

applied equally to Shone ejectors. It would be noticed that at Mr. Stevenson. the Broadway station, where the two chambers A_1 and B_1 were closest together, the efficiency was high, whereas at A_4 and B_4 , where the two chambers were far apart, and where the height the sewage had to be lifted was greater, the efficiency was the lowest; but a high efficiency was gained by utilizing the high-section sewage twice over in A_4 and A_3 , so that, combined, an efficiency of nearly 64 per cent. was obtained.

Mr. BURSTAL mentioned that the reason for not adopting the Mr. Burstal. outfall at Douglas Head was that it had been found that the set of the tide was such that on the flood-tide the sewage would have been swept right up the harbour, and into a favourite bathing-place. The Authors had selected the point Z (Fig. 1, Plate 5) for the outfall because observations and evidence, obtained from local mariners and pilots, showed that at every tide, both flood and ebb, the set was outwards. He was glad to be able to say that that had been borne out by experience. There had always been a sweep outwards, either one way or another; but never a set inshore.

Correspondence.

Mr. J. A. COOMBS, of Dukinfield, observed that two things stood Mr. Coombs. out clearly in Mr. Brunton's Paper; first, that there was a great loss by leakage in the Karachi plant in 1901 at the time of the first trials; secondly, that Mr. Brunton considered the efficiency of the pneumatic ejector to be less than was claimed for it by its inventors. Mr. Brunton was certainly correct as to the first statement, for as he had proved by the second trial, the leakage was preventable, and the result of trials in 1902-3 pointed to the fact that further improvement was possible. Mr. Coombs did not agree with Mr. Brunton on the second point, but considered that his figures really confirmed the efficiencies claimed for the pneumatic ejector by its manufacturers. In the last column of Table XII. (p. 237) were given the figures Mr. Brunton would expect to obtain for the efficiencies under varying heads. In arriving at those figures Mr. Brunton had taken the possible work of expansion and compared it with the work which could be done in the ejector; Mr. Coombs considered that the best comparison was between the actual work required in compression

Mr. Coombs, and the work which could be done in the ejector. The following Table was worked out on the latter lines. He had taken 0·65 as the counter of efficiency, just as Mr. Brunton had done; he thought this a fair assumption, as it gave figures which the manufacturers of pneumatic ejectors would be willing to guarantee in ordinary work, though the efficiencies obtainable under trial-run conditions would naturally be higher, as shown by Professor Unwin's efficiency in column 7 of the Table. Mr. Brunton's efficiencies

EFFICIENCY OF PNEUMATIC EJECTORS.¹

1	2	3	4	5	6	7	8
Gauge Pressures.	Total Head.	Foot-Lbs. of Work required to compress 1 Cubic Foot Free Air to Pressure in Column 1.	Foot-Lbs. exerted in Ejector by a Cubic Foot of Free Air when compressed to Pressure in Column 1.	Theoretical Efficiency.	Probable Efficiency Column 5 $\times$ 0·65.	Actual Efficiency.	Source of Efficiency given in Column 7.
Lbs. per Sq. In. 5	Feet.	Foot-Lbs.	Foot-Lbs.	Per Cent.	Per Cent.	Per Cent.	
11·54	647	537	83	54	..	..	
10	23·07	1,185	857	72	47	..	
15	34·61	1,650	1,069	65	42	48·9	Prof. Unwin, actual lift 21·6 feet.
20	46·14	2,063	1,221	59	38	..	
25	57·68	2,439	1,331	56	36	..	
30	69·21	2,779	1,421	51	33	..	
35	80·75	3,092	1,491	48	31	..	..
40	92·28	3,386	1,549	46	30	26	J. F. Brunton.

were higher than were shown by Mr. Coombs's comparison, but in the case of 100 feet head Mr. Brunton found the actual efficiency was 26 per cent. and the calculated efficiency was 42 per cent. Taking the same ratio of actual to calculated, the actual efficiency for 20 feet head would work out as 34 per cent., as against 48·9 per cent. as found by Professor Unwin, or against Mr. Coombs's figure of 47 per cent.; thus in the lower air-pressures the natural deduction from Mr. Brunton's method of

¹ This Table allows for adiabatic compression and for the air being used in the ejector without any expansion. The index of the compression-curve is usually about 1·25, showing a saving in compression; there is usually also a certain amount of expansion of the air in the ejector, and with high pressures such as are used in Karachi this expansion may be considerable.—J.A.C.

calculating was not fair to the ejector. If Mr. Coombs's figures Mr. Coombs. were taken on the low basis of Karachi results, an efficiency of 40·7 per cent. would be obtained with a lift of 20 feet. In his opinion the Karachi plant was not a typical one. Taking the sixty-seven cases in connection with which he had had some responsibility, the average air-pressure was 19 lbs. per square inch, or just one-half of that at Karachi, and thus the average efficiency according to his Table should be 38 per cent. with everyday conditions of working. The air-pressure at Karachi was, in his opinion, higher than it should be. If an intermediate ejector-station had been arranged at the main junction—which he understood was at one time contemplated—a working-pressure of 17 lbs. per square inch would have been required, and thus an efficiency of 40 per cent. could have been guaranteed. It would thus seem unfair to conclude that 33·9 per cent. was the highest efficiency obtainable with pneumatic ejectors at Karachi: it could be 40 per cent., as compared with the 26 per cent. actually found, if an intermediate station were added and the plant were working without the loss by leakage now complained of, and which, as Mr. Brunton said, ought to be eliminated. Mr. Brunton considered it safe to take the makers' rate for the quantity discharged from the ejector, and for low pressures Mr. Coombs agreed with this; but for high pressures, as used at Karachi, the tendency was for the ejector to discharge at more than the makers' rate. With high pressures there was always a tendency for the air to expand, as the automatic valve closed to compressed air and before it had opened to exhaust; and he would have preferred actual measurements as probably being more favourable to the ejector. In the case of Sydney, referred to by Mr. Brunton, the air-pressure was only 14 lbs. per square inch, and thus the tendency to discharge at more than the makers' rate would not be so great. In face of the efficiencies obtainable it might be well to recall the reasons why so many engineers used the pneumatic ejector for raising sewage. It was very simple in construction, and perfectly automatic and easy to handle; the more complicated part, the air-compressing machinery, could be placed where it could readily be attended to by those overlooking other machinery. Being so simple, the ejector could be left to itself with merely periodical visits of inspection, and could be placed below street-level at any distance from compressing-plant. In busy streets, where a pumping-plant would be out of the question on account of the cost of the site alone, the ejector could be placed just where it was required, the only cost being that of excavation and building, beyond the cost of the

Mr. Coombs. ejector and its connections. Further, no insanitary nuisance was caused by cleaning out an ejector-sump, as no strainers were used in connection with the sewage-inlet to ejectors. The facility for dividing a town into several drainage-areas was another advantage fully appreciated by engineers. As a sanitary appliance the ejector was very efficient, and for sanitary contrivances sanitary efficiency was surely of more importance than the coal-bill, if the latter were not out of all reason. For a town of the size of Karachi, 20 I.H.P. more or less was not of great importance, provided the ejector was otherwise the most suitable arrangement. He did not think it fair to compare the efficiency of the ejector with that of a pumping-plant—as was frequently done—on the basis of the quantity of sewage lifted against equal heads. If the ejectors were compared with pumps, a case favouring the adoption of several ejectors should be chosen, and both an ejector scheme and a pumping scheme should be laid out; and then the head required by the pumps should be compared with that required by ejectors. If this were done, the indicated horse-power required with ejectors would not appear in an unfavourable light. The pneumatic ejector was used in many cases to save deep and costly cutting in perhaps hard or treacherous ground, and the interest on capital thus saved should be credited to the ejectors. That the ejector was viewed in this broad-minded way, and not merely from the point of view of its mechanical efficiency, was proved by its growing popularity.

Mr. Hanssen. Mr. C. T. ALFRED HANSSEN remarked that the Paper showed the difficulties experienced by engineers in obtaining continuously the results obtained under trial conditions. The machinery for Karachi was designed in 1892 and completed in 1894. It was considered at the time a first-class installation, but considerable improvements had since been made in the design of air-compressors and in Shone ejectors, whereby the latter were made to work alternately, and better results than in 1896 could now be obtained. The chief defects at Karachi were, however, due to other causes. The air-compressors appeared to have been working well, but there was a loss of $42\frac{1}{2}$ per cent. between the compressors and the ejectors. The manner in which Mr. Brunton had determined this loss was correct as far as it went, but Mr. Hanssen suggested that the investigation should be carried farther by closing the air-valves to the ejectors, or better by disconnecting the pipes to the ejectors and closing them by means of blank flanges, so as to ascertain how much of this large leakage was due to the automatic valves and how much to

defects in the air-mains. It was also possible, by subdividing the air-mains into sections and testing each section separately, to localize the defects. According to his experience with Shone ejectors, which extended over 20 years, the excessive leakage was more likely to be due to some local defect in the air-mains than to leakage in the automatic valves. The air-mains at times, like gas- and water-pipes, were liable to be broken or drawn out of their sockets either by settlement of the ground or by expansion and contraction due to variation of temperature; while little difficulty was experienced in keeping the air-valves reasonably tight, as the automatic gear was provided with piston-valves which were carefully fitted in the cylinders with soft cup-leathers at their ends, and in addition had a block-tin seating bearing against a thin edge, so as to prevent leakage from the compressed-air pipe to the exhaust while the valve was at rest. He had himself carried out a number of experiments with Shone ejectors, but he had never found the leakage through the automatic valves to exceed 4 to 5 per cent. of the air used; and unless these valves had been altogether worn out by the neglect to which they have evidently been exposed, the leakage could not possibly be anything like 10 per cent. In Table I. (p. 222) Mr. Brunton gave the estimated frictional resistance for each separate length of rising main, based on the average flow of sewage through each length of pipe. This, however, was not the proper way to calculate the friction due to the discharge of an ejector. The capacity of the ejectors at Karachi, was 200 gallons each, and in order to keep the rising mains free from deposit it was essential that the ejectors should act as flushing-tanks and discharge the whole of this volume in less than 1 minute, so as to get a minimum velocity of not less than 2.5 feet per second during the time of discharge. If Mr. Brunton allowed an ejector to discharge at the rate of 80 gallons per minute, then the discharge would occupy $2\frac{1}{2}$ minutes, and the flushing action of the ejector would be lost. By calculating the frictional resistance on the basis of a minimum velocity of 2.5 feet per second, Mr. Brunton would see that the air-pressure should be considerably more than 30 lbs. per square inch; but although a higher air-pressure reduced the efficiency of the installation, owing to the impossibility of working air expansively in the ejectors, as Mr. Brunton correctly pointed out, still the extra expense was justified, as the low velocity of the sewage in the rising mains was sure to cause deposition of silt in them, and consequently sooner or later heavy expenditure in cleaning them out by manual labour. By carefully overhauling the air-mains and by replacing any defective

Mr. Hanssen. parts of the automatic air-valves or other parts of the ejectors, it should be possible to raise the efficiency of the installation to 35 or 40 per cent., as had been proved by experience in several hundred large installations. It should be pointed out, however, that the efficiency of an ejector-installation, owing to the non-expansive working of the air, was highest for low pressures and decreased as the pressure increased. The best results were obtained with pressures of 15 lbs. to 20 lbs. per square inch. It could not, however, be too strongly maintained that in dealing with a substance like sewage the main point was not the mechanical efficiency of the installation, but the effective working of the plant in discharging crude sewage without screening it or handling any part of it by manual labour. The coal-bill should certainly be kept as low as possible and no expense should be incurred by using defective or badly-designed machinery; but the true efficiency of the plant was measured by the way in which it conveyed the sewage from the town to the outfall, not by the coal-consumption.

Mr. Hewett. Mr. B. H. HEWETT, as the engineer immediately responsible for the working of the Shone system in Bombay, found Mr. Brunton's Paper extremely valuable, as he was not aware that such complete efficiency-trials of the system had been carried out before. In the Colaba district of Bombay there were three stations, each containing two injectors of 500 gallons capacity each, one station with two ejectors of 300 gallons capacity each, and one station with two ejectors of 100 gallons capacity each. These stations were started at the close of 1895. In the other districts of Bombay, sewered on the same system but worked from a separate compressor-station, the following ejectors had lately been set to work:—Four 1,200-gallon ejectors in two separate stations; four 1,000-gallon ejectors also in separate stations; and two 700-, two 600-, and two 250-gallon ejectors. No series of tests, beyond the contract trials, had yet been made of this latter group of ejectors, and it would be interesting to learn, when the time came for making further trials, how the efficiency of the system, comprising several ejectors of large capacity, compared with the figures given by Mr. Brunton and with those obtained from trials at Colaba. It was found at Colaba, where the air-pressure was maintained at 22 lbs. per square inch, that the average efficiency of the whole system varied between 0·21 during the dry season, and 0·24 during the monsoon months, when both engines and ejectors were approaching their maximum capacity. It was natural that the efficiency should be higher in the latter case, for though the losses, due to heating of air during

compression, were appreciably greater at high speeds than at low, Mr. Hewett. the leakage from air-mains and automatic valves was a constant, and far overshadowed any other loss. The efficiencies tabulated in Table IX., were, in Mr. Hewett's opinion, extremely favourable, and he was doubtful whether Mr. Brunton would be able to improve upon them without incurring heavy maintenance-charges. At Colaba it was the practice to test the air-mains for leakage once a year. The air stop-valves on the ejectors were first cleaned and ground, and the packing of all main and branch stop-valves was attended to. If it was then found, on shutting off all ejectors and filling the air-mains to 50 per cent. above working-pressure, that the fall of pressure in the mains did not exceed 5 lbs. per square inch per hour, no further work was undertaken. If the loss exceeded that amount each section was tested separately. Even after locating the defective section it had, on occasions, been a matter of several days' work to find the actual leak. If the pipes were not buried to a greater depth than 3 feet, the leak could generally be found by introducing some volatile oil, such as oil of peppermint, into the pipe through the stop-valve cover at the beginning of the section, raising the pressure and then carefully walking over the line of the pipe at an early hour on a still morning, making the utmost use of the sense of smell. If the pipe was over 3 feet in depth, this method generally failed, and the section then had to be divided and sub-divided until the leak was confined to small limits, when the whole of the defective sub-section was opened. The water-pressure test was found to be useless in this district on account of the sandy nature of the soil and its close proximity to the sea. With a well consolidated macadam road above the sand, a very large quantity of water could be dissipated through the leak without showing on the surface. In a comparatively small installation, such as Colaba, the daily coal-bill gave almost immediate evidence of a blown joint on a large pipe, or a broken pipe of smaller dimensions; but in the large installation, comprising the second group of ejectors, anything but a heavy leak on a large pipe would not be so self-evident, and it became a matter of some concern how best to keep losses under this head within reasonable limits. Dividing a section, testing it, and making it good again, when, as in this case, the section might be made up of 15-inch pipes, could not easily be undertaken without accumulating an undesirable quantity of sewage at the ejector-stations. Could any one offer a practical suggestion regarding the training and use of dogs for the detection of leakage, and the most suitable essence for the purpose?

Mr. Hewett. He agreed with Mr. Brunton that the leakage through the automatic valves of the ejectors often amounted to a serious item, and was not always easy to detect unless it was large enough to put the valve out of action. Systematic renewal of leathers at frequent intervals—gauged by the time which elapsed before they became hard and friable—appeared to be the only remedy. Measurement of flow by counting the number of ejector-discharges was generally the only method easily available, but it might give inaccurate results. In the Colaba ejectors, owing to the unsuitability of leather for Bombay sewage, the valves were faced with brass. Hammering and galvanic action, combined with the passage of large quantities of silt, had soon set up wear in the valve-seats and the slip past both inlet and discharge-valves had become so excessive in the case of the hardest-worked ejectors that it had been necessary 3 years ago to devise a remedy. New valve-boxes, with an additional joint on the line of the seat, were made with brass seats bolted on so as to be easily renewable, and the valves were faced with sheet "Dermatine." This arrangement had so far given every satisfaction. In the ejectors of later pattern, the valves had also been faced with "Dermatine," but the cast-iron seat forming an integral part of the valve-box had been retained. The box had, however, been much reduced in dimensions, so that it would not be such an expensive matter as it was formerly to renew the entire box when the seat became worn. The new ejectors had a non-return valve-box placed at the lowest point on the sealed sewage-main, immediately outside each ejector-station, and this valve materially assisted in reducing slip. But, apart from considerations of mechanical efficiency, it was often found that some foreign matter was preventing the perfect closing of the valves. It was claimed as one of the great advantages of the system that no preparatory screening was necessary before the sewage was dealt with by the ejectors, and he had nothing but admiration for the way in which they dealt with most foreign matter. In the Bombay Presidency large quantities of grass, rags, and cotton waste, used in cleaning cooking-utensils, found their way into the sewers, and it was this material which gave the most trouble by catching in the hinges of the valve and gradually accumulating. The compressor-engines at Karachi were, he believed, of the same type as those at Colaba. The principal difficulty experienced with the Colaba engines had been the maintenance of the low-lift annular valves, with which the compressor-cylinders were fitted, in good repair; and in consequence of the satisfactory results obtained with

Hughes gland-less Corliss air-valves fitted to the engines working Mr. Hewett. the group of ejectors outside the Colaba district, it had lately been decided to fit new cylinder-heads having valves of that pattern to the engines at Colaba.

Lieut.-Col. ALFRED S. JONES remarked that the Karachi plant Lt.-Col. Jones. seemed to have fallen into a bad state of repair before it came into Mr. Brunton's charge, and the difference between its efficiency after and before the attention he was able to give to its working was shown practically by his statement that the trouble previously experienced from overflows at the manholes had practically ceased, the amount of sullage dealt with had considerably increased, and the coal-consumption per unit of sullage discharged had been greatly reduced. With such encouragement to persevere in his endeavours to mend matters it might be hoped that he would yet attain the efficiency (0·453) at which he aimed. The efficiency (0·263) recorded as the result of Mr. Brunton's last five trials might be considered a low one in any pumping scheme, unless the circumstances described in the Paper were taken into account, as they showed that lifting power was required at six separate points, and had to be raised and exerted probably from a distant seventh point, as the site of the air-compressing station was not shown. It had been commonly held, however, that economy, in first cost of sewerage and in working-expenses (which would otherwise be incurred for a number of small engines and pumps) outweighed loss of power in heating air during compression, leakage, and discharge of a volume of high-pressure air equivalent to the volume of sewage lifted by the Shone system. Mr. Brunton correctly observed that it was difficult to get anything more exact than an ejector for measuring water, and it was satisfactory to know that there could thus be no doubt about the work done in his trials, which was perhaps more than could be said of ordinary pumping-trials with their slip and clearance errors.

Mr. H. BIRCH KILLON had been called upon in 1894 to undertake Mr. Killon. experimental work and the design of the earliest installations of the Adams lift, and to superintend all the work actually carried out during a few years following, including the first installation, namely, that for the Corporation of Grimsby. He had discarded the vase-shaped chambers at that time proposed, in favour of the horizontal cylinders, because in many cases economy of head in the liquid used to compress the air was important, and the elongated cylinder occupied a minimum of depth. The valve with a rolling ball then forming the outlet for the liquid in the air-cylinder he had also discarded in favour of the open siphon G, thus leaving no

Mr. Killon. moving part in the apparatus used to compress the air. The siphon G had proved to be perfectly reliable, but as it acted subject to the limited pressure of the atmosphere, it was not advisable to employ the design shown in Fig. 3, Plate 5, where it was required to lift the sewage more than about 15 feet. If, however, in place of the semi-trap shown at the outlet of the siphon G, a deep trap (limited to about 6 feet) was employed, the liquid in the trap offered resistance to the rise of liquid in the siphon above, thus allowing an increased pressure to be obtained in the air- and forcing-cylinders. An inclined fall-pipe might be employed with a view to reduce the depth of excavation for the air-pressure chamber, and for the tail drain, but this was seldom preferable to the vertical fall-pipe, which gave the maximum efficiency because it required a minimum time and amount of liquid to fill and empty it. A serious trouble, however, had had to be overcome, more especially in connection with the use of the vertical fall-pipe; the air, instead of allowing itself to be driven from the air-cylinder to the forcing-cylinder, would at times escape by way of the fall-pipe, and throw the entire apparatus out of working order. In order to obviate this he had introduced a nozzle within the fall-pipe, by means of which the falling liquid was made to pass down the centre only of the pipe, thus increasing its velocity, and a partial vacuum was produced around the nozzle on the principle of the injector, inducing an inward current of air, which found access by the vent-pipe. This also increased the work done by the lift, the air so induced being fully compressed. Where valuable water was used from a main for operating the lift, to avoid waste he had introduced a ball- or float-valve, fixed on the supply-pipe, so that the float was actuated by the rise and fall of the low-level sewage before it entered the forcing-cylinder. Where sewage was employed to work the lift, the absence of such control materially decreased the efficiency of the apparatus. The principle of the lift had been known from the time of Hero and his fountain, but its practical application depended for success upon the perfection of some of the details he had described.

Mr. Strachan. Mr. JAMES STRACHAN stated that the efficiency-tests which he had caused to be made when he was the Municipal Engineer of Karachi had been very carefully conducted, and that to the best of his knowledge the results were correct. Before advising the adoption of the Shone system in Karachi he had made numerous inquiries as to its mechanical and sanitary efficiency; and this at a time when, as he believed, its merits for water-borne sewer-

age on sanitary principles were largely under-estimated, and Mr. Strachan. when sanitary engineers who had no practical knowledge or experience of the working of the system alleged that the mechanical efficiencies of the ejector-apparatus and their accessories were absurdly low compared with high-class pumping machinery. Then, as now, some engineers were in favour of substituting hydraulic, electric or vacuum power, for town and district sectional sewerage works, adhering, however, to the Shone automatic principle. But he had believed then, and still did so, that the compressed-air method, as utilized in the Shone system, if only the works were correctly designed and properly executed and maintained, would always prove to be more economical, and better adapted for the automatic and sanitary collection and ejection of sewage within flat or low-lying districts, than any of the other systems named. Mr. Brunton had dealt with the data at his disposal in a very fair and able manner. The discrepancies between the results of his tests of the efficiencies of the Karachi works, and those recorded by Mr. Brunton, Mr. Strachan could not now explain away, as he had neither the documents nor the necessary memory to enable him to do so. But it was clear that, at the time when his own tests were made, the leakages from the compressed-air main were negligible, as they only amounted in the aggregate to 0·0156 per cent.! If Mr. Brunton had resorted to the same kind of tests as were described in Mr. Strachan's Paper¹ for proving the air-tightness of the air-mains, and if he had also coupled the air-mains to the ejector-valves and afterwards tested the combination, he would then have succeeded in locating the principal preventable leakages, both in the air-mains and the ejector-valves, and he would have been able at the same time to separate the one from the other: a process which would have demonstrated to him the absolute philosophical fairness of the statement in his Paper (p. 219), namely: "This bears out the conclusion previously arrived at, that about 42½ per cent. of the power developed was absorbed in making good losses due simply to waste of air, which could be prevented to a large extent, if not altogether." There must be something radically wrong to account for the loss of 42½ per cent. of compressed-air power. In Mr. Strachan's tests, so far as the air-mains were concerned, the total loss from leakages, for 2 hours, had been made good by 150 revolutions only of the compressing-engine; but to make good the losses from leakage in the ejector-valves and air-mains

¹ Minutes of Proceedings Inst. C.E., vol. cxxxv. p. 281.

Mr. Strachan. combined, as discovered by Mr. Brunton's tests, it had been necessary to run the air-compressing engine continuously at 50 revolutions per minute! Mr. Brunton was deserving of the thanks of all sanitary engineers who wished to understand both the practical and the scientific aspects of the Shone system, and his Paper demonstrated clearly and fairly the fact that the low mechanical efficiencies arrived at by him were not due to any inherent defects in the system but to some local causes which no doubt could easily be discovered and rectified by those in charge. Before leaving Karachi, Mr. Strachan had prepared and submitted a scheme for extending the Shone system there, and that scheme, doubtless modified somewhat by Mr. Brunton, was to be carried out.

Mr. Sturgeon. Mr. J. STURGEON considered that Mr. Brunton's Paper was a story of machinery utterly neglected and left to take care of itself for years, with the natural result—a falling-off in the efficiency. It spoke well for the design and workmanship that the plant did not break down utterly, as any modern pumping-engine would surely have done, if left without attention for years. What could those in charge, before Mr. Brunton took the matter in hand, have been doing to allow a leakage of $42\frac{1}{2}$ per cent. in the air-supply—easily preventable with ordinary care—and the temperature of the air at the compressors to rise to 265° F.—a matter merely of proper water-circulation, which Mr. Brunton had quickly remedied, and might yet further improve? As to the automatic valves being a source of leakage, any moving valve would become leaky in time if not attended to. Judging by the enormous leakage, it would not be at all surprising if it were found that the valves were left without oiling, glands without packing, and joints blowing; but Mr. Brunton did not say in what condition he had found the valves. Judging from the moderate sum spent on repairs and renewals (after the first 3 years), as given in Table XIII., this item would seem to have been limited to the surface machinery, leaving the underground work to take its chance. These conclusions were fully warranted by the improvement Mr. Brunton had effected by a proper, though belated, overhauling, which would, no doubt, have produced even better results but for the impossibility of overtaking the cumulative damage of years of neglect. It was not unreasonable to assume that the sewage-mains had been equally neglected. Mr. Brunton appeared to have calculated the frictional head on the basis of clean pipes of the full bore specified. But it might be taken as certain that the pipes were extremely foul, as the maximum flow given in Table I. averaged little more than half the velocity necessary for self-cleansing, and this

had been going on for years. Those pipes must have been choked Mr. Sturgeon. with foul deposits, especially at the bends. The frictional head would therefore be much greater than was estimated by Mr. Brunton, thus necessitating a much higher air-pressure. This would materially alter Mr. Brunton's calculation of the efficiency of the system. The air-mains had probably been equally neglected, and the moisture discharged from the air allowed to accumulate in the dips and bends, without any attempt to drain it off. Mr. Brunton's estimate of the weight of air delivered by the compressors had been calculated from the cylinder-capacity and piston-displacement. This, however, was not at all satisfactory. The air entering a very hot cylinder expanded rapidly, so that the cylinder was filled with a volume of air expanded by the internal heat and of proportionately less weight than the same volume of outer air. This expanded air would show a good compression-curve, undistinguishable from a curve produced by the full weight of air at normal temperature. *Fig. 8* (p. 216) showed this expansion of the entering air very distinctly in the occasional risings of pressure on the intake along the line DC, showing a pressure above that of the atmosphere (after the vacuum at the first effort of opening the valve) greater at the two ends of the stroke where the piston-speed was less, and less in the middle where the piston-speed was greater. As air increased in volume by about $\frac{1}{400}$ th for each 1° F. rise in temperature, it was certain, at the high temperature allowed by defective water-circulation, that Mr. Brunton's figures for the weight of air delivered must be over-estimated, and probably greatly so. This was a loss which could not be entirely avoided, but by proper attention to cooling-arrangements it could be greatly reduced. For all these reasons he thought Mr. Brunton's estimate of an efficiency of 26.3 per cent. was considerably understated; that it might really have been nearer to his assumed figure of 33.9 per cent.; and that even that might be increased by further investigation and improvements. There was a strange discrepancy in Table I. (p. 222) which required some explanation. The discharges from the six ejectors at the time of maximum flow were given as:—From No. 1, 80 gallons per minute; No. 2, 90 gallons; No. 3, 150 gallons; No. 4, 160 gallons; No. 5, 160 gallons; and No. 6, 120 gallons—total 760 gallons per minute—all ultimately converging into the 12-inch main, at the air-vessel (*Fig. 1*, p. 212). And yet the maximum flow in the 12-inch main from the air-vessel to the sewage-farm was given as only 420 gallons per minute. How had this last been ascertained, and what had become of the extra 340 gallons per minute, which all the time

Mr. Sturgeon. the ejectors had been discharging into the main? Could the ejectors, after all, have been doing far more than they had been credited with at the outfall. Investigation of the mechanical efficiency of the Shone system was useful in ascertaining the leakage, the undue increase of load by fouling of pipes, and other defects; but as a method of comparison with other systems it was misleading. There were two other kinds of efficiency which were of almost greater importance. First, there was what might be termed the commercial efficiency—that was, the cost per 1,000 gallons discharged at the outfall as compared with other systems, leaving out the question of the height of lift. The Shone ejectors intercepted the sewage at various levels, while with a pumping system the whole volume had to be run down to the lowest level and lifted thence to the outfall—a matter of serious importance in a hilly district. Even at Karachi, although the district was comparatively flat, the static head, between the highest and lowest ejector, varied, as shown by Table II., between 49·34 feet, and 53·42 feet. With a pumping system the whole volume would not only have to be run down to the 53·42 point before being pumped up, but would have to go even lower, as the gravitation sewer leading to the pump-well would have to be laid at such a gradient as to give a self-cleansing velocity. Thus, it might easily occur that the superior mechanical efficiency of a pumping-engine would be more than counterbalanced by the extra height of lift involved. Even then, the sewage-pump only dealt with the liquid sewage, all the solid matter which found its way into the drains having to be carefully screened off, and dealt with separately, at additional cost, which must be added to that of the pumping. The ejectors, on the other hand, took everything that came along, at their various levels, and sent all in bulk to the outfall. In ascertaining the commercial efficiency of the sewage-pump, the cost of the gravitation sewer to the pump-well, and the cost of dealing with the solids, would have to be taken into account. The other kind of efficiency was the sanitary efficiency of the system, and was of even greater importance than the two former. It was unnecessary to enlarge upon the sanitary advantages of a system which divided the area to be sewered into a number of sub-districts, separating healthy from unhealthy areas by the impassable barrier of the pneumatic ejector, shortening the length of the gravitation feeding sewers, and enabling them to be laid at self-cleansing gradients—as compared with a system involving long and deep-laid gravitation sewers, and, by a network of such sewers (too often sewers of deposit) over a large area, connecting the

healthy with the unhealthy parts. All this was now well understood, and he only alluded to it lest, in trying for a high mechanical efficiency the more important objects of an efficient sewerage system should be lost sight of.

Mr. BRUNTON, in reply to the Correspondence, stated that Mr. Coombs was mistaken in supposing that the Paper called in question the efficiency claimed for the pneumatic ejector by its inventors. The Paper merely stated that the cost of working for Karachi was originally under-estimated, and that the actual efficiency of the Karachi system had never been so good as it was supposed to be. As a matter of fact, the possible efficiencies given in the last column of Table XII. (p. 237), were, if anything, slightly higher than any efficiencies put forward by the inventors. The final efficiencies given in Mr. Coombs's Table appeared to be wrong, as the 0.65 took into account the work required to compress the air, which Mr. Coombs allowed for a second time in his ratio of column No. 4 to column No. 3, and called theoretical efficiency in column No. 5. Mr. Brunton was well aware that the air-pressure required at Karachi was higher than usual: in fact, he did not know of any other installation working at so high a pressure. He did not agree that the ejector had a tendency to discharge at "more than the makers' rate" when working at high pressures, nor that, under such conditions, the air had a tendency to expand. The automatic air-valve was closed and opened by the sewage, which at fixed levels raised or lowered bell-floats, and it was not easy to understand how the air-pressure could in any way affect the level at which this automatic action took place. He fully recognized the many advantages of the Shone system, and above all what had been called its "sanitary efficiency," and the fact that he had recommended an extension of the system conclusively showed this. Considering that in Karachi the static head, or difference of level between the highest ejector and the delivery-station, might be taken at 50 feet, it was not easy to see how Mr. Coombs arrived at the conclusion that the introduction of an intermediate ejector would have reduced the working-pressure of the air to 17 lbs. per square inch, equivalent to a head of only about 36 feet. With regard to Mr. Hanssen's objection to the manner in which the frictional resistance of the mains had been calculated, of course the figures given were not strictly accurate, being based on average discharges per hour. In practice the discharge no doubt varied minute by minute, but at the same time the maximum resistance from any ejector could not possibly be greater than that due to the working air-pressure. In the Author's experience the

Mr. Brunton. rising mains were exceptionally free from deposits, and it was quite safe to treat them as clean pipes in calculating the frictional resistance. They could, he believed, be kept clean at a very much lower velocity than 2·5 feet per second. Whatever might have been the leakage in the air-mains at the time when the tests recorded in Mr. Strachan's paper were made, it was not to-day a negligible quantity, amounting, as it did, to not less than 5 per cent.; and it was difficult to reduce it below this. Mr. Strachan's figures were based on a trial made by the Superintendent of Machinery in March, 1896. The sewage-discharge was then arrived at by multiplying the number of discharges by the capacity of the ejectors, in the same way as in Mr. Brunton's trials. No other method of measurement existed, nor could one be conveniently made. In the calculations, based on the result of his trial, the Superintendent of Machinery took the head as 85 feet. As the air-pressure was only 30 lbs. per square inch this could not possibly be correct, and in using the Superintendent's figures Mr. Strachan took the head as equivalent to the 30 lbs. pressure; but, so as not to reduce the efficiency, he arbitrarily took the discharge at 531 gallons per minute, instead of what it actually was, 437·5 gallons. Mr. Sturgeon's remarks were interesting in so far as they pointed out sources of probable waste, such as heating of air during the suction stroke of the air-pump, and consequent increase in volume. That loss from this cause occurred was well known, but in Karachi it did not appear to be large, amounting to not more than 3 per cent. There was no real discrepancy in the discharges given in Table I. These discharges were the average maxima during any hour, in the trial of the 12th-13th August, 1901. As stated in the Paper, the ejectors were never all working together, and consequently it did not follow that the maximum discharge from the 12-inch main should be the sum of the maximum discharges from the ejectors. *Fig. 2* showed that the maximum discharge through the 12-inch main amounted to about 25,000 gallons between 12 noon and 1 o'clock P.M., equivalent to just under 420 gallons per minute. Mr. Brunton fully recognized the value of both the commercial and the sanitary efficiency of any system of sewage-discharge: in fact, his Paper gave the commercial efficiency—the cost per 1,000 gallons discharged—of the Shone system in Karachi, and he would have been glad if the cost of the system at other places had been forthcoming. But he failed to see how useful comparisons of such efficiencies could be made, if the question of the height to which the sewage was lifted were neglected.