Discussion.

Sir Frederick J. Bramwell, Past President, regretted that the Author was not present. If he had been, he could have afforded some of those further detailed informations that were almost always needed on such occasions, and were still more needed in this instance, where the Author had not had present to his mind the fact that to many of the audience the subject came before them for the first time. Such a subject was obviously one of great importance, being nothing less than the distributing both power and heat, from a central source, to a large district. This, broadly considered, was no doubt novel. The Author suggested in his Paper that the principle, if he might so say, of distributing steam was applied for the first time in 1853; at least, this was the impression he derived from reading the Paper. In respect to this question of date he was glad to say there was present to-night Mr. Edward Woods, Past President, whose report, a good many years ago (in 1836), on the transmission of steam to Edge Hill, from the Wapping Tunnel (Liverpool), 448 yards, to work winding engines of 250 or 300 HP., was among the archives of the Institution. He trusted that Mr. Woods would, before the discussion closed, give the Institution the benefit of his views on the Paper now under discussion. Further, with respect to the general question of heating houses by steam, so far as he knew, the earliest proposition was to be found in the Philosophical Transactions for 1745, in which publication there was a very clear drawing by Colonel William Cook, of the steam-heating of a private house from the kitchen fire: and in 1801, Count Rumford heated the Royal Institution, using diaphragms to allow for the expansion. He did not mean to say that those were cases of heating from a central source in the sense to which he had referred, but they were early cases, and somewhat germane to the matter under discussion. He had placed on the black-board a rough sketch showing the position of the described station ("B") in New York. The district which this station served had a mean width between the Hudson and the East rivers of about $\frac{2}{3}$ mile, while the length from south to north, namely, from the Battery to Reade Street, which appeared to be the north termination of the work, was about a mile, the acreage being some 400. The total length of street within this district he had caused to be measured, and it appeared to be about 22 miles. The station "B" might, therefore, be taken

Sir Frederick Bramwell. as a fairly typical one for the supply of a large town, and as being well adapted for the purpose of testing practically the feasibility and utility of such an undertaking. Owing to the very great value of land in the heart of the City of New York, the Company had been compelled to resort to an ingenious plan for concentrating on a small area its large boiler plant. This plan consisted in putting the boilers in tiers, floor above floor, and already three tiers of boilers had been so placed, exerting what the Author called 12,000 HP., but it should be understood that that 12,000 HP. was not by any means derived from the old rule of a cubic foot evaporated per hour, but from one much nearer the truth, namely, the evaporation of 30 lbs. of water per hour, a little less than $\frac{1}{2}$ cubic foot of water per hour. The three tiers of boilers already in position were competent to boil off, and deliver at 70 lbs. above the atmosphere (plus the pressure needed to drive the steam through the pipes, giving a maximum of 80 lbs.) 12,000 times 30 lbs. of water in an hour; and when the fourth story was completed, 16,000 times could be evaporated. The steam produced by these boilers was distributed throughout the district by pipes carried in the ordinary manner of gas- and water-pipes under the surface of the streets. He thought there were four points which called for remark, and in respect to some of which the Paper was rather contradictory. In the early part of the Paper it was stated that the variators and the joints were found perfectly tight; and in the latter part it was stated that all the difficulties arose, not from condensation, but from leakage. Those two statements certainly appeared to be somewhat inconsistent. It was nowhere said of what material the pipes were composed; it could only be arrived at inferentially from the statement that the pipes were $\frac{1}{4}$ inch thick, and from the further statement of their being rolled out to unite them to cast-iron flanges, that this material was wrought-iron. One of the matters to which he wished to call attention was the mode in which these pipes were united to the cast-iron flanges; this was shown in many places. Plate 1, Fig. 9, was a good example. The cast-iron flange was bell-mouthed towards the face; the pipe was introduced at the back, and then by an expander was rolled out to fit the bell-mouth. The flange was provided with a little socket at the back of the bell-mouth, where it was stated it had been intended to put in a wrought-iron caulking-ring; but it appeared that, in practice, this plan had not been adopted, and that mere iron cement had been used. As he had said, the Paper declared that these joints were perfectly tight, but if they were he was at a loss to see where the leakage was. The

Sir Frederick Bramwell.

only explanation offered in the Paper was that the stuffing-boxes leaked; but as the expansion of the pipes was provided for, not by stuffing-boxes but by the variators, it appeared to him that there were not any stuffing-boxes to leak, except the small boxes on the service-valve, and he could not believe that the considerable loss stated, or even any important portion of it, could arise from such a cause as this. He should have thought that in an undertaking of this importance it would have been desirable to have had the pipes made with ends thickened out, so as to afford material enough to allow of flanges being thrown out in the solid. Such flanges could then have been readily nipped between pairs of thick cast-iron flanges. He could not help thinking that the flanges were not as satisfactory as the Paper stated. Probably the most noteworthy feature in the system was the mode by which the disk principle of expansion was made applicable, and apparently successfully so, to allow for the variation in the lengths of the pipes. The Author employed the term "variator" to express this kind of expansion-joint. Plate 1, Fig. 11*a*, showed the method, which no doubt was very ingenious. It appeared that at the outset an attempt was made to allow for the expansion by the use of a number of annular diaphragms, riveted together alternately at their outer and inner sides, so as to produce a sort of circular accordion, but this construction was not found to answer. Then simple diaphragms were tried, and that did not answer. Such diaphragms were used by Count Rumford in 1801 (no doubt those answered—3 feet diaphragms upon 2-inch pipes, probably with atmospheric steam). After these unsatisfactory results, recourse was had to the extremely ingenious plan described in the Paper and shown by the drawings. In carrying out this plan, the copper body of the diaphragm was thinned down until it was only $\frac{1}{25}$ inch thick, and was then corrugated by annular corrugation; and to enable it to resist the pressure of the steam, a set of radial plates, which he presumed were castings, was applied on the side of the diaphragm opposite to the steam-pressure; and, as it was feared that there might occasionally be a partially vacuous condition in the pipes, a corresponding set of castings, but of less strength, was put on the other side of the diaphragm, so that it would resist any tendency of the pressure of the air to cause a collapse. This construction of expansion-joint appeared to him to be a very ingenious mode of getting over a great difficulty, and it appeared to have been very successful. Out of a large number of these variators, it was said only one had failed when it was complete, two others having failed because the American workmen, emulating their

Sir Frederick Bramwell.

British brethren, had contrived to leave out some of the protecting radial plates, and the unsupported copper, a thickness, or rather a thinness of only $\frac{1}{25}$ inch, while admirably adapted to yield to the variations in the length of the pipes, was incapable of sustaining unaided the steam-pressure, but blew out like a balloon. Such an arrangement, when properly executed, appeared to him to afford an extremely likely mode of making a sound joint, while freely allowing for the expansion. But, he repeated, if it were so successful, and if the joints of the pipes and the flanges were so successful, where was the great leakage? He could not understand it; he was afraid there was a giving way somewhere, and he felt inclined to suspect, not the variators, but the junction of the pipes with the cast-iron flanges. The Paper stated that the expansion-joints, or variators, had been employed in two ways; one with an expansion arrangement on one side only, as shown by Plate 1, Fig. 9, and the other with an expansion arrangement on both sides as shown by Plate 1, Fig. 11. In either case the fixed portion of the variator box was the point from which the services to the different houses were taken off, so that these services and their points of junction with the main were not troubled by the expansion of the pipes. Another matter to which he wished to call attention was the extremely ready mode used to vary the direction of line of pipe, as shown in Plate 1, Fig. 8. Where streets were not at right-angles—and, even some of the streets in New York were not at right-angles—it was possible, by the method there shown, to alter the line of pipe without any special difficulty. With regard to the mode of making the connections for distribution, he had at first been unable to understand the diagrams, but probably that was his own fault. He could not understand Plate 1, Fig. 6, which was said to show the mode by which a service branch was unstopped in order to make a new connection. It appeared that at the outset of the distribution a screw-valve was put upon every one of these branches, so that nothing remained but to connect the service to the outer flange of one of them; but the expense of supplying so many valves was considerable, and if customers did not come, that expense would be incurred for nothing. The fixing of a valve to each branch was then given up, and the branch opening was closed by a mere screw-plug; then came the question how, without shutting off the steam, the plug was to be got out, the valve was to be put on, and the service was to be connected. As he had said at first, he could not make out what was intended, but at length it dawned upon him. Thinking that other members might have experienced the same difficulty in

Sir Frederick Bramwell.

reading the diagram, Plate 1, Fig. 6, as he had experienced, he had ventured to prepare a diagram[1] showing on the left hand the plug in the pipe and then the screw-valve in its opened condition fixed to the flange of the branch. A temporary cap with a stuffing-box and a mandrel passing through it being secured to the outer flange of the valve, the mandrel was caused to engage by means of a left-hand thread with the screwed plug, and by this the plug was unscrewed and was drawn close up to the temporary cap; the valve was then shut, and on this being done the temporary cap with the mandrel and plug were removed, and the valve-box was ready to receive the service. No doubt many members present would recollect Mr. Upward's ingenious plan by which he not only could have effected an operation of this kind, but by which he was able absolutely to tap a service into a pipe containing high-pressure steam without the slightest leaking of the steam or without loss in any way. That could not be done in the present case, because the pipes were not tapped, being too thin, and were expanding and moving about; nevertheless the principle was very much that which Mr. Upward worked out under circumstances of much greater difficulty. With reference to the loss of pressure, he searched the Paper in vain to deduce any figures that would enable him to thoroughly check the statements. The outside measurement of the pipes was said to be 11 inches. He thought there must be some mistake, because the Author called it 10 inches inside, and the pipe was $\frac{1}{4}$ inch thick. Whether he meant 10 inches inside or $10\frac{1}{2}$ inches inside he could not make out. Assuming that the Author meant 11 inches outside and $10\frac{1}{2}$ inches bore, also that the distance to the extreme point of supply was $\frac{1}{2}$ mile (as was probably the case having regard to the locality of the station), and that there was a velocity of 80 feet of steam at 75 lbs. above the atmosphere, and that the whole of it went through the length of pipe, none being taken off in the course of the journey, he made out that under those circumstances the pressure to produce the flow would be 12 lbs. to the inch, which was sufficiently near, in the absence of absolute data, to the 10 lbs. suggested. He had at the outset of his remarks referred to the Edge Hill tunnel experiments by Mr. Woods, in which there appeared to have been a much greater loss of pressure, but there seemed to have been difficulties in that case in making anything like accurate experiments owing to the variable nature of the work, and therefore of

[1] With the approval of the Author this diagram has been substituted for the original Fig. 6 in Plate 1.—Sec. Inst. C.E.

Sir Frederick Bramwell. the delivery through the pipe. The Paper dealt with four varieties of supply, ten hours a day during six months of the year, and the fourteen hours a day remaining during those six months —ten hours a day during the other six months, and the fourteen hours of those days. It appeared, as well as he could make out, that taking the distribution of steam on an average, as was done in the Paper in one or two places, for each hour in the year all the year round, and calling that average 3,000 HP., this must be multiplied by two and a half times in order to arrive at the average HP. needed during the ten hours of the six maximum months. But it appeared to him clear that such a multiplication would not suffice to give the actual maximum, because if the average of the ten hours during the six maximum months amounted to any particular quantity it was certain that neither all the days nor all the hours of the days in those six months were uniform, and that therefore there must be a maximum and a minimum; and he believed it would be found that in order to deliver hourly 3,000 HP. for every hour in the year, preparation must be made to deliver at least 9,000 during some one hour of maximum in the year demand. But, further, taking condensation and leakage, and the amount of steam used in the works, these appeared from the Paper to amount as nearly as possible to 33 per cent. of the steam sold to the consumer. If he was right in these calculations it followed that, in order to deliver an average of 3,000 HP. for each hour of the year, there must be the ability to deliver 10,000 at some time. As regarded the loss of 33 per cent. by condensation and leakage, it must be remembered this was 33 per cent. of the average delivery —not of the maximum, because the percentage would not increase as the delivery of steam increased. As regarded the need of the ability to deliver 10,000 HP. per hour in order to supply an average of 3,000 HP. for every hour throughout the year, this must be borne in mind when making calculations as to the financial aspect of such an enterprise. There were many interesting problems arising in reference to the undertaking. One was what was the most economical pressure at which to deliver. It was quite clear that the condensation must be governed by the temperature; it was equally clear that the leakage would, to some extent, depend upon the pressure, and equally clear that, however small a quantity was being taken away by customers, the whole of the mains had to be kept charged under the full pressure and at the full temperature. Therefore, during the periods of short demand, the loss from leakage and condensation became an extremely large percentage of that which was sold and was earning revenue. It was obvious that by doubling the pressure, say from 70 to 140 lbs., with the same velocity in the pipes, double the HP. would be sent through, while the condensation and leakage would be but slightly increased. It was true that the pressure producing flow must be doubled that would send this double force through, because, although the velocity would be no more, the gravity of the steam would be double, and, therefore, there would be needed double the pressure to produce the flow. It appeared that the Author was afraid of dealing with large variations of pressure in the pipes, on the ground that the customers were entitled to a practically uniform pressure, neither too high nor too low; and that if larger heads were used to obtain the flow, then, in order that those who lived remote from the station should obtain the stipulated pressure, those who lived near the station must have an excess pressure. He should have thought that nothing would have been more easy than to put a reducing valve for each consumer, so that, if the consumer lived near the supplying station, and there was a pressure at the station of 40 lbs. in excess of that which the consumer required, he would still obtain it at the agreed pressure, and in that way it would have been possible to diminish the size of the mains, and in diminishing the size of the mains, the loss by condensation and leakage would also have been diminished. Another point deserving consideration was how far it would be worth while to superheat the steam before it was put into the pipes for distribution. The temperature would be thereby raised and the bulk somewhat increased, but it would enable the steam to travel a great way before it deposited water or deposited it to the same extent. Those, he thought, were all matters to be borne thoroughly in mind if the system ever took root in this country. But, on the general question of distributing power from a central source, he wished to mention the relation that obtained between the power conveyed by 70-lb. steam and the power conveyed by means of gas. There were 153 cubic feet of steam per hour, at a pressure of 70 lbs. above the atmosphere, delivered to every consumer for 1 HP. Now steam at that pressure was practically two and a half times as heavy as air, while ordinary illuminating gas was twice as light. It therefore followed that gas was five times as light as this steam; it also followed that, as in a gas-engine, 1 HP. could be obtained for an hour for 25 cubic feet, instead of 153 feet, a sixth part of the cubic feet would suffice. A sixth part of the cubic feet going through the same sized main would need only one-sixth part of the velocity; and, taking the gravity into account, that

Sir Frederick Bramwell.

Sir Frederick Bramwell.

would come to one hundred and eightieth part of the head for the distribution of the same HP., or, instead of needing 10 lbs. of head, $1\frac{5}{9}$ inch of water would suffice to deliver in gas the same power. The Author had not given the particulars of the meter that he employed, but he had made a reference to a description of that kind of meter in the Transactions of the American Society of Civil Engineers.[1] It was there described as used on a large scale to measure water. It was called a Venturi meter, as it depended upon a vacuous condition in the middle of the Venturi jet, a condition which varied with the rate at which the water flowed past. It would have been interesting to have the particulars of an instrument for thus measuring steam, which would satisfy the customer and the seller that the customer was really getting the particular quantity of steam for which he paid, and was not getting it charged with water of condensation. There was one other point in the Paper which seemed to him to require an explanation. The water from the condensed steam; that which condensed in the line of pipes, and also that which condensed just outside the houses taking a supply, was brought back by the return pipes; and it was said that those pipes must be either over or under the steam-pipes. It was also said that it was desirable that steam-pipes should be laid with a fall, so that the water might trickle along the bottom in the direction in which the steam was going, and that if for any reason this fall had to be reversed, that then the rise should be made as abrupt as possible, in order that the steam might blow the water along, and then the fall might re-commence. Therefore the steam-pipes were on the whole clearly intended to fall away from the station. If that were so, how did the water get back again in the return-pipe to the station? It came out of the steam-pipes by means of steam-traps; but the steam-traps did not allow the steam-pressure to pass; they simply allowed the water to pass into the return-pipe. By the assumption he had made that water had to get up-hill; of course a very few lbs. of pressure of steam would do it; but it was not stated how it was done. It seemed to him that it could not flow along. He should have been glad if the Author had been present to elucidate that, amongst other questions. He did not think there was much chance of the introduction of the system into London, and that for one or two reasons, the primary one being that, if any body of undertakers proposed to introduce it, there would be a clause inserted in the Act giving them the power

[1] Vol. xvii. p. 228.

Sir Frederick Bramwell.

to do it; that at the end of twenty years they would have to sell to the parish, at the value of the materials, if the parish then chose to buy, and chose to buy because a profit had been made; but that if a profit were not being made, the parish need not buy, but at the end of five years the parochial authorities might come again, and say: "We will." This was the outcome of the present legislation in this country as regarded industrial undertakings for quasi public purposes. He thought that kind of legislation was not conducive to the promotion of private enterprise, and, if for no other reason than that, he did not think the system would be introduced into London. Another reason was that a large portion of the utility of the system was obviously for heating private houses; and he believed, in spite of what he knew Sir Douglas Galton would say, that Englishmen were so thoroughly wedded to a pokeable fire, that none of those contrivances would ever replace it. This pokeable fire might be supplemented by other modes of heating, as was done in his own house. He liked the house so warmed as to make it a matter of indifference whether the sitting-room door were left open or not, but he was not going to give up an open pokeable fire, which gave admirable ventilation in the room, and was, moreover, an excellent and cheerful companion. One statement had been made which might perhaps excite the surprise of some members who had not had an opportunity of trying the experiment, as he had done, namely, that meat could be actually roasted by means of the steam transmitted. On one occasion he was in the cigar-boat, and on the saddle-back deck of that vessel there was a double-cased pot, into which ribs of beef were placed, and at the end of two hours they came out as thoroughly well browned and cooked as anything he had ever seen, and that by means solely of contact with the sides of the steam-heated pot. But notwithstanding all these temptations in regard to cooking and heating without fire, he did not think the insular prejudices of Englishmen would be overcome, but that these prejudices would always remain a permanent barrier to financial success, even if the present practice of Parliament in regard to private enterprise of that kind were happily altered.

Mr. Ellington.

Mr. E. B. ELLINGTON felt personally indebted to the Author for having brought the subject before the Institution. He congratulated him upon the success he had attained in the distribution of steam, and in solving a difficult problem. That success was emphasized by the fact of the failure of another company in New York, to which allusion had been made. It appeared to him

Mr. Ellington. to show what, indeed, all engineers of practical experience well knew, the great importance of accuracy in detail. There were, however, one or two questions which he should be glad if the Author could elucidate. It seemed to him that there would be increasing difficulty in the maintenance of the steam-mains, and there was one fact mentioned in the Paper which, he thought, led to that conclusion. Reference was made to the HP., which was unaccounted for in the steam-pipes, as being 500 in 1886, and it was remarked that in 1887 it had only reached about 730; that was attributed by the Author to an increase in the leakage of steam in the pipes; but, as there was apparently only a small increase in the length of mains during that period, he could not see why there should be any material increase in the amount of leakage, if, as was stated, the pipes themselves were in a better condition at the latter period than at the former. The misfortune of all leaks in mains was that they went on continually during all hours of the day, and all the days of the year, until they were rectified; and with the same constant pressure in the mains he failed to see why there should be any increase at all due to increased supply of steam to the consumers. He doubted, however, whether the leakage alone was the principal cause of the unaccounted-for steam-power. He thought it was rather to be found in the deficiency of registration, and in the increase of condensation. The Author stated that between 1886 and 1887 the condensation, as represented by the measured condensed water, had risen from 150 to 350 HP., and he accounted for that by the fact that steam-traps had been put on the service-pipes to the consumers' premises; but it seemed to him that there was a probability—in fact, a certainty—that there was a great deal of condensation in the steam-pipes which would not be accounted for by the water returned through the steam-traps. While the steam supplied to the consumers was in a much drier state after the steam-traps were used than before, probably that steam still reached the consumer in a wet condition, and in that way condensation might take place which was not ascertainable by the amount of condensed water. The mechanical details did not offer a very large field for criticism, and he would therefore pass on to the figures which the Author had given with regard to the undertaking generally. It was mentioned that the total outlay had been £450,000 up to May 1886; but, as that sum was far in excess of what the works could now be executed for, it was taken for granted that the capital outlay on the first station should only be estimated at £320,000, and the figures appeared to be based on that amount. That struck him as rather peculiar when dealing with the capital. Passing on to the cost, he could not arrive at any other conclusion than that the total cost mentioned was really only the cost of the coal. He should be glad to have some further information on that point, because it appeared that the coal was \$3·25 per ton, and that worked out for 1 HP. for the whole year to \$48. The charge made was \$105, and all the figures seemed to accord with those statements. The surpluses given in the Table (p. 212), if he read them correctly, represented simply the excess of the receipts over the cost of the coal alone. If that were so, he failed to see how it was possible that the steam could be supplied at a profit at the rates at which it was apparently sold. The rates would have to be about doubled in order to arrive at a satisfactory basis. The average HP. sent out from the station throughout a whole year in 1886 was said to have been about 2,000, while the maximum HP. delivered at any time, and furnished at the station, was something over 5,000. It was curious that the proportion between those two figures was very much in accord with the proportion found in the distribution of hydraulic power in London between the maximum and the average. Considering the great variation in the kind of distribution of power, and in the purposes for which it was supplied, it was singular that the figures should agree so closely, and it rather tended to confirm the opinion which he had expressed, that it would be impossible to supply any power profitably from central sources in cities at rates very much below £20 per HP. per annum for the ordinary hours of work—fifty to sixty per week. Of course if he was wrong in the figures he had quoted, or in the interpretation he had placed upon them, he would be wrong in the statement he had made, because power was apparently being supplied at about £8 per HP. per annum in New York; but he thought when the figures were examined closely, it would be seen that it had been really supplied under its intrinsic value, at any rate, to a large number of consumers, especially those who were using it for power purposes. For heating, he considered it probable that a much higher rate could be obtained. He also wished to ask the Author whether he could give any information with regard to the distribution of steam in Boston. He understood that there was a system at work there for that purpose, but that the steam was not carried through the streets except in the form of water at a temperature of about 400° at high pressure on a circulating system. If heat was required, the hot water, on something like the Perkins' system, was available. If steam was required, the Mr. Ellington.

Mr. Ellington. high-pressure hot water was allowed to expand in a transformer where it was converted into steam. It would be interesting to know what the results had been compared with the results of the steam supplied in New York. The Author seemed to have done all that it was possible to do in the distribution of steam, and the question arose whether a thorough success could be made of a general steam distribution throughout a city.

Mr. Phipson. Mr. W. W. Phipson said that the Author had given some valuable information with regard to the distribution of steam, and the manner in which all the details had been stated proved the many difficulties which he had had to surmount. Those details had been so fully referred to, by Sir Frederick Bramwell, that very little was left to discuss. The difficulty in the arrangement was the relief of the steam-mains, which did not appear to have been thoroughly explained. That was, of course, one of the great difficulties in carrying steam long distances. No doubt the Author had thoroughly studied the question when he laid down the plant; but the Paper did not show how the condensed water was returned to the central station. He had said that it was by the use of traps. No doubt that meant return traps; because in some cases the return mains seemed to be on a level with the supply main, and therefore there would be considerable difficulty in relieving the supply main into the return unless an automatic trap was used. Probably that was done, but he could find no explanation. The mode of making the joints by a gasket of thin corrugated copper wire seemed to be good. That joint had been in successful operation in this country for some time with high-pressure steam. The question of steam distribution was not new, but there had not been any direct application of it. In 1881 a Paper by Sir Douglas Galton had been read entitled, "The Combination System of Steam Heating for Towns and Villages,"[1] in which the Author expressed a wish to see a system adopted similar to the Holly system. In the discussion which followed Sir Frederick Bramwell said he was very much in favour of gas as a means of conveying heat, and it would appear from his recent remarks that he was still of the same opinion. The late Sir William Siemens had stated that 1 cubic foot of gas contained 750 units of heat, which was about the same amount as would have to be supplied by $3\frac{3}{4}$ cubic feet of steam. In 1883 Mr. Goodyer read a Paper before the Society of Civil Engineers in Boston on water-gas as fuel, in which he stated that the latest experiments on a

[1] Journal of the Society of Arts, vol. xxx. p. 84.

large scale for the distribution of high-pressure steam had not been very successful. He said: "The system which furnished cheap gas of great heating power, easily distributed where wanted, without requiring pipes to stand high pressure, must eventually be the agent used." Unfortunately, in this country there had been no application of direct distribution of steam; but the very successful results obtained by the General Power Company, now in full operation in London, rather induced him to think that at some future time something else besides cold water might be conveyed at high pressure under the streets. That Company carried cold water at 700 lbs. pressure per square inch, and he saw no reason why superheated water might not be carried at 250 lbs. pressure. This was the scheme of the Boston Heating Company. That question had been before him since 1887, when a Paper by Mr. A. V. Abbot was read at a meeting of the Boston Society of Civil Engineers.[1] He thought the system was more useful than steam as a distributor of heat, and Mr. Abbot was of the same opinion, because that was the principle which he had carried out at Boston, where it was in full operation in December 1887, and customers were supplied in February 1888. The water was superheated at 400° Fahrenheit. There was a battery of boilers in a central position. Against the boiler was placed a pump, to draw the water out of it and circulate it round the different mains in the streets, and back again to the boiler. If no water was taken off, the pump withdrew the water from the boiler and returned it. That went on day and night. Under the supply-main there was a large return water-main, 8 inches in diameter, and in that was returned all the water of condensation from the different consumers, and also what might come from other sources. The return main again brought the water back into the central station; it was collected into a tank, and from that tank was sent back by another pump into the boiler, where it was heated afresh and again distributed. That appeared to be a very simple arrangement for the distribution of heat. The diameter of the supply-pipe was 4 inches. The distribution to the consumers was from a small pipe to a service-box. It was arranged to distribute heat to three buildings. From the box the pipe was led into the building, and at the end of the pipe was a reducing-valve, which reduced the pressure in it; then it flowed into a converter, where it was transformed into steam, taking up the superfluous heat. By means of the reducing-valve the pressure in the converter Mr. Phipson.

[1] Journal of the Association of Engineering Societies, vol. vii. p. 389.

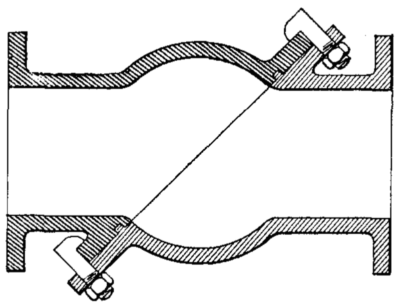
Mr. Phipson. could be regulated according to the consumer's desires. Mr. Abbot based his experience, no doubt, upon the results of district distribution of steam and water-gas fuel in other parts of America, which Mr. Phipson had not had the opportunity of seeing. The Author stated that to maintain a range at 350° Fahrenheit the water supplied should be at a temperature of 400°. Supposing that he introduced into the mains 1 cubic foot of water at 400°, the fall in the temperature being 50°, the heat liberated would be 2,728 units; but if 1 cubic foot of steam at the same temperature were introduced into a vessel, and a fall of 50° took place, the number of units liberated would only be 199·2. It was therefore concluded that one great advantage of superheated water was that pipes of much smaller dimensions could be used than would have to be used for steam, and that by working with an incompressible fluid like water, and the employment of a pump to produce circulation, the difficulties of the distribution level, and the direction of the pipes, were more easily overcome. It was also stated that the boilers for the superheated water were easier of construction, and more easily maintained. The Author had brought forward a very interesting subject; but if Mr. Phipson were asked to maintain a long range of pipes at an even temperature night and day, steam would certainly not be the agent he should employ; he should like a medium of greater density.

Mr. Silver Hall. Mr. W. Silver Hall wished to say a few words respecting the spherical joint shown by Plate 1, Fig. 8. In 1810, the Directors of the Glasgow Waterworks found a difficulty in carrying their mains over the undulating bed of the Clyde, and they applied to James Watt to help them. He designed for them a joint somewhat similar to the one represented, and with entire success. He had not been able to obtain the full particulars of it, but perhaps Mr. Cowper, who took great interest in Watt's inventions, might be able to give some information on the subject. It had been stated that Watt took his idea from the articulation of a lobster's claw. In 1878, Mr. Royle of Manchester brought out the universal joint. It would be seen that (Fig. 3), by slacking all the bolts and gradually turning one part round, any angle of pipes might be obtained from a straight line to a right-angle. Some years before, he had had occasion to solve a similar problem in a somewhat similar manner as shown by Fig. 4. A pair of pipes was made with flanges slightly inclined to each other, and by turning them round, any angle might be obtained from the angle shown in the Fig. to a straight line. The difficulty had arisen through the mistake of a pattern maker, who had set out

Mr. Silver Hall.

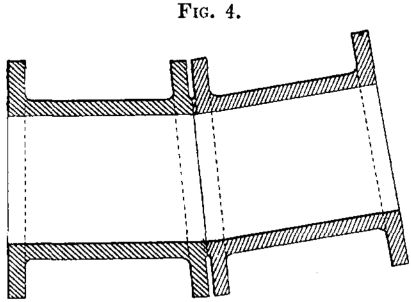
the flanges of both pipes to the full angle of deflection required, instead of setting each of them to half the angle. There was no time to procure fresh pipes, but it had occurred to him to turn one of them half round upon the other so as to get the requisite variation. In the steam-pipes described in the Paper there appeared to be ten bolts to a joint. If the angle of the pipe was set

FIG. 3.



to 10°, by turning from bolt-hole to bolt-hole there might be five variations from nothing to 10°; and those variations from a straight line would probably be enough in very many instances. He had had to solve a similar problem to that shown by Plate 1, Fig. 6. It was necessary for the supply of some boilers in a pit to tap the tubbing at a depth of about 90 yards from the surface

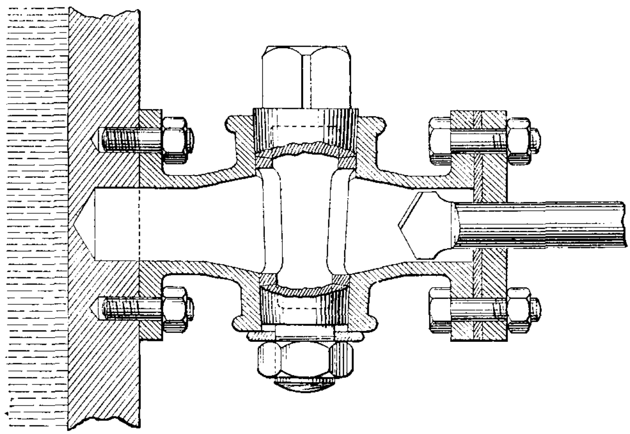
FIG. 4.



with a pressure of, say, 120 lbs. of water. To do that he drilled the tubbing-plate through as nearly as he dared (Fig. 5), then bolted on a 1½-inch cock, and introduced a drill with a long turned shank passing through a blank flange with a hole just large enough to slip the shank of the drill through. The only packing was a piece of leather between the flange of the tap and the blank

Mr. Silver Hall. flange. Before withdrawing the drill, it was necessary to clear out the cuttings, and to do that the bolts of the blank flange were slackened a little. There was then a tremendous display of waterworks, and the man who slacked the bolts was half drowned, but that did not count much in colliery practice. In

Fig. 5.



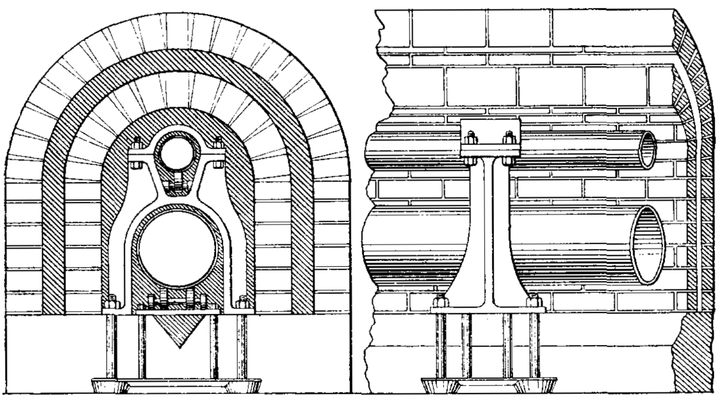
half a minute the tap was shut off, the flange taken off and the drill withdrawn. Of course, the plan was not universally adaptable, like that of Mr. Upward; but it had the simplicity of being adapted to the exact place wanted without any special expense or appliances except the drill, as even the blank flange was utilized by screwing the first length of pipe into it.

Mr. Dowson. Mr. J. E. Dowson said he had experienced the same difficulty as Mr. Ellington in arriving at the working cost of the system explained in the Paper, and had come to the same conclusion, namely, that the cost of the coal alone was given. Of course, that did not represent all that should be known; but taking the selling price, and assuming that it included some margin of profit, the result was that when the average price for the coal was 13*s.* per ton, and when the system was working on a large scale, the steam could be sold to consumers at an average of 40 cents per 1,000 kals. Each kal represented 1 lb. of water converted into steam at 70 lbs. pressure, and as 30 kals gave 1 HP., the selling price was about $\frac{2}{3}$*d.* per HP. In this system a net weight of 30 lbs. of steam had to be delivered to the consumer for each HP., exclusive of what was lost by condensation and leakage, but Sir Frederick Bramwell had made the rather striking contrast, that

Mr. Dowson.

about 1 lb. weight of gas would develop 1 HP. With a good gas engine 20 cubic feet of ordinary gas were required per HP., so that when gas was 2*s*. per 1,000 cubic feet, it would cost the same per HP. as the steam. In the United States gas cost much more than in England, and open fires were less used; and he could hardly see that in this country there was any large opening for a system of steam distribution except for blocks of warehouses, offices or workshops. The diagrams (Figs. 6) showed the high-pressure hot-water system used in Boston. The top pipe was the flow-pipe, 4 inches internal diameter, containing water at a temperature of about 400° Fahrenheit, under a pressure of about 250 lbs. per square inch. The lower pipe was 8 inches internal diameter, to enable the cooled water to return by gravitation to the boilers.

Figs. 6.



Both pipes were carried on saddles placed 15 feet apart, and under each pipe there was a friction-roller, so that the pipes were free to work longitudinally. There were telescopic expansion-joints at distances of from 100 to 150 feet; and he was informed that careful experiments had shown that the leakage had so far been almost nil. A rather remarkable feature was that the flow-pipe being charged with water at 250 lbs. pressure, the service-pipe for an ordinary building was only $\frac{1}{4}$ inch in diameter, and for a large warehouse $\frac{3}{8}$ inch. To supply a 25-HP. engine, the service-pipe was only $\frac{5}{8}$ inch in diameter. The service-pipes were made of copper, so that they could be bent easily, and in that way many joints were avoided. The mains were covered very carefully in much the same way as the steam-pipes explained in

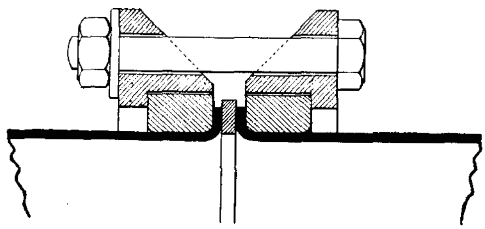
Mr. Dowson. the Paper, and it was stated by the engineer of the company, that in the coldest weather, in a circuit of 2 miles, the loss from radiation was only 3 per cent. He had had no practical experience of the system, and he had not yet received the details of the working cost; nor did he know how the supply of hot water to the consumers was measured. In the Paper on steam distribution it was also noticeable that little was said about the means adopted for measuring the supply to the consumers. He was in New York in 1884, and he was then told that the system of measuring the steam was unsatisfactory, and had the Author been present, he should have asked him for some further explanation on that point, because, with either of the systems, the financial results depended very greatly upon having some really efficient means of measuring. Speaking generally, and in the absence of full data, he thought that the high-pressure hot-water system compared favourably with the steam system, because the water had a much greater capacity for absorbing and retaining heat, and was therefore a better carrier of it, the specific heat of steam being only three-tenths that of water. The mains could be smaller, and the first cost reduced; and although the temperature of the high-pressure hot water was greater than that of the steam, the loss by radiation was probably about the same, because the water-pipes were smaller and the radiating surface was less. There was no condensation, and there could be no trouble with the ramming, to which special reference had been made in connection with steam distribution.

Mr. Stainton. Mr. WILLIAM T. STAINTON said that having had some experience of the distribution of steam in this country, and on the Continent, he thought there were several defects in the American system. It was stated in the Paper that the New York Steam Company had 6,000 HP. of steam, and lost 500 HP., which was unaccounted for other than by leakage, that loss being attributed to leakage through the joints. It appeared that wrought-iron pipes were attached to cast-iron flanges, and the tubes expanded into the cast-iron flanges. These might be kept sound for a certain length of time. To obviate the difficulty of leakage a recess had been left, in which it was proposed to put iron cement, or other metal, being held in position by clamps. That was only a makeshift way of meeting the difficulty. He had had a great deal of experience with steam at high pressures, and had invariably found that the only manner in which these joints could be made to stand was by putting a wrought-iron flange on to the pipe, expanding the pipe into the flange, braising it on and facing it, and making the joint as thin as possible. He had tried joints with asbestos, and they stood a pressure of 100 to 120 lbs. per square inch without difficulty. Another difficulty was the expansion of the pipes themselves. He also had noticed that the top side of the pipe always expanded more than the lower side, on account of the lower temperature of the condensed water. To obviate that an expansion-drum had been employed by the Americans which was simply a copy of Count Rumford's system, used at the Royal Institution early in this century; and in that apparatus, the pipes were cast-iron, about 3 inches in diameter, and the copper drums about 3 feet in diameter. There was an easier way of getting over the expansion, namely by forming spring or expansion-bends; he had used them to a great extent, and had found them to work better than the ordinary telescope expansion-joints. When he had made branches from long mains, it was found requisite to put expansion or spring-bends for the branch pipes, so as to prevent the breaking of the joints. One thing which he had successfully used to get over the difficulty of expansion was a corrugated copper cylinder about 2 feet long, according to the size of the pipe, the corrugated tube in its smallest diameter being about the same diameter as the pipe, and corrugated perhaps 1 inch deep. A certain action was produced by it without much trouble, and without having any large drum. He found the expansion to be about $\frac{1}{8}$ inch in 10 feet. Another point was how to get rid of the air out of the pipes when charging them with steam; that should have been pointed out, as it was one of the greatest obstructions met with in starting steam-mains; but he supposed the Company had little difficulty from this source, on account of the great amount of leakage. In a well-arranged system the air could be got rid of by the expansion of metal rods in chambers acting upon valves of special construction, so that on the steam entering the mains the air escaped until the steam caused the valves to close. This valve also acted as a vacuum-valve on the cooling of the apparatus, allowing air to re-enter the system. These, in conjunction with good steam-traps, obviated the above difficulty. It was stated that the Company took the condensed water back to the central station in the same trenches as far as possible. To do that, supposing the length of steam-pipe was only 1,000 yards, the trenches would have to be about 10 feet deep, allowing $\frac{1}{8}$ inch fall to the yard. That would involve a very great outlay; and if it was attempted to lay down a similar system in London, the streets would be always out of order. Mr. Stainton.

Mr. W. SCHÖNHEYDER believed it would be a long time before Mr. Schönheyder.

Mr. Schönheyder. the open fireplace would die out of this country; perhaps it would take a generation, notwithstanding its defects, its draughts to the feet, and all its other miseries and difficulties. The central heating system, therefore, was not so likely to find a place in England as on the other side of the Atlantic; but he believed there were many houses, shops, offices, and buildings of various kinds now heated by water, or in other ways, that might be supplied with great benefit from a central station, because the heat could be supplied cheaper, at less inconvenience, and more free from dirt. While making all allowance for the difficulty of introducing a new system, and while acknowledging the many ingenious devices invented by the Author, he could not congratulate him upon his arrangement of steam-pipes; he referred especially to the complicated arrangement of the joints which seemed to be very unsatisfactory. As had been remarked, it was

FIG. 7.



anything but a mechanical method to expand a wrought-iron pipe into a cast-iron socket; it did very well for small pipes, say 2-, 3-, or 4-inch pipes, but to expand a 15-inch pipe, only $\frac{1}{4}$ inch thick into a socket, and expect it to hold tight a long time, was unreasonable. A thin wrought-iron pipe could not be expanded out with sufficient force to maintain itself tight. If there was merely pressure from the inside to deal with, steam-pressure would no doubt help to maintain the tightness, but there were other factors at work. The most severe strain was the end thrust. The friction of the wrought-iron pipe in the cast-iron socket could never be so great as to prevent the pipe from sliding bodily endwise, and it seemed to him to be altogether a poor contrivance. He had taken the liberty of showing the arrangement of joints which he thought would avoid all these difficulties (Fig. 7). The ends of the wrought-iron pipe were simply flanged out without any increase in thickness. Between the flanges was placed a ring of softer material than the pipe. Outside the wrought-iron pipe, behind the flanges, were two rings which were necessarily in

Mr. Schönheyder.

halves in order to get them on the pipe, and those rings were clipped by solid collars with perforated holes for the bolts. The collars were of such inside diameter that they could be slipped over the flanges of the wrought-iron pipes before they were put together. After the half rings were in their places, the solid rings were slipped over the half rings, and the whole bolted together. It formed an exceedingly simple arrangement, and it had the advantage that after the joint was made, if it should prove leaky, it could be caulked like any other piece of boiler work, and the bolts tightened. There was no leakage through the bolt-holes as in the case of the cast-iron flanges described by the Author. With regard to the arrangement of the pipes in the streets, it was impossible to get at the joints without cutting away the brickwork, which involved an enormous expense. Why could there not be at every joint a sufficient space left to get round and repair it in a proper workmanlike manner? The expansion-joint shown by the Author was an exceedingly neat arrangement, and he had no doubt it worked well. It would be interesting to know when the Author devised it, because he found that in 1886 a patent, No. 6,447, was taken out for precisely the same arrangement. It was not for the purpose of letting the street pipes expand in the way described, but for the purpose of making a pressure-reducing valve, and he had no doubt that it formed an exceedingly effective arrangement. With regard, however, to the arrangement of cast-iron plates on the top of corrugated copper, if the copper was very thin, the plates would have a tendency to wear the copper through. To avoid that he should prefer, in each of the little circular copper grooves, to insert wrought-iron rings; they would lie in the recesses, and the cast-iron plates would rest on the wrought-iron rings, thereby avoiding all friction against the thin copper plates and preventing their wearing out. The Author had referred to his meters as if they were the contrivances that rendered the system successful, at any rate, to a large extent; but he had not explained their details. The meter appeared to him to have two very great defects. The movements of the internal parts of the meter were communicated outside through stuffing-box packing, and, of course, any friction of the stuffing-box packing would make the meter less sensitive. Secondly, the registration of the meter was, as the Author had described, drawn on a strip of paper in the form of a diagram. He was certain that that would never satisfy people in this country. There was not only the initial error existing in all meters, but there was a difficulty of interpreting the diagram.

Mr. Schönheyder. People would never be convinced that it was done correctly, carefully, and honestly enough. One important point in connection with heating by steam or by water was the regulation of the temperature; there was no statement in the Paper how that was done, and, as far as he knew, no arrangement had yet been made for the purpose. From what he had seen of steam-heated places, either the steam was full on and they were heated to the full temperature, or when the steam was turned off the heat was deficient. Perhaps the Author would explain how the temperature was regulated to meet the requirements.

Mr. Davey. Mr. HENRY DAVEY said he could speak with some confidence on the subject, having had considerable experience in long lengths of steam-mains in mines, collieries, and the like, and he could quite appreciate the great genius which the Author had brought to bear on the mechanical details described in his Paper on a subject bristling with difficulties. No doubt the expansion-joint described was as good a one as could be devised, but it did not appear to him to be of sufficient permanency for the purpose intended. The position of the pipes could be realised from a paragraph in the Paper which stated, "The ground underneath the streets was, moreover, much obstructed, there being near the surface various of the early telegraph conductors and pneumatic tubes; also the Edison installation for electric lighting. Below these were the gas-pipes of two companies, each of which had, in a street like Broadway, several pipes, which had been laid from time to time to keep pace with the demand. Below these, again, were two sets of water-pipes, one set, laid after the original Manhattan water-pipes were abandoned, the other being reinforcing pipes, to supply the hydrants, and keep up the pressure. Beneath came the sewers, and frequently the streetway below the surface was narrowed materially by vaults projecting from the buildings under the sidewalks and roadway." To put down such a system of mains with all the complications of joints, in a situation like that, might well be said to bristle with difficulties. He should like to know what influence the heat of those pipes had had on the telegraph-wires and other apparatus in their immediate vicinity. The ground would necessarily be very much heated, and he imagined that it would cause considerable mischief to the gas-pipes and water-pipes. As to the actual construction of the diaphragm expansion-joint, the copper diaphragm was fatigued at two points —at the inner and the outer extremities of the disk. The Author had not stated what the range of expansion was; but he thought it might be inferred, from the frequency of the expansion-joints, which were put in every 50 feet. In his experience of long steam-mains in collieries, where the pressure of the steam had been about 60 lbs., he had been accustomed to allow 2 inches per 100 feet for expansion, and taking the coefficient of expansion, the temperature of the steam corresponding with the pressure given in the Paper, it came to a little over 2 inches per 100 feet; so that, if an expansion-joint was put in at every 50 feet, and if there was a diaphragm at each end, each diaphragm had ½ inch play, or if there was only one, it had 1 inch play. That seemed to be a large amount of fatigue for the copper. Then, as had been previously pointed out, the frictional action of the supporting plates must tend to wear away the copper. As to the insertion of a wrought-iron pipe into a cast-iron flange, he thought it was mechanically wrong, and there were certainly better methods. The expansion had been estimated by a previous speaker at ⅛ inch for 10 feet, and that would give 1¼ inch for 100 feet. He thought, if the coefficient of expansion was worked out, it would be found to be more than that, namely, 2 inches per 100 feet. There was another mechanical detail which he wished to criticise. An iron plug was inserted in an iron pipe with a considerable length of fine threads; he should imagine that, after it had been in a considerable time, it would take a very powerful wrench to move it. With regard to the general distribution of power by the system described, Sir Frederick Bramwell had pointed out that much more power could be sent through the pipes by means of gas, and with much less difficulty. Mr. Davey had also advocated the employment of cheap gas for the distribution of power, and he believed cheap gas should be looked to for that purpose. Five hundred engines were said to be actuated from the central source of power; but no mention was made of the proportion of steam used for power and that used for heat. Taking one-half the steam employed for power purposes, it gave an average of from 10 to 12 HP. per engine; it was evident, therefore, that the average power of the engines driven from that source was small, and he thought that, generally speaking, small engines would be driven from such a system of power distribution. He had roughly estimated what the power might be, put through the largest main spoken of, 16 inches in diameter, with gas. He observed that 6,000 HP. was sent through in steam; but if cheap gas were sent through the same main at the same velocity, and consequently with about one-fifth of the frictional resistance, 18,000 HP. could be transmitted, or three times as much as by steam. The cost of the steam was put in rather an involved way. It was said

Mr. Davey.

Mr. Davey. that the cost of power was equivalent to buying coal at from 28*s.* to 30*s.* per ton. That, taking the quantity of steam supplied per nominal HP. at 30 lbs. weight, came to 0·66*d.* per HP. per hour. Taking 25 cubic feet of gas per HP., then in order to supply the power in gas at the same price, the gas would have to be supplied at about 2*s.* 3*d.* per 1,000 cubic feet.

Mr. Cowper. Mr. E. A. Cowper remarked that in America the frosts were very severe and the winters very long, and there was, therefore, a great demand for heat in the most economical and easily applied form. In this country the winters were mild and there were scarcely any very severe frosts, making it necessary to have hot-water pipes in houses. That, he thought was at the root of the whole matter. Another strong argument in favour of steam for heating purposes in America was the great cost of gas. With regard to the question of cost of steam for power, it appeared that in America it was $105, or £22 per HP. per annum. In London, with coal at 20*s.* per ton, the cost was £10 per HP. per annum, and with very economical engines, £4 10*s.*

Mr. Anderson. Mr. W. Anderson (of Erith) said there were one or two points in the Paper which did not appear to be very clear. One was with reference to the cast-iron rings supporting the copper diaphragms. As far as he could make out from the drawings, the cast-iron rings were solid, but he did not think that could be so. They were said, by one of the speakers, to be in four segments, but even that would be insufficient subdivision to give a considerable range. With reference to Mr. Davey's remarks respecting the amount of expansion, he appeared to have overlooked the fact that the Author stated it to range from 1¼ inch to 1½ inch in the 50-foot length.

Sir Frederick Bramwell. Sir Frederick Bramwell said he thought that instead of the set of protecting plates being in four segments, it was clear it was made up of a large number of radial segments; not only was this shown in Plate 1, Fig. 12, but it would be remembered that the Author had spoken of having put the segments in at first with too much clearance, and finding a difficulty, because they bunched themselves at the bottom and left a space at the top.

Mr. Anderson. Mr. W. Anderson replied that the number of pieces was not stated. There was one point of great importance, namely, the use of copper rings for making joints, instead of red-lead putty. In all installations, such as those under discussion, little details were very important. When red-lead putty was used it was almost impossible to prevent the workmen from applying a great excess of it; a certain quantity was squeezed into the pipe and, being carried on by the steam, became a source of endless trouble in the valves; a certain quantity formed a fringe inside the pipe, which, hardening under the high temperature, materially interfered with the free passage of the steam. If the copper rings answered, they would, no doubt, be very desirable things to use. He had himself employed them in petroleum-mains, and they had answered admirably; but he had no experience of their use for jointing steam-pipes under high pressure. The mode of making service connections was very ingenious, and was very much like the method introduced by Mr. Upward many years ago. He observed that all the cocks used were sluice-cocks, and there was nothing to lead to the supposition that they were not satisfactory. Engineers were greatly prejudiced against them when applied to steam-pipes, and seemed to prefer the screw-down valve; but they appeared to have answered very well, and they had this advantage over the screw-down valve, that they left a straight passage for the steam instead of a tortuous one. He was in the same difficulty as Mr. Ellington with regard to the boiler power and the price at which the steam was sold. He could not make out how 1,000 lbs. weight of steam could be sold for 40 cents or 20*d.* 1,000 lbs. weight of steam corresponded to about 1,000,000 heat units, and taking gas at 3*s.* per 1,000 cubic feet, for 20*d.* the result would be about 555 cubic feet, capable by combustion of yielding about 343,000 units of heat; so that apparently, at that rate, steam was supplied at about one-third of the price of a corresponding amount of gas. Taking, for the small powers employed, 25 lbs. of steam per HP. per hour, for 20*d.* 40 HP. of steam would be obtained; and taking 26 cubic feet of gas per HP. for a gas-engine, only 21 HP.; so that, as far as power was concerned, steam was apparently about half the cost. He thought with Mr. Ellington that the 40 cents ought to be doubled in order to arrive at what the steam would really cost. The difficulty which the Author had experienced of finding a unit of power for boilers had, no doubt, occurred to most engineers, and the method of estimating the power of a boiler, by the weight of steam produced, was no doubt rational; and it would be desirable if the Institution, or some other body, would take upon itself the task of fixing a standard by which boilers could be measured. It was ridiculous to talk about the HP. of a boiler, because such a term did not convey any definite meaning. A boiler could only yield power through the agency of a steam-engine, and the HP. thus produced depended in a great measure on the kind and quality of the engine. The standard he had used for the power of a boiler was Mr. Anderson.

Mr. Anderson. 62 lbs. of water evaporated per hour from and at 212°. He did not know why he had taken that particular value, except that, by measuring a good many boilers, and ascertaining the amount of water they evaporated per hour, and comparing that with their nominal power, he had found that 62 lbs., or a cubic foot, evaporated per hour, represented 1 HP. The North-east Coast Institution of Engineers and Shipbuilders had found a difficulty of this kind with regard to marine engines, and appointed a committee to investigate the subject. Last May a report was presented fixing upon a unit for marine-engine power. It was a tolerably complicated one, involving the boiler, the initial pressure, and the rate of expansion. If D was the diameter of the low-pressure cylinder in inches, S the stroke of piston in inches, P the initial pressure above the atmosphere in lbs. per square inch, H the heating surface of the boiler in square feet, then the normal indicated HP. would be

$$\frac{(D^2 \sqrt[3]{S} + 3\,H) \sqrt[3]{P}}{100}$$

provided the steam was always expanded to the same terminal pressure. The formula was further defined by certain conditions, which seemed to make its application trustworthy.[1] It was very important commercially to know what people meant when they talked of the power of a boiler. The HP. that the Author had spoken of was undefined. He was not surprised that there should be much leakage, considering the way in which the flanges of the wrought-iron pipes were arranged. The method pointed out by Mr. Schönheyder appeared to be a very excellent one. He had himself often used it, not exactly in the same form, but by putting a loose flange behind a narrow flange turned over out of the solid pipe, and making the joint between the flanged ends with a copper ring cast of a rhomboidal section. He agreed that the Paper was a very important one. The Author had been very honest, and had described his difficulties, and how he had overcome them; and he had no doubt that his reply to the discussion would be very valuable, because based upon wide experience.

Sir D. Galton. Sir DOUGLAS GALTON observed that as he had brought the question of steam combination forward about eight years ago, before the Society of Arts, he should like to say two or three words on the sub-

[1] Transactions of the North-east Coast Institution of Engineers and Shipbuilders, vol. iv. 1888, p. 335. "Report of the Council on the Horse Power of Marine Engines."

ject. The importance which he attached to it was in consequence of its appearing at that time to afford an opportunity of diminishing the enormous amount of smoke in London. The question was one which he thought well deserved the attention of the Institution of Civil Engineers, for by the smoke and the fog which it assisted in creating, there was a loss in winter of at least two-thirds of the daylight. The only remarks which had been addressed to that question were those of Sir Frederick Bramwell, who had said that Englishmen would never give up pokeable fires; but as the price of coal increased, as it infallibly would increase before very long, it would then be felt necessary to adopt some system by which to provide warmth and cooking without the enormous useless waste of fuel now prevailing. Whether it was by steam heating or by gas or the new water-gas, or whether power was required for domestic purposes, some combination system was certainly wanted to get rid of the very great evil now oppressing the Metropolis. There was the Hydraulic Power Company, and possibly that and the gas-engines might do what was required; but, as civilization progressed, additional power was required in houses and establishments, and every appliance which could be obtained for that purpose was a benefit to the community. If the Institution of Civil Engineers thought, as he was himself disposed to think, that the system of steam-heating and steam-power was not very applicable to London, he hoped that it would propose some method for supplying houses with heat and with power, so that it might no longer be necessary to burn coal in every house in the Metropolis, and obscure the skies as at present. Sir D. Galton.

Mr. W. W. Beaumont said that some Americans appeared to be a little ahead of Englishmen in regard to boiler-power nomenclature, as they sold their boilers not per HP., but per 1,000 lbs. of water evaporated per hour. In the Paper there were several sets of figures which would be of considerable interest to engineers, if they were not contradictory, or apparently so, concerning the condensation of the steam in very long pipes. It was stated in one place that the loss by condensation was about 3 per cent., and in another place that it was so many HP. out of another number of HP., and the quantities did not appear to agree. A few years ago he made some experiments on the subject with a long length of steam-pipe. A great part of it was underground, in a rather steep gradient in one of the Staveley coal-pits. About 1,900 feet of pipe was underground in a lead, and some hundreds of feet above ground, partly in the shaft and partly leading to the boilers. Altogether the piping was about 2,300 feet Mr. Beaumont.

Mr. Beaumont. in length. It had been used for a considerable time working an engine, and at the time it was placed at his disposal for experiments the pit was worked out, and the plant was about to be removed. Before stopping the engine, the quantity of water condensed in ordinary work in the long length, had been carefully recorded over a considerable period. The figures differed considerably from the quantity of steam condensed in the same pipe with the same pressure of steam, when the engine was not working. It would be interesting if the Author could tell what difference was found between the quantity of steam condensed in the long length of pipe, or in parts when power was chiefly supplied, and when steam was only being used for heating purposes. In the long length of pipe, to which he had referred, when the steam was passing in the ordinary way to the pumping engine, the quantity condensed per hour, per square foot of surface of the pipe, was as nearly as possible $\frac{1}{4}$ lb.; but when the engine was standing, it was reduced to rather less than half that quantity. The measurements were easily made, and there could be no doubt as to the correctness of the figures. The whole 2,000 feet of pipe that lay in the lead was covered with the rough stuff left after cutting away the coal, and in some places it was covered, perhaps to a thickness of nearly 2 feet, with rubbish, partly that which had fallen from the roof; large quantities of it would be fine shaly dust, which would be a tolerably good non-conductor. But the total quantity of water condensed per hour, when the engine was at work, was 14,000 lbs.; so that a large quantity of heat was given off, although the pipe was protected in that way. The pipe was $6\frac{1}{2}$ inches in diameter, and the total length exposed was 5,680 feet. It was an experiment [1] on a scale sufficient to compare with the results obtained, or obtainable, by those long lengths of pipe in America, and it would be interesting to know how far the figures he had given agreed with those results.

Dr. Emery. Dr. C. E. Emery desired to express his gratification at the amount of attention given to the Paper, the closeness with which it has been studied, and the appreciation of its general features shown during the discussion. He wished particularly to refer to Sir Frederick Bramwell's criticisms, which were calculated to elucidate the Paper. Sir Frederick Bramwell had probed the only real difficulties that had occurred in connection with the work, and had failed only to understand the details where the plans and descriptions were at fault, from the Author not realizing in all

[1] The Engineer, vol. xlix. (1880), p. 199.

cases how little was generally known of work of this character. Dr. Emery. Some omissions had also occurred in abridging old reports. The large amount of leakage had been a matter of general surprise. This leakage had been of two kinds, namely, ordinary leakage from the stuffing-boxes of the numerous valves, necessarily buried out of reach of the care and adjustment ordinarily given to steam-work. Such leakage, with that which occurred occasionally from the oversight even of the best workmen, was an item in itself; but as the work became more and more developed, it was got better under control by the more general use of ball-joint metal packing instead of stuffing-boxes, and by obtaining more careful workmen. A much larger amount of leakage was, however, due to preventable causes, which should not have occurred to mar the otherwise good character of the work. Many of these leaks were in the joints, where the lengths of the large wrought-iron pipe, $\frac{1}{4}$ inch thick, were rolled into fittings as indicated in several instances. But such leaks were not due to the design of the joint or to its workmanship. They occurred under conditions which caused leaks in the joints of thicker pipes of smaller diameter screwed into the fittings, and which probably no pipe-joints could withstand; these conditions were only referred to incidentally in the Paper, because they had little to do with engineering. The first third of a mile, laid of the largest wrought-iron pipe then constructed, of 15 inches outside and $14\frac{1}{2}$ inches inside diameter, was connected with joints as described in the Paper, and had been at work continuously since the summer of the year 1882 without leaks, simply from the fact that it was laid slowly, and every portion of the work in detail had been supervised by the Author personally. While this work was in progress, the best of the men were selected to teach others as to the details, and it was only necessary that the organization should be kept up to secure satisfaction throughout. But the work fell into other hands, and was carried on by a private corporation with means raised by a contractor, who raised in the beginning about $1,000,000, say £200,000, but spent the greater part of this sum in the purchase of real estate in different parts of the city before any work was done; and, as additional subscriptions came in slowly, most of the plant was purchased with borrowed money. As a consequence, when the money market was easy, the work was pushed on in as many streets and with as great rapidity as possible; when it was tight, every influence was used to reduce the work, independent of season, to a rate of progress proportioned to the rate at which money could be borrowed. In the latter case, of course, the number of heads to prosecute the work rapidly in a proper

Dr. Emery. manner, represented an unnecessarily large portion of the cost of the work actually done, and frequently the staff had to be reduced, so that experience was lost again and again. Mr. Ellington would now understand why he estimated that the same plant would be less costly under certain conditions. Besides, the promoter, who had constructed railroads on a considerable scale, interfered with the working force in all sorts of ways, depending largely on the condition of the money market, and this led to the intermediate foundations supporting the pipes not being properly attended to. All the pipes of the Holly Company had hitherto been laid in wooden pump-logs, the pipes being wound with paper and kept in place by longitudinal strips of wood, bound on with copper wire. These logs were slipped over the pipe before the fittings were screwed on, the lengths socketed together, and the log, which had been covered with pitch, was then rammed in the earth to the approximate grade. Some of the pipes of the New York Steam Company were at first required to be laid in this way, but logs could not be procured large enough for the larger pipes. This proved fortunate, as before long all those logs placed upon the smaller pipes had to be removed, the difference in temperature of the steam, and the heavy traffic in the streets, causing the difference in result. Brickwork, as shown, was recommended for all the work, but its use for the larger pipes was the continual subject of attack, being quoted as an example of extravagance, it being sometimes assumed, for example, that too much cement was being used in the brickwork. The system adopted was this:—At the main junctions, and at each of the variators and service-boxes, a brick foundation was laid in cement on the original soil and capped with a flat stone, at the elevation required to bring the centre of the pipe to the proper gradient. As the distances between the variators did not exceed 50 feet, the spacing due to the lengths of the blocks generally brought the interval down to 42 to 48 feet, so that there were usually three lengths of pipe between the main fittings in 14-foot to 16-foot lengths, and provision was made to support these lengths at the flanges on brick piers 8 inches square, built in all cases upon undisturbed soil. Each of these piers was, like the others, capped with a flat stone, on which was placed a cast-iron saddle, to engage with the flanges. Since, however, the large pipes were not perfectly straight when bolted together, the plan originally adopted was to leave the cap stones of the intermediate piers loose, and while the pipe still rested on the original blocking, such cap stones were raised, by inserting wooden wedges between the stone and pier, till the saddles pressed against the

Dr. Emery.

flanges. The joint thus opened was carefully grouted, the mortar allowed to set, the wedges were then removed, and the openings left by them grouted. A little later, at the suggestion of the street superintendent, to enable him to finish the piers at one operation, the wooden wedges were left in, and their ends built into the side walls. These wedges were only about 3 inches wide, and it was calculated that the grouting on either side of the same would support the weight, which would rarely be more than 1,000 lbs. in any case. This weight could readily be carried on 5 square inches of surface, which would be obtained by little more than pointing up the edges on two sides of the 8-inch pier. Shortly after the most important work had been completed, it was discovered that the masons had, for a large portion of the distance, deliberately omitted to grout the joints on the sides of the wedges of these intermediate piers; and the intense heat of the high-pressure steam, transmitted through the saddles and stones, shrivelled the wedges, and practically left the pipes without support for lengths of 42 to 48 feet. The continued pressure and jars from the streets gradually caused the joints to yield. After about two years, imperceptible leaks started, and, once initiated, mechanical action set in, and the joints became grooved; not simply the rolled joints, but screw joints on pipes of 8 inches internal diameter. The leakages cost an immense sum of money to repair. Every single joint had to be opened. The repairs to those along Broadway under tramways, laid after the pipes had been inserted, cost from \$100 to \$200 each; but the fortunate provision of leaving a place for caulking enabled the rolled pipe to be made tight, so that with the foundations properly renewed they would probably give only occasional trouble. The screwed pipes gave more trouble originally, for the reason that no provision had been made for caulking, and the joints had to be tightened with bands connected by bolts, extending from one side to the other of the fittings. All this work was necessarily done with the pipes under steam-pressure, as the demand was so great that steam could not be shut off anywhere by day, and in many cases not even at night, except only for a few hours on Sunday. The openings in the streets to stop the leaks, and the clouds of steam escaping therefrom, caused great complaint; but the steam users acknowledged that the operations of the company were a great public benefit, and, by hurrying the work, the matter finally quieted down. The same bad workmanship was also found in details of the simplest kind; in some exceptional cases it was discovered that the smaller steam-pipes had been put together with only two threads holding. But before

Dr. Emery. these difficulties had fairly developed, success had been attained on a magnificent scale, entire confidence had become established, and disorganization reduced to errors of habit rather than of principle. The mischief was, however, already done, and had to be met. The Author would not again use rolled joints for such work, as screwed pipes were now made of all these large sizes, and miles in length of pipe had been laid for natural gas distribution. The conditions obtaining when the rolled joints were used, however, warranted their employment, and their success, where the foundations were good, showed that the system was not mechanically incorrect. At the time the large rolled pipes were very costly, being considered rather as boiler tubes than pipes. The thickness adopted, $\frac{1}{4}$ inch, was ample to withstand the pressure, and, before the method of connection by rolling in the way that smaller boiler-tubes were set was adopted, specimen pipes were rolled in specimen flanges and thoroughly tested. He thought Mr. W. Schönheyder had not carefully examined the drawings. The ends of the pipes were turned off, and abutted squarely against shoulders, and the variators tended to hold the ends of the pipes against these shoulders with a pressure of 20 to 25 tons, according to the sizes of pipe, so that there was no danger of them pulling out. The resistance which the rolling would give to a direct pull was tested by subjecting the pipes to hydraulic pressure when the ends were closed with blank flanges, and it required 360 to 400 lbs. hydraulic pressure, in a $10\frac{5}{8}$-inch pipe, before the flanges started sufficiently to produce a leak, although they were only held by the expansion of the metal on to a slightly conical seat in the fitting. These experiments, and similar ones on smaller tubes by the United States Navy, showed that the American practice of staying a boiler-sheet with iron tubes, simply rolled in the sheets and without hollow screw-stays, was warranted. Even when three lengths of the steam-pipe were practically unsupported, except at the ends, no yielding of a dangerous nature took place; the strains, as explained, merely started leaks which, if the pipes had been exposed, could have been stopped at once, but which, left alone, subject to continuous pressure, became eroded. The grooves, however, were rarely more than the thickness of a sheet of tissue paper, and hardly ever as much as $\frac{1}{8}$-inch wide; but they were sufficient in the aggregate to cause a great deal of loss and annoyance. It was a subject for comment that jets of so minute a size could not be kept open by any mechanical means, if they were employed for any useful purpose in the arts. The steam-pipes, by continuous use, had become very clean, and not enough deposit was carried along to close the openings, so the process of mechanical erosion by escaping steam and water was practically not interfered with. When screw-threads were strained sufficiently to start a leak, the sharp surfaces at the ends of the threads were cut off more rapidly, and the leaks were, if anything, of larger area than those on the rolled joints. The difficulty was not fully developed until about the time the up-town plant was started. For this it was resolved to use nothing larger than 10-inch wrought-iron screwed piping of full thickness, threaded carefully and screwed into flanges at each end by special machinery at the station, the holes at opposite ends being brought to a common vertical plane. The provision for caulking was also made behind the screw-threads, as with the rolled joints. These pipes were then laid down in lengths of 14 to 16 feet, and bolted together rapidly; but the saddles supporting the flanges were made with grooves on the under surfaces to receive iron wedges, which in place bore on the cap stones of the supporting piers, the stone being cemented on to the pier, just as at the expansion-joints. In this way the possibility of a settlement, due to a want of continuity in the pier, was prevented, though at the risk of having the pipes bowed upward, so as to produce initial strains by improper use of the wedges by careless workmen, a condition which could not obtain with the original plan. No trouble had been experienced with the up-town plant from leakage, nor would there have been with less careful work, for the steam-pressure was carried below 40 lbs. per square inch and shut off in summer, and any initial leaks while the pipes were under pressure would close during the periods of disuse, or on turning steam on again. The difficulties above referred to did not cause leakage of the variators, as the elasticity of the diaphragms was sufficient to prevent injuries to the joints. It would be found that many specific questions were answered by the above explanations, when taken in connection with the text of the Paper; but it might be further explained that the greater portion of the large pipe was practically made up of wrought-iron boiler-tubes, of 15 inches outside diameter and $\frac{1}{4}$-inch thick. A small length of pipe of 13 inches outside diameter and $\frac{1}{4}$-inch thick, and a considerable length of 11 inches outside diameter and $\frac{21}{100}$-inch thick, was laid, the fittings for the latter being used for screwed pipes of 10 inches inside diameter. At a later date, some wrought-iron pipe, of 16 inches outside diameter and $\frac{1}{4}$-inch thick, was used. The smaller were standard heavy wrought-iron pipes, with screw-threads of customary sizes, such as 8-inch, 6-inch, 5-inch, 4-inch, 3-inch, $2\frac{1}{2}$-inch, 2-inch, and 1-inch, Dr. Emery.

Dr. Emery. these being used only on services and for short lengths of return-pipe. It should be noted that the boiler-tubes were designated by their outside diameters, and the regular piping by its inside diameter. Referring to Sir Frederick Bramwell's plan to check the loss of pressure, it should be stated that the number of mains originally contemplated had not been carried out from the boiler-house. All the steam now had to pass through one pipe, 11 inches in diameter, a second 15 inches, and a third 16 inches in diameter. The 15-inch pipe reached Broadway at a distance of about 1,000 feet; the steam from the 16-inch pipe reached Broadway through an 8-inch pipe at Liberty Street, and a 15-inch pipe at Rector Street, and the 11-inch pipe extended northward, connecting Greenwich Street with Broadway at a number of streets above the station, the connection in Barclay Street being 11 inches in diameter, to keep the pressures equalized and to enable a large supply of steam to be transmitted to the Post-office and Printing House districts, in case it should become necessary to shut off other pipes. Though the pipes leading out of the station were as yet small for the amount of steam transmitted, the distribution of steam, after reaching Broadway, was through pipes much larger on the average than those given by rule, so that the loss of pressure, though rapid at first, did not increase greatly near the ends of the lines. With respect to Sir Frederick Bramwell's suggestion to maintain a large difference of pressure between the boiler-house and the ends of the line, and to use reducing-valves, practical experience suggested the desirability of dispensing as much as possible with reducing-valves, or any automatic apparatus, on individual premises. The best of them needed attention under certain conditions; their operation was stopped with the slightest particles of foreign matter, and though in some cases working for days, months, and even years without attention, they were in the latter case so thoroughly depended upon, that great mischief might be caused by their inevitable failure at some time or other. One such valve, in charge of an engineer continuously present, could be kept up to its work, and the care bestowed upon it in connection with other matters would not be noticed; but the five hundred valves already required on the steam plant for heating purposes were left to the charge of attendants not always present, and most of them not engineers; consequently skilled attention by regular inspectors was required, and the apparatus was generally so designed that no serious mischief would occur if the automatic apparatus failed between the periods of such inspection. For instance, it was desired to have pipe radiators which would not explode in case the full pressure of steam came upon them, and where very light radiators were employed, the precaution was always taken of putting a safety-valve at some point, which would prevent the pressure from rising above a certain limit. In relation to the suggestion that steam should be superheated, such a system had been tried by the American District Steam Company, which started the plant on the east side of Broadway. It was expected that condensation would be prevented to the ends of the lines, and therefore no provision was made for grading or draining the pipes. The consequence was that water-rams were continually occurring, and extra heavy piping, 8 inches in diameter, was split for lengths of 6 and 8 feet again and again, and several times in nearly the same place. With a graded and drained system, like that of the New York Steam Company, the only possible danger of water-hammer was on first turning on steam. The District Steam Company not only had difficulties from water-rams when turning on steam, but during regular operations. When the superheated steam was flowing through the pipe it prevented condensation near the boiler-house; but when only a small quantity of steam was used, there was an insufficient current to maintain it in the superheated state, and deposition of water took place in the dips, which became colder at the bottom than was due to the temperature of the steam. Accordingly, when a demand for steam arose, this water was carried on by the current of steam, which condensed, forming a vacuum, into which steam and water rushed from all directions with a blow, called a water-ram, as explained in the Paper, of sufficient force to rupture pipes of great thickness. The superheating only made the matter worse in such a case, as the reduction of volume, due to the absorption of the extra heat by the water, also aided in inducing a current to set towards the cold point, and augmented the difficulties. Dr. Emery.

The difficulty in understanding how the water of condensation was returned to the station arose from the fact that engineers, not directly connected with the design and construction of steam apparatus, did not realize fully the operation of certain details. If a pipe containing steam under pressure had water in it at the bottom of a dip, and a small pipe, with a valve therein, was connected below the surface of the water in the dip to another pipe containing water, the pressure would, on opening the valve in the connecting-pipe, force the water in the steam-pipe into the water-pipe, so long as the pressure in the first was greater than in the second pipe. The steam-trap was simply a device to open such a valve when water was present in the steam-pipe, and to

Dr. Emery. shut the valve after the water had been blown down to a certain level. The full pressure in the steam-main was available to blow the water out during the time the valve was open. One end of the return-pipe opened at the boiler station into a tank, connected with the atmosphere, in which the return-water, together with the additional water required to supply waste and the exhaust-steam from the engines, were mixed by flowing over a series of pans and diaphragms, and any exhaust-steam not condensed escaped into the atmosphere through a relief-valve. It followed, since the pressure in this tank was practically that of the atmosphere, that the pressure in the return-pipe gradually increased away from the station, sufficiently to give the difference of pressure required to move the return-water and the steam it disengaged, plus or minus the pressures due to differences of elevation at the different points. On the west side of Broadway the grade was toward the boiler-house, and the pressures in the return-pipe were very slight; on the east side the pressure necessarily rose sufficiently to lift the water over the ridge, and at the same time gave sufficient velocity to the current. The pressure in the returns at the lowest point on the east side was less than 15 lbs. when little work was being done, but rose to about 20 lbs., and occasionally 25 lbs., during cold weather, when a considerable amount of water of condensation was being returned, any bad leaks in the traps of the buildings causing the pressure to rise materially. In all cases, however, it was only necessary to carry on the radiators in the building a few lbs. more pressure than that in the return-pipes. The traps draining the street system always had a large surplus power, as they had 80 lbs. to overcome the back pressure of 20 lbs. or less in the worst localities. In buildings fitted up with low-pressure heating apparatus, it was customary to allow the water of condensation to run back to a tank, and to pump it from thence into the returns of the Company, the pumps frequently being controlled by a float in the tank. There were also in use a number of return-traps, practically pumps on the old Newcomen system, in which the water of condensation flowed into a closed vessel, thereby raising a float till the reverse-valve was tripped; this shut off the inlet from the radiators, and admitted live steam at full pressure to the vessel, whereby the water was blown out through a check-valve to the returns. As soon as the level again fell, the float following it reversed the valve, steam was exhausted either into the air or the upper part of the heating pipes themselves, and the water again flowed in from the latter, when the operation was repeated. The hydraulic system of the General Power Company, now in full operation in

London, at a pressure of 700 lbs. per square inch, was of small magnitude compared with the steam system in New York. A circular had fallen into his hands several years ago, giving the number of customers of the Power Company year after year; this showed approximately the same number and same rates of increase as the New York Steam Company. But the number of gallons of water pumped under a given pressure was also given. Reducing the work done to HP., it appeared that the maximum for the previous year represented, so far as his recollection served, less than 200 HP., or a total aggregate delivered to several hundred consumers of only about the same as was delivered in several instances to single buildings in the city of New York through the mains of the New York Steam Company. The business of the hydraulic company had greatly increased, but the power delivered even now was only a fraction of that regularly sent out by the steam company. It was, moreover, principally applicable for lifts, and not for general power purposes, electric lighting and heating like the steam. Mr. Davey had endeavoured to ascertain the sizes of the engines furnished with steam by dividing the number of engines by the HP. probably used for power. The number of engines given included very many steam-pumps, small engines driving printing-presses, and light manufacturing establishments, each requiring very little power. In fact, the company for several years had furnished steam for one of the original stations of the United States Electric Illuminating Company, where the engines indicated during the busy hours 300 HP.; the distance from the station in this case was, however, only between 600 and 700 feet. Steam was regularly supplied to the very large pumping engines now used for the half-dozen elevators in many of the large buildings, which, with electric-light engines, required 50 to 100 HP. In a building like the New York Post Office, where there were large numbers of passenger and mail elevators, 100 HP. was a small estimate for the power in busy hours, and a building of this kind, with 5,000,000 cubic feet capacity, required several hundred HP. to heat it in winter, independent of the amount of steam used for power. Some of the printing-houses had engines of 80 to 100 HP. One eating-house used not less than 50 HP. per day, and more in winter. It had been mentioned that steam was employed in some of the large new buildings to dry the walls during the process of construction, the windows being closed with simple muslin. In addition to the above examples, the company supplied steam for an inside station of the Edison Company, $\frac{1}{3}$ mile from the steam station, where 200 Dr. Emery.

Dr. Emery. to 300 HP. was required at times to supplement the current from the regular station at the busiest hours of the day. The Western Union Telegraph Company also used steam, in addition to that required for heating, to work dynamos for telegraphic purposes, as well as for electric lighting, at each of the two principal offices, and also for operating a large air-compressing plant. A comparison had been drawn between the merits of steam and hot water for the transmission of power, the latter illustrated by the hot-water plant in operation at Boston, Massachusetts. This enterprise had been admirably worked, and certainly had attracted a great deal of attention. He had been at first placed in the embarrassing position of his utterances on the subject being attributed to his connection with a steam-plant. To avoid misunderstanding, he wrote a Paper on "The Comparative Value of Steam and Hot Water for Transmitting Heat and Power,"[1] in which the subject was discussed in the abstract. A brief statement of the general conditions affecting the problem would be of interest. First, hot water of a certain temperature should be compared with steam of the same temperature, as each required the same pressure to confine it. If the water was carried at a temperature of 400°, it necessarily must be transmitted at a pressure of at least 235 lbs., the pressure corresponding to that temperature. With steam of that pressure, baking bread, broiling meat, &c., could be performed as well as with water. From the fact that all calculations were made on the basis of thermal units per lb., not per cubic foot, it was evident that in reducing the temperature of hot water it could only give up its sensible heat, represented practically by the difference between its original and final temperatures, whereas steam could give up all its latent heat on the slightest reduction of temperature, as well as that due to the loss of temperature of the water to which it was condensed. For instance, if 1 lb. of water at 400° lost 1° of temperature to an external body, only 1 thermal unit would be transmitted for each 1 lb. of water circulated; but if 1 lb. of steam were circulated over the same surface, it would impart over 800 thermal units, and become reduced to water at a temperature of 399°, when, its place being supplied by other steam, the number of thermal units transmitted would exceed eight hundred times the number derived from 1 lb. of hot water circulated as such. The inferiority of hot water decreased as the range of temperature was increased. The comparison in the Paper had

[1] Transactions of the American Society of Mechanical Engineers, vol. viii. p. 512.

been made on the basis that the temperature would be allowed to fall about 11° in circulating water for cooking; about 87° where the hot water was allowed to flash into steam to produce power corresponding to a reduction of pressure from 235 to 70 lbs.; and about 177° where the water was allowed to flash into steam of 5 lbs. pressure, or the water was circulated direct for heating purposes, and discharged at the temperature due to that pressure. In the first case 72·7 times the weight of water circulated would be necessary to do the same work as if steam were used; in the second case 10·2 times as much, and in the third case 5·7 times as much. Since, however, water was of a greater density than steam, a greater weight would be transmitted for the same difference of pressure at the ends of the line. Hence on this basis, when the balancing conditions were considered, the size of a pipe of a given length would be a little less, for a hot-water heating system simply, than that of a steam-pipe, but somewhat greater for a hot-water power system, and very much greater for a hot-water cooking system, in which, unless the temperature could be disposed of "in series" in the same building, the surplus heat represented by the high temperature at which the water was rejected necessarily came back to the boiler-house. Since, however, the water-pipe must be returned to the boiler-house of the full size at which it started, in order to keep up the circulation, and the water-pipe for a steam system could be much smaller, as the volume of water was so much less, another compensation took place; first, in friction, from the fact that the water-pipes were practically of double length, and secondly as respected cost, on account of the relative sizes of direct and return-pipes taken together. It was therefore estimated in the Paper that, for heating, the cost of hot-water pipes, proportioned to their size, would be a trifle greater even for heating purposes, 35 per cent. greater for transmitting power, and three times as great for transmitting the high temperature required for cooking. In actual practice, as in Boston, the water system required a loop of which both ends were returned, and an accompanying pipe much larger than the hot-water pipe, to restore to the boiler-house the much larger quantity of water required to perform the several operations of power and heating. Evidently, also, the expense of operating a hot-water plant would be much greater, for the reason that steam was transmitted with a slight loss of pressure represented only by a very few thermal units, and the smaller quantity of water was returned by the steam-pressure direct at a nominal cost, whereas the water in a water system must be circulated by powerful pumps, and the work done paid for at the rate in thermal Dr. Emery.

Dr. Emery. units required to work such pumps. An additional source of expense was due to the fact that all the water used in the buildings and sent back in the return-pipe, and which had fallen in pressure from 235 lbs. to that of the atmosphere, must be pumped again into the boiler against that high pressure, the amount of work to be done being, as shown above, 5·7 to 72·7 times as much as for a steam system. It should be recollected that these conditions were not those of an ordinary house-heating plant, where water at practically constant pressure, except the variations due to elevation, was circulated by the differences of temperature due to the transmission of heat to external objects. Another great disadvantage, in working a hot-water system on a practical basis, would arise from the fact that only 1 part in 72·7 parts of water, at the high temperature used for cooking, or 1 in 10·2 for power, could be utilized, and there was no way of returning the surplus heat of the water to the station, except through the return-pipe. A portion of the water would at once flash into steam as the pressure, in order to receive the returns from the heating systems, must necessarily be near the atmosphere. This steam would not go entirely to waste, as it could be used to heat the return-water so far as practicable. Of course if there were other operations going on in the same building, as for instance power and in winter heating, the hot-water system might to some extent be worked "in series," first for cooking, next for power, then for heating; but evidently the exact quantities of the different varieties of work required would never be present in each and every place; so that, if such a system were largely used for power and heating, there would necessarily be a large quantity of heat discharged into the return-pipe, particularly in summer. The only response to the Paper that had been brought to his attention was in a publication different from that in which the Paper appeared, stating in effect that some person, in discussing the relative advantages of steam and hot water, had considered the heat available from the whole lb. of steam, and only that from part of a lb. of water. This might be considered an abridged method of stating that the water could only transmit the thermal units due to the difference in temperature, while the steam could add to that its whole latent heat for the slightest change in temperature. There was practically nothing for the Author to notice, except an implication that the method was erroneous. It was, however, to be hoped that the parties interested were not making a large expenditure on the representation, or in the belief, that the method of treatment of the subject in that Paper was incorrect. He preferred at this time

Dr. Emery.

not to say much about the system in Boston. With ample capital, and no difficulties of organization, Mr. Abbott did creditable work in its construction, and the plant worked satisfactorily in a mechanical sense. Some considerable difficulties, however, were being encountered, which he hoped would be overcome satisfactorily. He watched the plant with interest, to ascertain the practicability of carrying a hot fluid, at such a high pressure, regularly in the public streets and into the various buildings on the line, feeling that the final outcome would in any case depend upon the considerations above stated. Sir Frederick Bramwell and Messrs. Ellington and Dawson had expressed some difficulty in checking the working cost. It would be found that the average power for every hour in the year was the result of simple arithmetical calculations; or each of the several items was multiplied by the HP., and the number of hours mentioned, thus giving for each the equivalent HP. for one hour (called HP. hours). The sum of these divided by the number of hours in a year was the average HP. for every hour in the year. There was not quite so extreme a range as supposed by Sir Frederick. The quantity of steam delivered for power was nearly constant throughout the year, and was not subject to extreme fluctuations. The quantity required for heating, however, varied with the weather. The average required was about the same as for power, but the quantity on a windy March day was sometimes 50 per cent. greater than the average, thus increasing the total power 25 per cent. This was readily obtained by increasing the actual above the rated power of the boilers to that extent by the use of forced draught. Mr. Ellington's statement that the costs were based only on that of the coal was warranted by the Paper, from the fact that in abridging a long report he had neglected at the outset to state that the price, \$3·25 per ton of coal, included station expenses, which could only be inferred from what followed. For several years previous to the 1st of May, 1886, at which time the report was made, the average cost of fuel and handling had been progressively reduced. The price for coal included delivery alongside the dock; during the winter of 1883–4 it was \$2·85 per ton; for the summer of 1884, \$2·57; during the winter of 1884–5, \$2·50; for the year 1885 and spring of 1886, \$2·00; and, at the date of the report, a contract had been made for all the coal required in the succeeding year at \$1·85 per ton alongside. The average cost of firemen and engineers had been gradually reduced from 55 to 45 cents per ton of coal. The average cost of carting coal, hoisting it to the bunkers in the building, and taking away the ashes, had not varied greatly from 45 cents per ton. As about half the water

Dr. Emery. was returned, the average cost for supplying the water wasted was about 17 cents for each ton of coal consumed. The total station expenses in 1885 had been about \$3·60 per ton of coal consumed, including the cost of the practical staff required to keep the boilers in repair. At the time the report was made the average was less than \$3·00 per ton; but, taking into consideration the low price for fuel alongside, which the company had been able to command as its operations increased, and such reasonable reductions as could be made in other expenses, the probable cost of all station expenses, including first, the coal; second, cartage and handling coal and ashes; third, the water; and fourth, the repairs; was fixed at \$3·25 per ton, as stated. All the calculations were made on this basis, so that from the surplus amounts named the cost of repairs and maintenance of the street plant, and next, business expenses, had to be deducted, before a net profit would be shown. In New York City there was no restriction upon the use of steam-boilers in any part of a building, consequently many of the smaller boilers were handled by men with other duties to perform; and even in larger buildings an unskilled labourer could take care of the apparatus while the engineer tended the mechanical work of the building, so that the charges for steam could not be made as large as would be considered reasonable in Great Britain, and on the Continent of Europe, where stringent municipal restrictions existed. Sir Frederick Bramwell and Messrs. Phipson and Dowson appeared to favour the distribution of heat and power by gas instead of by a heated fluid. Mr. Anderson alone seemed to think this would be more expensive. There was no question that gas, at a much lower price than it was sold for in the United States, could be used economically for the production of power; but, so far as he knew, no gas-engine had yet been developed which could be regulated so well under extreme variations of load as a steam-engine, and few would preserve an economical rate of performance under wide variations of load. The attempt to heat steam-boilers by gas on the premises of course introduced another set of apparatus with its consequent losses. A good business was being done at Pittsburgh, Pa., U.S.A., and was now being extended to cities distant several hundred miles therefrom, in the collection and conveyance of natural gas, of which the expense was represented only by the cost of the property where gas could be procured, and the cost of the wells and of the pipes for conveying the gas to the towns and for distributing it to the consumers. It had been found extremely difficult to conduct this gas under high pressures through the streets of the cities. In spite of extreme care leaks had occurred,

Dr. Emery.

resulting in dangerous explosions. The latter and better practice had been to reduce the pressure as the gas entered a town, and to ventilate every one of the joints throughout the streets into a casing, from which pipe-connections, at regular intervals, were carried up to the height of the gas-lamps. When there was much leakage these pipes could be lighted, and burn night and day. Leakage from natural gas was particularly dangerous from the faintness of its odour. These considerations were only preliminary to the problem, as to whether or not gas could be used for power and heat in lieu of steam, and be more economically generated and distributed than any other fluid. This would depend so much upon the cost at which the gas could be produced, and the various conditions affecting the laying of the pipes in different localities, that he was not prepared to discuss it; he had examined the subject preliminarily for American towns, and could find no economy in such a system. Upon thoroughly investigating any novel scheme there were always considerations, not at first thought of, which had an important influence on the result. No better illustration could be had than by reading the remarks of Mr. Phipson, in relation to hot water; in which, apparently on the authority of a prospectus, it was stated that a cubic foot of water would yield 2,128 thermal units, and a cubic foot of steam only 199. But when the subject was considered on the basis of thermal units per lb. weight of fluid, the only basis considered in standard books; an entirely contrary result would appear, although this was modified by questions of transmission. In response to the suggestions of Mr. William Stainton, that the "easier way of getting over the expansion" would be "by forming spring or expansion-bends," it need only be stated that such a system was impracticable in a street. The pipes were 11 to 16 inches in diameter, which would require frequent off-sets the whole width of the street, in order to ensure sufficient elasticity. Such a system would necessarily be underneath all other systems of pipes, and would then prevent the use of any other pipes at that level for the entire width of the street. The method of off-sets was commonly used by the New York Steam Company for small connections, and sometimes drainage was secured, when vertical off-sets were necessary, by means of a yoke, one branch being run down under an obstruction, and carrying the water of condensation, while another was run up over the obstruction to carry the steam. The largest pipe made with bends in the United States, to his knowledge, was at Manchester, N.H., U.S.A., where, in making additions to the steam-plant of one of the mills, the boilers had to be placed on one side of a canal, and the engines on the other. Here the

Dr. Emery. pipe was carried down one bank to a bridge across the canal, and back along the other bank to the engines, the off-sets providing properly for expansion, although the pipe was as large as those used by the New York Steam Company. In reply to the suggestion of Mr. W. Schönheyder, in regard to the regulation of temperature, the Paper did not attempt to deal with that question, which was incident to the general subject of heating houses by steam. The temperature was, however, being successfully regulated by a combined electrical and pneumatic process in many houses in the upper part of the city. This consisted of a metallic thermometer opening and closing an electric circuit, thereby operating valves which admitted or released pneumatic pressure to diaphragms, in connection with the regulating valves of direct radiators on registers, in the hot-air pipes of air furnaces, heated either directly by the combustion of fuel or with steam-coils. The inquiry of Mr. Henry Davey, as to the effect of the heat of steam-pipes on telegraph conductors, was an important one. When steam-pipes were tight they raised the temperature of the ground very little, if protected as well as those of the Steam Company, and no harm resulted to short telegraph lines; but the engineers of the Atlantic Cable which came into New York were very careful to make wide detours, to avoid having the cable anywhere near steam-pipes, as the slightest variation of temperature modified the resistance of a long cable materially. There were serious difficulties with the wires in the subways along the line of Broadway before the leaks were thoroughly repaired; but matters were getting quieted down, and adaptations had been made, so that both companies could do business with lines 8 to 10 feet apart in the same street. In regard to Mr. Davey's remark that the copper diaphragm of a variator would be fatigued at the inner and outer extremities of the disk, a careful examination would show that with the system adopted, namely, with steam on day and night, the actual motion of the diaphragms was trifling, being only that due to the change of temperature corresponding to the difference in the pressure of the steam; the direct motion was so small that there could not be an appreciable transverse motion to slide the corrugations of the diaphragms on the supporting plates. The extreme movement only took place when steam was shut off, which was very rarely. Some sections of the pipe had not been relieved from steam-pressure since steam was turned on in April, 1882, others only once or twice, and at most not more on the average than twice a year. In response to Mr. Anderson's remarks on the unit of HP., he had, at the Centennial Exhibition in Philadelphia, fixed the unit, afterwards adopted by the Committee of the American Society of Mechanical Engineers, at 30 lbs. of water evaporated at 70 lbs. pressure from a temperature of 100°, because 1 HP. could actually be procured with this much water in well-constructed high-pressure engines of 80 to 120 HP. While such quantity was too small for smaller engines and too large for larger engines, the mean was still a good one, for the reason that for smaller and for larger engines both engine and boiler were generally furnished by the same party; the portable or semi-portable types were largely used for smaller sizes, and the importance of the work rendered the services of an engineer necessary for much larger sizes. In regard to "pokeable" fires, it was not supposed that any improvement could prevent a considerable proportion of the community from having the good cheer and comfort of an open fire. This had been recognized in the better houses in the United States, where the heating apparatus was amply sufficient, by the large introduction of gas logs in various forms, a device familiar to many, in which pieces of pottery were made in the form, and coloured, to imitate wooden logs. They contained pipes so arranged, that minute jets of gas could be burned on the surfaces of the logs, and skilfully disposed tufts of asbestos be kept red hot, so as to form an excellent imitation of a wood fire, though not a "pokeable" one. Such logs gave off sufficient heat for warmth during the cool evenings of autumn and spring, before starting the heating apparatus. The discomforts mentioned by Sir Douglas Galton, in regard to smoke obscuring the daylight, together with the incidental disadvantages of handling coal and ashes, would, if the matter were once put in hand, be found quite sufficient to warrant overcoming the difficulties of legislation and public opinion, required in order to put down a proper plant to furnish power in manufacturing districts, and for heating and cooking purposes in dwellings. Pittsburgh, Pa., U.S.A., formerly the most smoky city in the United States, was now nearly free from smoke, simply from the introduction of natural gas, and a district steam-supply would have a similar effect. In the lower part of New York the number of chimneys sending forth smoke had been greatly reduced, although this difference was not so evident since anthracite coal was burned universally. The great advantages of a district steam system were, that houses could be kept warm in every corner continuously day and night, regardless of weather, from a supply entirely outside the building; the nuisance of handling coal and ashes could be avoided; in any part of a building near the line of a steam-main steam-power in any quantity desired could be obtained without danger from fire; and manufactures of all kinds, small or large, could be

Dr. Emery.

Dr. Emery. promoted. So also, as in New York, buildings, formerly second-class, constructed without any provision for boilers, could be provided with elevators and an ample water-supply for modern sanitary arrangements, and thereby be made first-class by a simple connection with a steam-pipe. The large numbers of escaping steam jets from the roofs of buildings throughout the lower portion of New York, which passed away without doing any harm, were evidences of the importance of a steam-supply to the business methods and personal comfort of the inhabitants of a great city.

Correspondence.

Mr. Bernays. Mr. JOSEPH BERNAYS had been much impressed with the great amount of leakage testified to by the Author. It might be admitted that the mode of attachment of the pipes to their flanges was a doubtful feature; but nevertheless, the joints should be strong enough to resist any direct strain that could come upon them. Taking the dimensions from the drawings, the surface of adhesion between a 15-inch pipe and its flange would amount to about 160 square inches; whilst the greatest end-strain that could be brought to bear on them through the action of the variators amounted, at 70 lbs. pressure per square inch, to about 25 tons at most. This was only equal to a little over 3 cwt. of end-strain per square inch of adhesive surface—surely not excessive—without even taking into consideration the hold afforded to the flange by the collar worked on the end of the pipe. The cause of leakage, therefore, must be sought elsewhere, and would, he thought, be found in the method of attaching the connections to the walls and foundations, which appeared of too rigid and unyielding a character. The Author had made ample elastic provision for changes in length; but would appear not to have provided sufficiently for changes in other directions. The elbow, shown by Plate 1, Fig. 5, representing a junction of mains at a street corner, was a case in point. Here, within the short distance of 5 or 6 feet, there were no less than four independent attachments to the trench walls, two at the saddles, and two at the outer and inner bend of the elbow. It was obvious that, by the rigid attachment of one of the flanges, considerable strains might arise on expansion in the other three attachments, if these were not allowed to accommodate themselves to changes induced by alterations of temperature. If the outer diagonal flange, on which the Author