Mr. DAVEY said his object in preparing the Paper had been rather to show the conditions on which economy depended could be made available in the direct-acting engine, than to demonstrate the economy of such engines from the records of actual results. If he had succeeded in proving that those conditions existed, it was only necessary that the engines should be properly constructed and economy must be the result. But he was not without data as to the actual consumption of steam. The engine from which the indicator diagrams, Plate 7, Fig. 12, were taken, showed, on very careful experiment, the use of 22 lbs. of water per indicated HP. per hour; and when it was remembered that the engine was working at a colliery where the boilers were not roofed over, and the steam jacketing was far from perfect, he thought the result a very good one.

Dr. POLE remarked that the subject was well worthy of a Paper, as the kind of engine referred to had many peculiarities as contrasted with the one best known, the motion of which was governed by a crank and fly wheel. He had already said a good deal, elsewhere, about the Cornish engine, which was an example of the kind of engine referred to. It would be remembered that at one time the Cornish engine excited much curiosity. Its performances were treated as fables, and it was thought impossible that an engine could work so economically as it was said to do. At length a Cornish engine was brought to London and set up by the late Mr. Wicksteed at Old Ford in connection with the East London Waterworks, affording an opportunity of seeing what it could do. It was there shown that the account given was no fable, and that a Cornish engine working with high pressure, with expansion, and with great attention to economy of heat, was able to do a very high duty. The engine was thoroughly investigated practically and theoretically. The late Professor Moseley undertook the theoretical part of the investigation, and he had the honour of assisting in it. All the elements of the engine were thoroughly worked out, and the details were given partly in a report to the British Association,[1] and partly in his work on the Cornish engine.[2] That was the first time that the velocity of the Cornish engine had ever been measured. An ingenious instrument was made by General Morin, the eminent French physicist and engineer, and the velocity of the engine was measured at different

[1] *Vide* Report of the British Association for the Advancement of Science, 1844, p. 90.

[2] *Vide* "A Treatise on the Cornish Engine," part iii. By W. Pole. 4to. Lond. 1844.

points of the stroke. Although there was an enormous plunger of great weight, the velocity was very high, the maximum being about 10 feet a second. It was theoretically investigated by Professor Moseley and himself, and compared with the steam force, and a great many interesting points were brought out in regard to the theory of the motion of the engine, some of which were referred to in the Paper under discussion. The conclusion arrived at was that there was no mystery in the Cornish engine, and that it did exactly what it ought to do on mechanical principles, nothing more nor less.

He had also had occasion at a former meeting[1] to say something with regard to the double cylinder engine. When the late Mr. Simpson, Past-President, Inst. C.E., took the source of the Lambeth Water Works supply up the river he was anxious to get a good engine for pumping. He had to pump through a long main, and he did not like the Cornish engine on account of its irregularity of action; he wished to have an engine that would act more uniformly; he desired for that reason to apply a crank and fly-wheel, and Mr. Simpson accordingly commissioned Mr. David Thomson and himself to endeavour to find such an engine. They thought that a double cylinder engine would answer the purpose, and they inquired what had been done with it; but the result not being satisfactory, they made some suggestions with a view to its improvement ending in the production of the engines made by Messrs. Simpson for the Lambeth and Chelsea Waterworks which had acted exceedingly well and very economically. They were controlled by a crank and fly-wheel, and their action was so regular that they could pump through the large main without danger. For waterwork purposes where mains had to be pumped through, which were always liable to burst under irregular action, he should prefer an engine controlled by a crank and fly-wheel to a Cornish engine, especially when such an engine was used in conjunction with another element of pumping action which he considered very valuable—the combined bucket and plunger pump. This kind of pump had the great advantage, that instead of a reversal of the action of the motion of the water at every stroke the water was always moving in the same direction, which was conducive to steadiness of action. No doubt, however, there were many cases in which a free acting engine on the Cornish principle was more suitable, and in deep mines that was likely to be the case. The great merit of the Paper was its practical cha-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 85.

racter. The Author had gone thoroughly into the details of such engines. There was a great deal to be said on that branch of the subject, and the Author had said it very well.

Mr. BRAMWELL had already expressed on several occasions his opinion with regard to the Cornish engine in relation to water-works, and was afraid he could say nothing new upon that question; but, as it was pertinent to the subject of the Paper, he might be permitted to repeat what he had said before. Cornish engines gave large results in Cornish mines, where they were worked in pumping water to a definite height. That having been ascertained, they were brought to London, and were put to pumping water for waterworks. He thought that in many cases where they had been so applied they had been wrongly applied. Although the engines might have given great economy compared with the work that they did in the engine-house, that work was unnecessary. They did not give great economy compared with the necessary work that they did in the mains. What he meant was this. A Cornish engine as ordinarily constructed must work against a heavy and a definite load. In order to obtain this condition of things beneficially in waterworks, it was necessary to have a main extending from the engine to an elevated reservoir. The velocity of the water, if the main was of considerable length, should be pretty uniform, so that the resistance caused by the friction of the water through the main, added to the head of the reservoir, should not vary more than that inevitable variation due to the difference of level in the reservoir, owing to the rate of drawing off from time to time, and even that variation was an objection. But so far from that being the ordinary condition which Cornish engines had been put to work for water-work purposes, they had been put to work under very different circumstances. In one case they had been put to work against a constant load produced by a stand-pipe: that stand-pipe was not opened to the main which was to take the water away, but it was furnished with an overflow at the top, so that while the engine pumped against a constant load of 205 feet, the water, when it got to the top of the stand-pipe, tumbled down on the other side in the return legs of the stand-pipe and stood there at elevations of 100, 105, or 180 feet, depending upon the draught of water upon the mains. In order to make the engine work, the water was at all times pumped up to 205 feet. It never was wanted at 205 feet in the main at all, and frequently it was wanted at little more than half that pressure. Such an engine might work with great economy when its duty was taken as

raising water to 205 feet; but it worked with very poor economy when it was taken as pumping water against the average resistance prevailing in the mains. He knew of another case in which within a few years two large Cornish engines had been put up in a pumping house of a waterworks from which a main proceeded to a reservoir, and that main served also as a service main. If at the time when an engine was working, any person opened two or three fire-cocks in the main, the pressure was reduced and the engine went "out of doors" with a bang enough to startle any one, and it was a mercy if the thing did not break to pieces. What was then done? The engineer rushed to the second engine and put it to work as hard as he could, in order that the extra friction due to the double quantity of water being sent along the pipes might restore an adequate resistance to the engines, which, if they had not adequate resistance, were perfectly uncontrollable. But that expedient not being sufficient, there was a screw-cock in the delivery main close to the engine, in order that by it the waterway might be throttled and that this resistance might be produced. Even that, however, did not suffice, and a valve was introduced in the equilibrium pipe, in order that the steam might be strangled as it came from the top of the piston to the bottom, and that further resistance might be produced. It appeared to him, that when it was necessary to resort to all these contrivances to make artificial resistance, resistance required solely to enable a particular class of engine to work, that whatever the intrinsic economy of this class of engine might be it could not be sufficient to counterbalance far less to outweigh the disadvantages thus artificially raised and essential to its use. He therefore thought that, except under the circumstances he had stated of pumping through a main, which was not a service main, into an elevated reservoir where the resistances were pretty regular, the Cornish engine for waterworks purposes was a mistake.

Passing to the real subject of the Paper, the Author appeared to have set himself the task of devising two important improvements in those pumping engines where (as in the Cornish engine) the length of stroke and the velocity of the stroke were not controlled by a crank and fly-wheel. The first of these improvements was the doing away with the very high rate of speed which prevailed at the commencement of the "in-door" stroke of the Cornish engine (even when there was a great weight of pitwork to be set in motion); and prevailed equally whether the engine were making a large or a small number of strokes per minute. The high velocity of the Cornish engine at the com-

mencement of the in-stroke rendered it difficult to provide sufficient waterway through the valves, and also caused the valves to work very uneasily and uncertainly. For this a remedy had been found by the Author in the use of the compound engine, and it had been shown that by its employment, as arranged, a much larger effective working piston speed than was reached in the Cornish engine could be reached while the initial speed was materially reduced. The second improvement was the prevention in such engines as those under consideration of "banging," in the event of a valve not shutting, or of a pump barrel bursting. This improvement had been attained by the use of the ingenious gear shown in Plate 6, Fig. 6 c, by the application of which it was perfectly possible for the engine to be brought to rest without any shock, even should a pump barrel burst. It would be seen that one end of the lever controlling the valves was actuated by a regularly moving cataract piston, and the other end by the piston of the engine itself. If the resistance to the motion of the engine piston suddenly disappeared, in consequence of the holding up of a suction valve, or of the breaking of a pump barrel, the engine in its effort to rush to make the outdoor stroke at a great speed, overran the pace of the regularly moving cataract piston, and in so overrunning it not only shut off the steam which was urging the piston to move, but actually readmitted steam on the opposite side of the piston and thereby brought the engine quietly to rest against a steam cushion. He thought that was an arrangement which did away with one of the great objections to the Cornish engine, as applied to variable resistances, namely that it was impossible to tell from one moment to another whether there would be a quiet equable motion or a violent shock. He was glad to hear the testimony of the Author in favour of steam jacketing, especially as during the present session a member, greatly interested in the economic use of steam and highly instructed, had cast grave doubts upon its utility.[1] Such doubts certainly were not in accordance with Mr. Bramwell's experience. He might be permitted to instance the case of an engine which for many years had driven the machinery of a saw mill, and had worked uncommonly well. This engine had a steam-jacket supplied with steam from the boiler direct, the condensed water going back to the boiler in the manner common in the steam-jackets of the Cornish engine; the pipes were small, and after some years they became choked by a deposit of lime. The owner came to him and said he did not

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., p. 8.

know what was the matter with the engine but it would no longer work. It was a double-cylinder engine with very considerable expansion. He could not make much out of it until he put his hand on the jacket return pipe and found it and the jacket quite cold. The pipes were taken down and cleared out; steam was reintroduced into the jacket, and the engine went as well as ever. That was not a case of experiment but an actual occurrence after years of successful work. Looking at the doubt which had lately been cast upon the utility of jacketing he was glad to find the Author speaking of it as a matter of necessity if economical working were desired.

Mr. BALDWIN LATHAM wished to say a few words in favour of the Davey engine, which had been adopted at Croydon upon his recommendation. It was not the first engine on the Davey principle that he had used. It appeared to him that many of those who had spoken of the Cornish or direct-acting engine for waterworks could not have had much acquaintance with it. He had himself had charge both of Cornish and of rotative engines, and he knew that for economy there was no engine that could exceed the ordinary Cornish engine, unless it was the class of engine which the Author had introduced. In the use of the Cornish engine none of the accidents referred to in the course of the discussion had occurred. Every one who employed a Cornish engine adopted safeguards which prevented the occurrence of such calamities. The pair of engines at Croydon, which had been working since 1850, were fitted with a weighted balance valve, so that in the case of a main bursting the engine would still have its load to lift by means of the weighted valve. The larger Cornish engine at Croydon had no such appliance, and it had supplied the town direct with great variations of pressure, but the engine itself to a considerable extent adjusted the difference of pressure, for the reason that if the load was taken off, the engine made so many more strokes per minute, and itself increased the resistances, thus getting over a difficulty which was more mythical than real. The greater economy of the Davey engine consisted in the fact that whereas the Cornish engine was single acting, the other, with the same amount of material, combined in itself twice the power, being double acting. The wonderful piece of mechanism to which Mr. Bramwell had alluded appeared to him almost to apply intellect to the engine, by which the forces of the steam controlled its own action. It was impossible with an engine of that description, with differential gear, to make a false stroke. There were great drawbacks to the use

of rotative engines, especially from an economical point of view. It was impossible to get economy in a pumping engine without the pump barrel being filled with water. He ventured to say that there was hardly a pumping engine of the rotative type in existence without a slip of water through the pumps, in some cases to the extent of at least 25 per cent. Owing to the slow motion of the crank in passing the centre at the starting of the stroke the motion of the piston of the pumps was very slow, and also at the termination of the stroke. In rotative engines pump valves did not open at the commencement of the stroke so rapidly as they did in the direct-acting engine; and at the end of the stroke, the motion still being slow, the valve remained open, so that a portion of the water slipped back. The water lost had been raised by the engine, but as part of it slipped back, so much of the power produced no useful effect. That explained the useful effect of the direct-acting engine as compared with the rotative engine. It was well known that crank engines never raised a quantity of water equal to the capacity of the pump. Taking, however, a fire-engine as a typical example of a direct-acting engine—an engine with a quick impulse—the discharge was often greater than the capacity of the pump barrels. It was the circular motion of the crank which interfered with the filling of the pump in the rotative engine. With regard to the pump valve, there could be no doubt that the smaller the lift the less would be the slip of water back through the pump. When the valve was lifted to its full extent, and delivered the charge of water into the pump barrel, it must take time before the valve could again fall into its seat, and it was during that time that the water was apt to slip back, especially when the engine was beginning to make its return stroke. Therefore the less the lift of the valve, in proportion to the area of its opening, the greater would be the economy in pumping—the greater would be the percentage of the discharge of the pump compared with its capacity. From the results which he had obtained in the working of the Davey engine, especially with regard to the economy of fuel, he was able to state that its use was extremely economical. So far it had shown itself to advantage when working side by side with the Cornish engine, and it therefore commended itself to the attention of those who had charge of pumping machinery. When it was stated that an engine of that kind, with all its appliances, could be made for a cost not exceeding £25 per HP., that sum was sufficiently low to commend itself to the favourable consideration of the engineer.

At the City of Ely Waterworks some experiments were made a few years ago to test the slip of water through the pumps. At that time there were two horizontal engines, each engine driving three pumps from a three-throw crank. The suction pipe of each set of pumps extended about 130 feet in a horizontal direction, and then dipped about 16 feet to the water. The pumps were single acting, and raised the water against a total head of 157 feet. The pump valves were of the hanging flap type, a description of valve noted for its slow action. The amount of slip in these pumps was never less than from 20 to 25 per cent. Under the conditions of working these pumps, one pump would tend to rob the adjoining pump, and thus increase the slip of water. No doubt if these engines had only worked one double acting pump the total slip of water would have been considerably less. A large number of rotative engines were now working pumps from three-throw cranks, and the slip of water in this class of machinery was very great. The substitution therefore of a direct-acting engine in these cases would result in considerable economy.

Mr. G. R. STEPHENSON, Past-President, said it had not been his intention to speak upon the Paper, but after the observations of Mr. Latham he thought the experience of others should be given on the subject. He could quite bear out Mr. Bramwell's statements with regard to the Cornish engine, and the same objections applied to the Boulton and Watt engine. It had been his misfortune to be largely connected with heavy pumping engines at collieries. Thirty-five years ago he was at a pit 175 yards deep where there was one of Boulton and Watt's largest pumping engines, with a beam one half of which was inside the house and the other half outside. There ran along each side of the beam, three large balks of timber one on the top of the other. At the end of the beam was a large cross-beam, which, in case of accident, came down upon the spring beams with a view of saving the cylinder if accident happened to the pumps. He had seen those three balks of timber broken through with ease. In the case of another engine worked by spur-gearing, a spur-wheel broke, and in less than four or five seconds there was not an atom of either the pinion or the large spur-wheel to be seen anywhere about the place. One of the pieces was found at a distance of 200 yards, having been thrown over a large coal-heap. He did not agree in the remark that equal efforts had not been made to expand steam in one cylinder as in two cylinders. Experience had shown that steam could be expanded in one cylinder as economically as in two; but there was a practical objection to it—the enormous

amount of pressure thrown into the cylinder, and on a large piston area, suddenly made the motion so uneven, and the strain brought upon the crank pin and other parts of the engine so great, that nothing could stand it. The valve in the Davey engine appeared to be exceedingly ingenious; and if it would do what the Author had stated, it would be a very great improvement. He had never seen one of the Davey engines at work, and therefore could not speak of it. He had, however, just completed for one of his collieries one of the largest rotative pumping engines ever put up. He had fallen back upon the rotative engine because he had the greatest dread of the beam engine. The main cylinder of the engine was 75 inches, the boiler pressure was 50 lbs. per square inch, the weight of the fly-wheel and crank-shafts 50 tons, the pumps 30 inches, the lift 500 feet; the working barrels were both of the same size, 26 inches. He had not tested the consumption of fuel, but he believed from a rough calculation that it would be an economical engine. He had not experienced the difficulties which the Author appeared to have found in the old-fashioned engines. He had had an engine at work at a colliery for two years without stopping; and he knew of a pumping engine which had been at work since he was four years of age. That did not bear out the idea of the different parts being knocked to pieces. He thought the great secret of pumping engines was simplicity, and so long as that was adhered to, a far better class of engine would be obtained. In the large engine which he had put up the valves were very heavy. The flywheel enabled them to run at a low speed. They could go at 4½ strokes per minute, but they were actually running at 5 or 5½ strokes, and there was no noise of any description, except the snorting of the steam going from the high-pressure to the low-pressure cylinder. He did not believe in the expediency of heavy plates upon the valves, but they might be required if the engine was making 20 strokes per minute. He had certainly never seen and did not believe that 25 per cent. of the water went back through the valves in consequence of slips.

Mr. DAVID THOMSON remarked that his experience with regard to the alleged loss of water in pumps worked by rotative engines was the reverse of that mentioned by Mr. Latham. He had always found that when the buckets and valves were in good order pumps worked by a crank could be depended upon for the full amount of water due to their size and the number of strokes, and in many cases much more. In one case of a pump put up to raise sewage at the Barking sewage farm this was specially tested. It was

supposed that the pump could be used to measure the sewage put upon the land. In order to ascertain whether it could be depended upon for that purpose, an iron tank was made to measure the sewage coming from the pump. It was found that the delivery varied somewhat according to the speed of the pump, but in all cases it was 10 or 15 per cent. more than was due to the size of the pump. There was nothing, however, extraordinary about it. The pump had a considerable length of suction pipe between it and the sewer. At each stroke, the water was put in motion, and when the stroke of the piston was coming to an end, and the motion was getting slower, the water by the impetus acquired kept up its motion and was carried through the valves. Wherever the valves and pistons were in good order he had found that the full quantity of water was delivered by pumps driven by a crank.

Mr. DAVEY, in reply, said the first question raised was with reference to the value of the steam jacket. As that was a question on which there were various opinions he would mention one or two instances which were conclusive in favour of the jacket. Mr. Bramwell referred to an engine which was provided with a steam jacket, and when the jacket was out of use failed to work satisfactorily. A similar case came recently under his own observation, and it was thoroughly conclusive in favour of the jacket. It happened in this way; the engineman was unable to start a large compound pumping engine; the colliery manager was alarmed and telegraphed to him to come down and see if the engine could not be started, as the mine was in danger of being flooded. But before his arrival the engine was working. The reason for its not starting was the non-use of the steam jacket. The engine was direct acting, of the type shown on Plate 5, Fig. 4, and the full load was on the engine. Owing to the peculiar construction of the valve-gear it was possible to admit high-pressure steam into the high-pressure cylinder, then to reverse the gear without moving the engine and throw that steam on to the low-pressure piston, performing the operation that took place in the usual working of the engine. In another instance, without the steam jacket the engine refused to move with the load, but immediately the jacket was put on the engine worked properly, and it was ascertained that it required 10 lbs. higher boiler pressure to work satisfactorily without the jacket than it did with the jacket. At Croydon he had questioned the men as to their experience with the jacket, and one of them gave his experience very forcibly; he said the engine could not be worked without a jacket. The reason was obvious. Without the jacket there must

be a certain amount of condensation of steam and accumulation of water in the low-pressure cylinder, unless the valves were kept open to drain away that water as fast as it was formed. If the drain valves were kept closed the water would accumulate, and a large portion of the steam on entering the low-pressure cylinder would be condensed.

With reference to the percentage of slip with pumps driven by rotative engines, he might say, that slip depended chiefly on the construction of the valves; with rotative engines it was common to use short-stroke pumps and then the slip must be a larger percentage of the total capacity of the pump than if the pump had a long stroke. That was one reason why three-throw pumps were often found to give so much slip. It was because the stroke of the pump was short that the amount of slip formed a large percentage of the total capacity of the pump. It was not unusual to meet with slip amounting to as much as 20 or 25 per cent. though not under ordinary circumstances. He had met with it as high as 50 per cent. under extraordinary circumstances, but with long-stroke pumps and double-beat pump-valves the slip, in a well-made pump, was not more than 5 or 7 per cent., and sometimes much less than that. With flags and butterfly-valves which were so sluggish in action the slip was considerable. He had tested two engines made from precisely the same patterns and the pumps from precisely the same drawings, the one provided with double-beat valves and the other with the ordinary butterfly valves. The water was accurately measured and the engines driven at the same speed. The slip given in the case of the butterfly valves was $7\frac{1}{2}$ per cent. more than that of the double-beat valves, and the experiment was repeated over and over again with the same result.

In regard to the comparative advantages of the direct-acting and rotative engines for pumping purposes he would remark that the motion of a long stroke, direct-acting engine was more suitable to pumping and better adapted to a high efficiency of the pumps. The direct-acting engine acquired its maximum speed earlier and maintained a quick motion longer, and the valves fell to their seats not when the engine was moving but when it was at rest. That accounted for the difference in delivery found sometimes with direct-acting and rotative engines; it was because the pump valves fell to their seats when there was no motion taking place on the engine or the pump plunger. In the majority of cases, the direct-acting pump delivered more than the rotative pump, but not necessarily so; because if the valves on the pump of the rotative engine could be brought to their seats before the

return of the stroke, or immediately the crank was on the centre, there could be no slip. That was not always the case, but it was so when everything was perfect.

In the Paper he had stated that geared engines were not suitable for heavy pumping or deep mines, and that was borne out by what Mr. Stephenson had said in reference to the breaking down of a geared engine applied for that purpose. With respect to the application of the direct-acting engine to heavy pumping, Mr. Stephenson had endeavoured to show that the rotative engine was suitable. On examination it would be found that the rotative engine for such purposes had serious drawbacks; for a mine pumping engine to be perfect, it should be capable of working either at its maximum speed, or at a speed as low as one stroke per minute. In the Paper the dimensions and weight of a direct-acting engine and pumps were given. That engine was capable of working at a speed varying from one stroke in two minutes up to eight or ten strokes per minute, with 1,400 feet of 16-inch spear rods hanging to the quadrant. The height of the lift in this case was 700 feet, the plungers were 20 inches in diameter, and the length of stroke was 10 feet. Mr. Stephenson's rotative engine had pumps 30 inches in diameter. The pumps were single-acting from the bottom, that was, they were not twin sets. In the case to which he referred they were twin sets from the bottom, so that there were two 20-inch plungers lifting from the bottom of the mine, or equivalent to one 33-inch pump from the bottom. That engine weighed, including the holding down bolts and connecting-rod, 66 tons, while the weight of the fly-wheel alone in the rotative engine was 50 tons. The weight of the fly-wheel, shaft cranks, and plummer-blocks was about the same as this direct-acting engine, which pumped from the depth of 700 feet as against 500 feet, with pumps of a little larger capacity. Of course he did not contend that a greater power or larger pumps could not be put on the rotative engine; but could a rotative engine be worked at a moderate speed without an enormous fly-wheel, connecting rods, and apparatus, which were unnecessary in the other case? To drive an engine of that size, at the rate of one stroke per minute would require a fly-wheel of unprecedented weight. Pitmen liked an engine to make a brisk stroke, so that the greatest efficiency might be got out of the pumps. With the rotative engine working at low speed the pumps were always creeping, and a little leakage then meant a large percentage of the power given out by the engine, because there was such a long time for that leakage to take place. In the case of the direct-acting engine the piston

speed was just the same, whether it was making one stroke a minute or eight strokes; it made the stroke briskly, the valves acted briskly, and reduced the percentage of leakage, and by that means the greatest efficiency was got out of the pumps. If it could be shown that an engine of half the weight of a rotative engine, could do the same work and could be worked as economically and safely, he did not see why the simpler, the cheaper, and the lighter engine should not be adopted.

Mr. STEPHENSON, Past-President, said the large engine he had referred to had to pump water from mines considerably deeper than those sunk at the present moment. It was expected that the engine would be able to pump from seams 150 or 200 feet lower than those at present working. It was not constructed simply for the purpose of lifting water 500 feet, but was twice the size required at the present moment. An engine had been provided that he expected would dry the lower seams of the colliery for sixty years to come.

Mr. W. H. BARLOW, Vice-President, observed that although the subject was one which might be considered rather a technicality of engineering, yet it was of great importance. During a recent trip to America, he observed that great importance was attached to direct-acting pumps, judging from the large number exhibited at the Philadelphia Exhibition, compared with pumps of other classes. Of course there were rotative and other pumps in that exhibition, but the direct-acting pumps were in much greater numbers.

Mr. EMERSON BAINBRIDGE expressed, through the Secretary, his regret that the Paper did not deal more with the actual practical economy of the compound condensing direct-acting engines designed by the Author, as compared with the ordinary Cornish engine, not only with regard to the question of fuel and stores, but also with respect to the important matter of valves, clacks, &c. To a colliery, a small difference between the consumption of fuel, by one description of engine and another, was really of less moment than the importance of having machinery unlikely to break down, and not constantly needing repairs; and it was in this respect that he had found the advantages of engines like those to which the Author specially referred. Pumps worked by several sets of spears, unless exceptionally well arranged as to the velocity of the stroke, were always liable to accidents from the breakage of spears, or of the bolts fastening the spears together; or to the breakage of the Y piece which attached the spears to the bucket-door piece. Direct-acting engines erected

underground overcame most of these difficulties. The statement by the Author as to the undesirability of placing pumping engines at the bottom of a pit owing to the danger of flooding, certainly appeared condemnatory of this mode of pumping; but it was nevertheless correct, and when the system was adopted it was important to have either a duplicate engine below or a duplicate engine on the surface working with spears; or arrangements in readiness for drawing water by means of cages. Having three of the largest of the Author's engines at work, under conditions unfavourable to the engines, he had been able to examine the effect of impure water on them. A slight grooving of the ram had been destructive to the large glands, which corresponded to the buckets used in "lifting" sets, and a slight grooving in the air pump had also tended to reduce the vacuum. To work at their best economy these engines should be supplied with a higher pressure of steam than could generally be conveniently obtained underground. His chief difficulty had been with regard to valves. Cast-iron valves had been spoiled in a few days. These were replaced by brass valves, which in a few weeks required refacing, it being found both with regard to the iron and the brass, that the slightest "streak" or inequality on the face of the valve which allowed water to pass, resulted, owing to the pressure and impurity of the water, in its eating away passages through the valves, soon rendering them almost useless. These difficulties led to the adoption of the combined hippopotamus hide and brass valves, which at present were answering well. He was also trying, as an experiment, one valve with both the top and bottom beats of hide. In machines which entailed so much working cost as pumping engines, the annual expense not only of fuel and stores, but of accidents, and all repairs, could be the only true test of economy.

Mr. F. E. DUCKHAM observed, through the Secretary, that he had always been impressed with the ponderous and somewhat complicated character of the mining machinery in Cornwall, and the small visible result of its action. The Author had expressed his ideas in saying that, in several Cornish mines, hundreds of tons, 872 tons in one instance, had to be put in motion, and brought to rest at each stroke, to raise to the surface probably less than 1 ton of water. He had recently adopted a simple design of direct-acting pump for the production of hydraulic power, equivalent to raising water in one lift to a height of 1,600 feet. It had worked satisfactorily, and he believed that such an engine compounded and proportioned to local requirements would be both economical and efficient in mines and in waterworks. The engine had two steam

cylinders 24 inches in diameter, with a length of stroke of 48 inches, and four pumps having plain cast-iron plungers 5½ inches in diameter, connected direct to the piston rods, which were prolonged for this purpose through each cylinder cover; "machined" parts were as few as possible. The cylinders and pumps were interchangeable. The cost of this engine, fixed with pipes, valves, tank, &c., but without masonry, was £6 per effective HP. There were instances in which such an engine could not be conveniently placed within suction distances of the water to be raised. In those cases he would suggest an extension of the use of hydraulic power, to which the Author had referred. An engine of this class could be placed almost anywhere. He led the power down the mine by unobtrusive pipes. One or more hydraulic pumps, the counterparts perhaps of the engine, could be connected with it either in the shaft or in any of the workings; and the water could be brought to the surface by a common delivery. As to valves for high-lift pumps, he had recently seen dismantled an engine which had been working almost continuously under 1,600 feet pressure for nine years. The valves and seats were of hard gun metal of the common "mitre" type, with closing springs of indiarubber washers. They had not been touched during the period named, and were practically as good as when new. The water passed through them was from the river Thames.