworks engineers in this country. The Author was to be congratulated, as were also his directors, for their courage. He was glad to see that the results, after several years' working, had borne out completely the Author's prognostications.

SIR ARCHIBALD DENNY asked why the Author had included the capitalized value of the first year's working, because he presumed that during the first year the working-costs were the same as during the second and subsequent years in supplying the necessary extra

Sir John Snell.
Sir Archibald Denny.

Sir Archibald Denny. pressure to deliver water to the customers. He was glad to hear that the mercury rectifier was now applied to such large powers. He had a small one working a cinema projector in his own house, and found that its efficiency was very high. One of the services which the Author had rendered to The Institution was to bring prominently before its members the fact that there was now similar apparatus for such high power.

Mr. Sayer. Mr. C. E. SAYER remarked that on p. 129 the statement appeared : " It is estimated that at the present rate of increase the boosting-plant will have to be continuously in action in about 20 years ; but long before that time boosting will have become unremunerative, and the capital expenditure on a new pipe-line will have become justified." Some balance-sheet would be helpful in connection with that remark. What exactly was meant by the statement " long before that time boosting will have become unremunerative " ? He took it the Author meant that the boosting of the whole quantity of water passing would have become unremunerative, but that the boosting-station would still remain in its present form, or, as it then would have been extended, to continue in action in the same way as it was doing at present. The loss of head in the pipes, although they were found to be clear of any internal encrustation, was considerably more than had been estimated ; and further remarks from the Author on that point would be desirable.

Mr. Hanssen. Mr. C. T. A. HANSSEN congratulated the Author on his courage in adopting an entirely new line of automatic control. It was an example to engineers not to be too timid in adopting the latest and most advanced appliances. He would like to know, with Mr. Ackermann, why the frictional resistances in a pipe which was not corroded, and which was in practically new condition, should be 50 per cent. higher than calculation would indicate. Any information which the Author could give on that point would be valuable to water-engineers, to whom the question of frictional resistance was of primary importance.

Mr. Thorpe. Mr. W. H. THORPE remarked that the basic principle of pressure boosting to accelerate the flow of water in pipes had characteristics common to most sound engineering propositions, namely, simplicity and—when once stated—obviousness. An important aspect of the scheme described concerned cases where it might be proposed to adopt such a pressure-boosting arrangement, but where apprehension might be felt as to the effect of failure of the electricity supply or of part of the apparatus. That was hardly a serious objection in such an instance as the present, where, without boosting, the supply met the mean demand of the city. If the apparatus

broke down, or if the current failed, the supply would merely be limited to what it had previously been ; and even if that occurred when there was a heavy demand for water, it would only mean a slight interference with the amenities of the city, and no danger to the public health. Mr. Thorpe.

Dr. W. L. LOWE-BROWN was pleased to see that the Author had paid so much attention to a point which, personally, he considered very important, namely, the factor of cost, which was the determining factor in choosing between various means of augmenting the supply. There was always a temptation to adopt a conventional way of doing a thing, and, when the conventional way was just as cheap, it was nearly always the best ; but there were cases, like the present, when it should be ruled out because of its cost. He admired the Author's courage in adopting the mercury rectifier. It was to the engineers who showed courage that progress was due, and he felt sure that many of the numerous examples of the rapid obsolescence of electrical plant were due to lack of courage on the part of the designers, who had simply gone on in a rut, being too timid to adopt new features, even after their advantages had been amply demonstrated by theory and experiment, which were generally so much more reliable in electrical engineering than in ordinary civil engineering. Dr. Lowe-Brown.

Mr. M. B. BUXTON drew attention to an important point brought forward by the Author's remarks on p. 131. The Author had evidently taken great trouble to invite all the chief manufacturers in Great Britain to meet his requirements ; and Mr. Buxton thought that was an example of patriotic spirit which younger engineers might well follow. Mr. Buxton.

The AUTHOR, in reply, stated that the only respects in which the full automatic properties of the installation had not yet been developed were the two mentioned in the Paper. In order to cover certain contingencies, a switch had been put in which, though it did not prevent the motors from starting, prevented them from speeding up. The pumps generally started early in the morning, before the attendant had arrived, and worked for an hour or so on their first increment of speed. All the contingencies provided against had not yet arisen, but it had been thought wise to take every precaution. Mr. Anderson was in error in supposing that the large pump was not automatic. Hand regulation was introduced to enable the machinery to be tested when the demand for water was not sufficient to call it into use, and also to provide a cheap, and in the circumstances a sufficiently efficient, stand-by for use if any of the automatic appliances should be out of repair. The Author

The Author. It had also been of great service in the preliminary operations by which the controllers were regulated. The provision against the leakage of mercury was intended as a safeguard only. It had not been installed, because the mercury had never leaked; but the precaution was mentioned in the Paper to complete the description. The mercury tubes worked very well. There was a very slight electrolytic action in spite of the oil, but not enough to cause any harm if the tubes were cleaned out about once a year, which was easily done. The delicacy of the bulbs was not a matter of great importance. They called for careful handling, and the value of a broken bulb or two had to be added to the capital expenditure; but, when once installed, their durability was very considerable, and it did not appear that the cost of upkeep would be at all high. When providing for the increased head in the first three sets, it had been necessary slightly to modify the interior of the casings of the pumps, so as to accommodate the larger impellers. Several speakers had referred to the high friction in the pipes. The work had been designed on a conventional basis with regard to hydraulic friction, but subsequent tests had shown that the conditions were extraordinary, and that the pumping head would have to be increased from 100 to 150 feet to maintain merely the designed pressure of supply. He was trying to find out the cause of that. With a complicated system of piping, involving long distributing-mains and numerous branches, frictional conditions prevailed which were quite different from those indicated by ordinary experiments and the formulas deduced from them. Even if the cause of that friction were never found out, the figures given in the Paper would still be valuable. The Author sympathized with the desire to study the figures upon which the pipe-discharges were based, but the figures in their crude form would probably not be intelligible to anyone unfamiliar with the work in detail. He had, moreover, recently come into possession of other figures beyond those used in the preparation of the Paper, and he hoped before long to be able to submit a further communication to The Institution dealing specially with that point. The use of a mechanical variable-speed gear had been considered during the development of the design, and the reason for its rejection would be, perhaps, best explained by a brief recital of the history of that development. In the early stages both coal and oil had been considered as sources of power, but the expense was found to be far too great. Then it was suggested that an attempt should be made to burn coal or oil only when power was needed; but that had been found very unsatisfactory: day by day the conditions changed, and it was

never known from one day to the next when power would be required; The Author. and therefore constant attendance would be necessary. In the end the difficulty was solved by the use of electricity obtained from the public supply, the Government taking the responsibility for its continuity. The next problem was to effect the required change of speed. The use of variable-speed alternating-current machinery had been proposed, but he had not been able to find, in the course of his inquiries, any firm which would undertake to make suitable machinery. The same remark applied to rotary converters—no firm had offered one capable of automatic control. The use of some mechanical change-speed gear had appeared more promising; but, when figures were gone into, questions of cost and efficiency made it less so than the other alternative of direct-current electric plant. Before adopting the mercury rectifier, he had made very careful inquiries. Their advantages were a combination of high efficiency and high power-factor. They were cheap to install, economical to work, and, up to now, had proved quite reliable. Regulation by the means suggested by Mr. Lupton had not been very much considered, because the range of head required was more than the pumps and motors alone could deal with: they had to be controlled by some external agent. Further, although there was a direct relationship between the delivery and the head of a centrifugal pump when it was working against friction alone, that was by no means the case when the pumping head was a combination of lift and friction. In the present instance the combination was peculiar, since there was a “negative lift” on the pumps. The conditions governing the need for increased head were somewhat complicated. First there was the pressure at the various points of delivery, depending upon the level of the ground and the height of the houses. That was constant, whether the demand for water was large or small, and could be obtained only in some parts by gravitation. In addition there was the head required for friction, which varied with the quantity of water demanded. The head to be created by the pumps constantly varied according to the equation $y = v^2 + x - z$, where v , x , and z varied independently. *Fig. 3* showed that in one main, taken as example, a delivery of 112,500 gallons per hour was possible without the pump working at all, and the existence of that initial flow upset the ratio of head to quantity which was usually characteristic of a centrifugal pump. To secure economy in working, the head produced had to be coerced into agreeing with that required by the quantity of water being taken, and it was that necessity which lay at the root of the need for automatic working. There were, moreover, four mains, each of

The Author. which might develop different requirements; and there was no guarantee that those requirements would remain constant. On the contrary there was a certainty that they would vary considerably as the area of the district supplied extended. It was necessary, therefore, to provide some highly elastic method, and that devised by the Author, of using two opposed rows of electric contacts, which could be linked together in an almost unlimited number of combinations, had proved in every respect satisfactory. The automatic control, which was viewed with some suspicion by Mr. Anderson, was necessary for two reasons. First, in order that the pumping should start when it was required, and not at some time varying with the vigilance of the attendants, and secondly, to secure that the pressure produced by the pumps should never be greater than was required by the friction in the pipes. If that had not been provided for, a careless attendant might cause considerable damage; that danger was automatically provided against. This answered Mr. Smith's point as to the pumps working on the rising part of the curve; they decelerated also on the falling part, and from the point of view of safety and "fool-proofness" the latter action was the more important. He agreed with Mr. Anderson that automatic equipment could be overdone, but that had not occurred in this installation, which was the outcome of careful calculation of costs and a good deal of thought. The purely automatic part of the apparatus was a very small portion indeed: whereas the indispensable part cost thousands of pounds, the part which made it automatic cost hundreds. Perhaps 10 per cent. of the cost was devoted to the entire elimination of personal attendance. The principal working-expense was the current. It had to be borne in mind that in Uruguay electricity was not particularly cheap, even for the purpose under discussion, since it cost 2*d.* per unit. Therefore the method would show to much more advantage where electricity was cheaper. The capital sum of £65,000 represented the total expenditure of all kinds upon the boosting-station up to the time the Paper was written, and therefore included maintenance and attendance during the first 3 years of the station's existence, during which, as construction work had been continually in progress, the separate items could not very well be kept apart. The other sum, which happened also to be £65,000, was the capitalization at 5 per cent. of the cost of 1 year's consumption of electricity, based upon the experience of the first full year of working. Thus the saving of £16,000 per annum which Sir John Snell had calculated was net saving after the cost of energy was allowed for. The only sums which it might be necessary to deduct from that in the future were

the costs of the special attendance and of repairs to the machinery. The Author Those appeared likely to be very low. The present staff consisted of one electrical engineer and two mechanics, whose wages aggregated about £800 per annum; and they had so far executed without further cost all the repairs, and had spent besides considerable time on operations in connection with the waterworks as a whole, in the workshop attached to the boosting-station. He sympathized with Mr. Ackermann's objection to the right-angled junctions; but, since the velocity through those pipes never reached 3 feet per second, the head lost in turning a right angle was only a small fraction of a foot. The justification for the right-angle turn was that it was not quite certain which way the water would be required to turn at any particular moment. Sir John Snell had alluded to electrolysis, and the Author remembered the time, 20 years ago, when that was a very serious matter in Monte Video. Special attention was paid to the problem, and for years past he had never heard of any further trouble. Sir John Snell had also referred to the importance of the use of electricity from the point of view of improving the load-factor of the electrical station. The Author believed this to be so great an advantage that all the boosting could actually be done for next to nothing. With regard to Sir Archibald Denny's question why the first year's working expenses only were taken, perhaps it would be better if the text read, "the first complete working year." Mr. Sayer had raised an important question regarding the limit of economy of the boosting process, which could only be answered by carefully watching the development of the city's demands in future years and the true cost of electric energy when the improved load-factor was taken into account. The dominant factor was always the rate of growth of the demand for water. As that continued, so did the expenditure upon electricity continue to increase, and *Figs. 2, 3, and 4* showed that the rate of increase of power was very much higher than that of the demand for water, so that the greater the demand, the higher was the cost of pumping per unit. If provision were made for the extra quantity by increase of piping, the reverse condition prevailed, namely, the larger the quantity, the less the cost per unit; it followed, then, that a point was reached when the cost of boosting exceeded that for interest upon piping, and that showed the limit at which boosting was remunerative. In the case under discussion, however, a partial halt might have to be called before that point was reached, as it was highly probable that, by laying selected portions of the £325,000 worth of piping, the cost of boosting might at an early date be reduced in a degree more than proportionate to the partial

The Author. expenditure of capital. He thanked Mr. Thorpe for accentuating a difference which was often neglected by engineers, but which was of real importance, namely, that between an inconvenience and a disaster. Failure of the electric supply would involve the town in the first, but not the second of those experiences, a point which it was important to bear in mind in judging the boosting scheme. He wished to supplement in two respects what was stated in the Paper concerning the electric control. He had hardly done justice to the balance switch. This could be made to work with much greater accuracy than that stated, as the lag of 2,000 gallons per hour (p. 134) was to a large extent deliberately introduced, being one of the devices by which quick make and break were effected. The description of the method of control of the large motor, given in the Paper, was based upon the method evolved by the Author, which the experiments of Mr. Lupton demonstrated to be theoretically sound; but the electrical experts to whom the design in detail was unreservedly handed over found it necessary to modify the details so as to bring the field current down to the limit imposed by the mercury tubes. The control was therefore effected as in an ordinary shunt-wound motor, with the exception that the energy in the field current was absorbed not by heating resistances but by causing the small motor to do in a varying degree a part of the work of the big one. Then only the greatly reduced field current corresponding to the small motor had to be dealt with by the mercury tubes and their attached resistances.
