

## Correspondence.

Mr. Clark     Mr. G. M. CLARK observed that there was sometimes confusion between the efficiency of an engine and the efficiency of the steam cycle of supply. The efficiency of a practical engine was a function of the ratio of expansion and diminished with the increase of this ratio. That was to say, for the same type of engine it was an easier matter to obtain an efficient engine, as measured by the ratio of work produced to available energy, with a low ratio than with a high one. Thus, to increase the efficiency of an engine it was not correct to increase the pressure and superheat and improve the vacuum; the heat-drop must be reduced so as to reduce the ratio of expansion. With triple-expansion engines working from, say, 200 lbs. per square inch pressure to a vacuum of 2 lbs. per square inch, the ratio of expansion was 100 to 1, but with a turbine working from 350 lbs. to 0.7 lb. per square inch the ratio was 500 to 1. Hence it was easier to get a high efficiency, say 70 per cent., for the engine than it was to get, say, 65 per cent., for the turbine; and the efficiency of the engine would be improved by making the steam conditions worse. At the same time the engine gave a smaller output, and it was the weight-output factor, or the price-output factor, that controlled the practical efficiency. In a cycle of supply it was the efficiency of supply that was improved by raising the pressure and superheat and improving the vacuum. This efficiency of supply (a term that was not used as much as it might be) was the ratio of the available energy in the steam to the total heat reckoned from the water state at the temperature of the vacuum. The heat-drop was shown on the Mollier diagram and was controlled by the difference of temperature in the boiler and in the condenser.

Neither the Mollier diagram nor the  $T\phi$  diagram could give the efficiency of the engine, but from them could be found the efficiency of supply of the cycle used. This on the  $T\phi$  diagram was the ratio of the area  $H_a$  above the condenser temperature line  $T_2$  to the whole area,  $H_s$ , of the diagram that showed the successive state-points for the steam cycle used. The area below the line of  $T_2$  was the heat

rejected,  $H_r$ . The efficiency of supply was the ratio  $H_u/H_s$  which was  $(H_s - H_r)/H_s$ , or  $1 - H_r/H_s$ . But  $H_r$  was equal to  $T_2\phi$ , where  $\phi$  was the increase of entropy, so that the efficiency was

$$1 - T_2\phi/H_s, \text{ or } 1 - T_2/(H_s/\phi).$$

But the last expression  $H_s/\phi$  was the area of the diagram divided by its length  $\phi$ , and on the analogy of the  $PV$  diagram in which the area divided by the length was the mean effective pressure, so on the  $T\phi$  diagram the mean effective temperature was  $T_m$ , and the efficiency of the cycle of supply was  $1 - T_2/T_m$ .

If an example were worked out for a superheating cycle, it would be seen how little the mean effective temperature was raised and how small a primary influence superheating had upon the efficiency of supply. There were, however, secondary effects on the efficiency of use, such as the dryness of the walls in a reciprocating set and the postponement farther down the blading of the dew-point in a turbine, that were of greater value. As touching this value of superheating, it was often confused with the gain on the engine when the boiler was left out, but it must be considered with the boiler taken in, as coal had to be burned to superheat the steam, and, further, when this was done, the entropy was increased and the theoretical gain became very small indeed. For ordinary working-pressures about 200 lbs. per square inch absolute  $100^\circ$  F. would give on the cycle of supply a gain of 5 per cent., but it would take 3 per cent. to heat the steam from saturation to the total temperature, so that on the cycle the gain would be 2 per cent. only. Taking the feed-water temperature to the boilers as that of the vacuum in the engine exhaust, (1) the efficiency of production as given by the boiler was the ratio of the total heat in the steam, reckoned from this level, to the heat of combustion of the fuel; (2) the efficiency of supply as given by the condenser was the ratio of the heat available to the total heat in the steam; and (3) the efficiency of use as given by the engine was the ratio of the work done to the heat available. The overall efficiency was the running product of the three and was the ratio of the work done to the heat of the fuel.

The engine did not make the heat-fall any more than a water-wheel made the waterfall, and the cycle of energy operation could be looked upon as being boiler-condenser-engine instead of following the cycle of the matter as boiler-engine-condenser. From an improved cycle of supply an engine was given a greater available energy to operate upon, but the practical difficulty lay in making

Mr. Clark. an engine which could operate on this larger supply with the same efficiency that it could on the smaller. As the ratio of expansion increased it became necessary to change the type of engine in order to maintain the efficiency, and just as simple and compound engines had their limits of efficiency, so, too, had the triples, and the type must be changed to turbines when the ratio of expansion was still further increased. The term ratio of expansion might be either the ratio of decompression  $p_1/p_2$ , or the ratio of increase in volume  $V_2/V_1$ , and a comparison could be made for an equal ratio of expansion on either basis. For example, with steam at 350 lbs. per square inch absolute exhausting into a vacuum of 3.5 lbs. per square inch, the ratio of expansion  $p_1/p_2$  was 100 to 1, and this was the same as for a cycle operating between 200 lbs. per square inch and 2 lbs. per square inch. If in the former case the steam was superheated to 600° F. and in the latter to 580° F., then the ratio of expansion would also be the same for the two cases when defined as the change in volume  $V_2/V_1$ .

The comparison of these two sets of conditions was:—

|  | (A)   | (B)   |
|--|-------|-------|
| (1) Steam-pressure, . . . . . lbs. per sq. in. absolute    | 350   | 200   |
| (2) Temperature of saturated steam . . . . . °F            | 432   | 382   |
| (3) Final superheated temperature . . . . . °F             | 600   | 580   |
| (4) Degrees of superheat . . . . . °F                      | 168   | 198   |
| (5) Back-pressure, . . . . . lbs. per sq. in. absolute     | 3.5   | 2.0   |
| (6) Ratio of expansion (1)/(5) . . . . .                   | 100   | 100   |
| (7) Heat for steam-production, . . . B.Th.U. per lb.       | 1,203 | 1,225 |
| (8) Available heat . . . . . "                             | 352   | 348   |
| (9) Heat rejected to condenser. . . . . "                  | 851   | 877   |
| (10) Efficiency of supply (8)/(7) . . . . . per cent.      | 29.3  | 28.4  |
| (11) Reciprocal of (10) . . . . .                          | 3.42  | 3.52  |
| (12) Ratio of A to B in (11) . . . . . per cent.           | 97    | —     |
| (13) Specific volume at inlet, . . . . . cubic ft. per lb. | 1.72  | 3.01  |
| (14) Specific volume at outlet . . . . . "                 | 85    | 148   |
| (15) Ratio of expansion (14)/(13) . . . . . per cent.      | 49.4  | 49.2  |

Thus for two sets of conditions chosen so as to make the ratio of expansion the same in pressure (6) and in volume (15) the advantage to the extent of 3 per cent. (12) lay in the use of higher pressures in production and supply of the steam, and there would be further advantages in use in the engine.

Mr. Fairley. Mr. WILLIAM FAIRLEY observed that the Author, in making comparisons (p. 226), stated that "Town-gas engines are free from these objections, but the cost of their fuel is generally prohibitive," while on p. 227, in dealing with electrically-driven pumps, he raised

no objections to the fuel-costs ; it would be interesting to know Mr. Fairley. the grounds for thus dismissing town-gas-driven plant. Mr. Fairley agreed with the Author that with large units steam was invariably the most economical in fuel-cost, but he had generally found town-gas plant more economical in fuel-costs than electrically-driven plant. At a station on the Thames with units of 6 to 10 million gallons per day the fuel-cost for town-gas plant connected by gearing to centrifugal pumps was 0·35*d.* per 1,000 gallons lifted ; in the same station with electrically-driven motors, direct coupled to centrifugal pumps, the cost was 0·39*d.* per 1,000 gallons lifted. The lift in both cases was less than 40 feet ; the price of gas was 4*s.* per 1,000 cubic feet, and electric power 1·14*d.* per unit.

Mr. G. E. HIDER observed that the Paper constituted one of the Mr. Hider. very few attempts to analyse the thermal action of a high-class reciprocating engine. It was remarkable that many classical experiments had been carried out on engines of bad design, which rendered the alleged results open to grave doubt because many factors, other than those it was sought to investigate, were of unknown magnitude, and wrong assumptions might easily have crept in.

As he had recently stated in a Paper read before the South Wales Branch of the Institution of Mechanical Engineers criticizing the uniflow engine, the history of the reciprocating engine was remarkable. First there had been the single cylinder engine using very wet steam ; then the steam was superheated to do away with condensation losses ; next, due to lubrication difficulties the superheaters were scrapped and the multiplication of cylinders was resorted to ; then superheaters were reintroduced ; and finally the uniflow engine reintroduced the single-cylinder engine. These were the steps in the evolution of the reciprocating engine, and he considered justified the conclusion that there had been much confusion of thought.

He was interested to find that the Author produced results showing that for powers of about 600 I.H.P. better results might be obtained with counterflow engines than with uniflow engines. The Author, in dealing with improvements and developments, also referred to the steam-turbine and the uniflow engine, and stated that, with regard to the heat-exchange between metal and steam the steam-turbine, and to a very much less extent the uniflow type, were superior to the counterflow type.

He questioned whether the heat-exchange in a uniflow engine was less than in a well-designed counterflow engine : it

Mr. Hider. certainly was difficult to find any evidence in practice, and it was equally difficult to explain why condensation would be very much less in that type of engine, because the temperature and pressure of the steam were undergoing cyclical variations which were sensibly uniform throughout the whole steam space; the turbine was the only unit in which there was no reason for alternate give and take of heat at any point between admission and exhaust, because each part of the metal was continually in contact with steam of unvarying temperature. The very slight advantage in steam-economy of the uniflow engine could be more than accounted for by the elimination of receiver losses and by the ideal arrangement of exhaust allowing instantaneous reduction to condenser pressure; these facts threw grave doubt on the claims made that condensation losses were less in this type of engine. The Paper showed that at last the design of the reciprocating engine was receiving scientific consideration. The combination of diagrams in Fig. 3, Plate 4, showed that full consideration had been given to the question of receiver losses: the complete agreement between the back-pressure line of one diagram and the initial pressure in the following cylinder was remarkable, and showed that the Author had his finger on one of the vital weaknesses of multi-cylinder engines. Mr. Hider assumed that that was due to the use of Corliss valves, and the only doubt was whether that type of valve remained permanently tight or whether there would not be a gradual falling-away as the valves began to wear. It was interesting to note that better results were obtained when the low-pressure jacket was cut out, and that clearances were very small and the adjustment of compression very accurately arranged, the latter being another vital phase of engine-design, usually neglected, but which constituted one of the essential factors contributing to the economy of the uniflow engine. He wondered whether the extreme jacketing and reheating which was arranged for was justified, and whether a consumption of 9.92 lbs. of steam per indicated horse-power-hour could not be obtained by less expensive arrangements. With regard to incomplete expansion, he had put into operation in conjunction with Messrs. Davey, Paxman & Company, Ltd., of Colchester a method of effectually reducing this loss by by-passing steam towards the end of expansion to the other side of the piston to fill up the clearance spaces. This, of course, was merely a partial solution, but many extensions of the principle were possible. If the Author would search further into the weaknesses of the uniflow engine, he would discover the essential points

in the usual design of that engine which led to economy, namely, Mr. Hider. the hot end, small clearances, and ideal exhaust, in which the potential energy of the steam at release was converted into kinetic energy; and if he embodied those features in a counterflow engine, he would be able to eliminate many of the thermal complications which the arrangement at Lea Bridge possessed, without sacrificing economy. Either three high-pressure cylinders designed with hot ends, small clearances, and rational exhausts, or one high-pressure cylinder dealing with the upper part of the pressure-range and exhausting into two low-pressure cylinders, would give very low steam-consumption, especially if the by-pass principle were embodied, or some modifications of it which allowed of the utilization of the heat contained in the steam at the later part of expansion, just before release. Finally, it was interesting to read a Paper which did something to call a halt to the "uniflow" worship which appeared to be the fashion nowadays, and for which there was no justification except that in the past British engine-builders had violated many first principles and had thus contributed to the apparent success of the uniflow engine, which clearly owed its small advantages in steam-consumption to features apart from the steam-flow arrangements.

Mr. T. D. KEY remarked that in the case of the Lea Bridge engine Mr. Key. the losses occurring between the engine stop-valve and the condenser appeared to have been reduced, when compared with the very similar type of engine under his charge and belonging to the Alexandria Water Company, by reduced cylinder-clearances, more accurate distribution of the steam in the cylinders, and better design of the steam-passages and receivers. He thought the direction in which still further economies could best be obtained was in the use of higher initial steam-pressures at moderate superheat. In connection with the Author's estimate of the cost per water horse-power of other types of pumping plant, Mr. Key had a few comparative figures, showing the difference in working-costs of steam-driven pumps of the Lea Bridge type, as against reciprocating pumps driven by Diesel engines through gearing. At the Alexandria Water Company's Rond-Point works were installed six pumping-sets of the Lea Bridge type and two sets of similar reciprocating pumps driven by Diesel engines through gearing. All those pumps drew water from the same source and delivered into the same rising mains; the steam and the Diesel-driven plants were, however, housed in separate buildings and each had its own staff of engine-drivers and assistants. Pumping was continuous throughout the 24 hours, the staffs being divided

Mr. Key. into three 8-hour shifts. Careful records of the working-costs had been kept over a number of years, and the following was a summary for the two years 1923-1924 :—

|   | Steam Plant.  | Diesel-driven Plant. |
|---|---------------|----------------------|
| Total work done : million foot-tons             | 2,782·68      | 2,393·34             |
| Average price of fuel per ton . .               | £2 15s. 2d.   | £5 8s. 7½d.          |
| Cost per million foot-tons of work done :—      |               |                      |
|   | £             | £                    |
| Fuel . . . . .                                  | 5·185         | 1·597                |
| Stores . . . . .                                | 0·071         | 0·192                |
| Maintenance, repairs, and spare parts . . . . . | 0·183         | 0·323                |
| Wages . . . . .                                 | 1·335         | 0·182                |
| Total . . . . .                                 | <u>£6·774</u> | <u>£2·294</u>        |

The Lea Bridge engine on the 9 hours test used about 0·61 ton of coal per million foot-tons of work done, or just about a quarter of the fuel-consumption given above. Taking the official test figures of one of the steam-engines at Rond-Point as a basis of comparison, the fuel-consumption should not exceed 0·9 ton of coal per million foot-tons of work done, and yet from the figures given above for the 2 years' working, the coal actually used was more than twice that quantity. The difference seemed enormous, and yet after careful inquiry he was by no means convinced that any very different result could be obtained under actual working conditions. The principal causes leading to higher fuel-consumption than that given on the basis of test figures were : (1) Intermittent working, with heat-losses every time the engines were started or stopped ; (2) banking fires in the boilers during periods of low pumping output ; and (3) blowing down, cleaning, and again raising steam in the boilers. Those losses were inevitable, and in a plant where the units were many and comparatively small, their importance was correspondingly great. There were also other losses, which could be avoided, but whose importance was generally greater than the above, namely : bad stoking, leaky drains and steam-taps, valve-gear out of adjustment, and leakage past valves and pistons. To obviate those losses a highly trained and keen engineer should be on each shift, and such men could not economically be employed on a small plant. The greater part of the discrepancy between test figures and those actually obtained in running practice was mainly due to the inferior quality of the coal. The calorific value of the coal used in the Lea Bridge test was 15,000 B.Th.U. per pound. Coal of that quality was unobtainable in Alexandria. A nearer approximation to the mean average calorific value of the best Welsh coal obtainable

there was about 9,500 B.Th.U. per pound; and a large portion Mr. Key. of the coal sold for steam-raising purposes was of even lower calorific value. He appreciated the fact that it was unfair to debit a steam-engine with anything except the heat supplied to it, but at the same time it should never be forgotten that the steam-user had to buy and pay for coal by weight and not on its heat value.

The greatest defect of the Diesel engine used for pumping purposes was its liability to cause awkward situations. A very small fault often necessitated an engine of this class being brought to a standstill at a minute's notice and before any preparations could be made to put additional pumps into service; and if, as at Rond-Point works, the rate of pumping depended largely upon the number of filters at work, efficient arrangements must be made to throw filters out of action immediately an unexpected stoppage took place. Apart from this inconvenience, however, it appeared that the advantages were on the side of the internal-combustion engine. With that class of machine the losses occasioned by bad stoking were entirely eliminated, and it might almost be said that the fuel-consumption was independent of the engine-room staff. It was true that adjustment of all moving parts in the engine must be more carefully attended to than in a steam-engine, but that in reality was an advantage, in that small defects must be immediately remedied, whereas in a steam-plant the temptation was always to put off the evil hour and keep the engine running, with consequent loss of efficiency. One of the disadvantages attributed by the Author to the use of oil-driven pumping-plant was "less flexibility as regards speed." That was a point which should not be passed over without comment—at any rate as far as the Diesel engine was concerned. All the Diesel engines under Mr. Key's charge were fitted with a speed-regulating device whereby the speed of the engines would be immediately and easily reduced from their rated speed of 250 revolutions per minute to 160 r.p.m., and any engine-maker would fit that small accessory at a cost of a few pounds. His considered opinion was that when Diesel engines were to be used for waterworks purposes it would be better if the engine-maker, even at the risk of unfavourably affecting his price per horse-power, reduced the speed of the engine to say 10 per cent. below the normal rating for its type. The price per horse-power was increased, but the client would benefit enormously by freedom from stoppages and in the reduced cost of renewals.

Mr. ARNOLD MAUDE observed that the high efficiency of the Mr. Maude. ram pumps and the excellent way in which the low-speed steam-

Mr. Maude. engine was adapted to drive them with very small transmission losses certainly placed this combination in an extremely strong position, though the schedule (Table IV), would have shown centrifugal pumps in a somewhat better light than it did, if building and foundation costs were allowed for and also if a longer life than 10 years were assumed for them. There certainly were many centrifugal pumps which had worked on heads of the order in question for well over 10 years, the renewals, if any, being confined to inexpensive sleeves and bushes. Of course, steam-turbines could show a similar record, though there had sometimes been considerable deterioration of the blading—a trouble which should practically disappear with the adoption of stainless steel. If the wide adoption of turbo gear drives for powers of the order in question had been too recent to make it possible to point to many such gears of 10 years life, examination of gears that had run for 6 or 7 years certainly did not suggest a 10-year limit. The fact that the largest individual loss in the Lea Bridge engine was the toe of the low-pressure diagram suggested the possibility of a gain by substituting a turbine, driving a centrifugal pump, for the low-pressure cylinder, with a corresponding reduction in the ram pumps. An approximate result was—

Total pump horse-power, Lea Bridge test, 530  
 „ indicated horse-power „ „ 566, of which 184 horse-power  
 was due to the low-pressure cylinder.

The pump horse-power due to the low-pressure cylinder was assumed to be  $184 \times 530/566 = 172$  HP. (this was not quite fair to the turbine, since the high-pressure end of the reciprocating engine was the more efficient). For simplicity, taking steam at point N, Fig. 4, Plate 4, allowing for a drop to turbine to, say, 10 inches vacuum and  $20^\circ$  superheat, and adopting a condenser vacuum of 28.75 inches which, with ample cooling water, should be possible except in very hot weather, the heat-drop was 174 B.Th.U. With an efficiency of 79 per cent. for the pump and 66 per cent. for the turbine and gear, the consumption worked out at 28 lbs. per pump horse-power-hour, so that the 4,967 lbs. of steam which passed through the engine-cylinders should yield 177.5 pump horse-power from the turbo pump, that was, about 3 per cent. more than the 172 HP. assumed to be due to the low-pressure cylinder. It would seem worth consideration, therefore, whether possible savings in capital cost, particularly if building and foundation costs were allowed for, would not make this an attractive combination. The diversity of

the plant might be considered to be a disadvantage; on the other Mr. Maude. hand, in an emergency, either part of the plant could be run alone, so reducing need for stand-by plant. The combination of reciprocating engines and exhaust-steam turbines had, of course, been successfully used in electric power-stations and for ship-propulsion.

Mr. Mawson. Mr. J. H. MAWSON remarked that there were one or two points in the trial figures (Tables II and III) upon which comment might be made. The difference between the quantity of feed-water to the boilers and the steam used by the engine was 1,012 lbs. per hour, or 18 per cent. of the steam used by the engine. That difference was ascribed to the consumption of boiler feed-pumps and other auxiliaries. Could it not have been reduced by fitting the boiler feed-pumps to the main engine? The temperature of the feed-water entering the boilers appeared to be rather low, and the saving due to the economizer was only about 5 per cent. He would be glad to know if any reason could be given for that moderate result. It was to be regretted that no meter had been available to measure the water pumped. The Author considered that the slip probably did not exceed 1 per cent., but it was doubtful whether the evidence of the pump indicator-diagrams could be accepted on this point. Leakage past the valves could occur which would not be apparent on the diagram. His experience was that slip was generally more than was anticipated, and that a meter was very desirable, both for the duty trial and afterwards as a regular check on the pump efficiency. With regard to the analysis of losses in the cycle, the most serious, and apparently the only one which could be attacked with much hope of success, was the 10-per-cent. loss through the cutting-off of the toe of the low-pressure diagram. In that connection the Author stated that he was experimenting with a new condenser, but, presumably, any result achieved thereby would only be to widen the limits between which the engine worked, by improving the vacuum. More complete expansion (using the toe of the l.-p. diagram) could only be obtained by greater cylinder-capacity, that was, by using larger cylinders with earlier cut off throughout, or by adding a fourth cylinder. As the Author remarked, much more was to be gained by increasing initial pressure, and it appeared clear that pressures would increase until the point was reached where further gain in thermal efficiency was offset by the increasing practical mechanical difficulties incidental to the higher temperatures. It was difficult to see how this limiting point could be found, except by some sort of trial-and-error process. The comparison of various types of pumping-plant given in Table IV

Mr. Lawson. was doubtless reasonably accurate as far as it went, but it covered only a small part of the ground which must be reviewed when a choice as to type of pumping-plant was to be made. The number of types available was so large, and local conditions influenced the choice to such an extent, that every separate scheme must be considered on its own merits. It was safe to say, however, that under suitable conditions there was no type of plant which would prove more reliable or more economical in fuel than that described in the Paper.

The Author. The AUTHOR, in reply to the Discussion and Correspondence, remarked that the main point of criticism, raised by several speakers, was that he had taken, in his comparisons of running-costs, much too high a price for electric power. Electric pumping reminded him of Savery's engine as applied to the driving of machinery. That engine pumped water, and the water ran over a water-wheel and worked various appliances in his workshop. An electric drive in which a steam-engine pumped alternating current through a main, and that alternating current worked a motor driving a pump, had distinct points of analogy. It might be that power could, in many places, be obtained at a cheaper rate than 1*d.* per unit, and many authorities stated that its price was likely to be reduced in the future. According to the Electricity Commissioners the average price over the whole country might be expected by 1940 to be reduced to 1*d.* per unit (or, in the view of the Committee which considered Sir John Snell's report, 0·844*d.* by that date). Who then could reasonably quarrel with the round figure of 1*d.* being taken as a basis of general comparison? The figure was further justified by the Report of the Weir Committee, who found that the average price of power over the United Kingdom in 1923 was 2·047*d.* per unit. When it was realized that most pumping-stations had to be placed in remote positions, it would seem that, if anything, the figure actually taken erred on the low side, in spite of the advantageous rates offered by many power-stations to customers whose load-factor was high. The matter, however, was clinched by the consideration that the generation of power at the pump crossheads of a plant such as that described was, in general, more efficient, reckoned on steam-consumption, than at the coupling of a motor driven even from a super power-station. In the calculation the power-station mean consumption was taken at 11 lbs. of steam per unit generated. Of the units generated, 10·4 per cent. was assumed to be used in station auxiliaries; of the busbar power 5 per cent. was assumed to be lost in transformation and transmission, and the

efficiency of the motor was taken at 92 per cent. This involved a steam-consumption (generally of very much higher grade steam than that required by the pumping-engine) of 10·5 lbs. per horse-power-hour, as against say  $0\cdot94 \times 10\cdot6$ , or 9·97 lbs. for the Lea Bridge engine at the pump crossheads. If then an electric power-station and distributing plant, which involved a very large amount of capital, used as much fuel per brake horse-power as the steam-driven pump used per crosshead horse-power, it was, in general, impossible for the former to compete in the long run. Two speakers had quoted the surprisingly low rates for high load-factor power now available in the districts surrounding the largest power-stations. The Author, however, was of opinion that such rates could hardly be taken as typical. Moreover, in fairness to the steam plant, it should be remembered that the price of coal for the purposes of Table IV was taken at £1 per ton, whereas in localities where the cheapest power was available coal of good thermal value cost little more than half that amount. But even comparing power at  $\frac{3}{4}d.$  and coal at £1 per ton in a station such as Lea Bridge, the electric power would cost about  $1\frac{1}{2}$  to  $2\frac{1}{2}$  times as much as the coal.

He did not at all agree with Mr. Thwaites's contention that he had taken too high boiler-efficiencies. At Lea Bridge the efficiency of the steam-raising plant was 75·4 per cent., and efficiencies in large waterworks plants rarely fell below 70 per cent. Nor, as mentioned above, did he think 23s. a fair price for coal in districts of cheap electric power. But taking Mr. Thwaites's amended figures of combined capital and fuel costs per water horse-power-hour for steam plant, those figures referred only to examples 8, 9, 10, 11, and 12 of Table IV (p. 237). Of these Nos. 9, 10, and 12 were not of the Lea Bridge type, while No. 8, though of that type, included borehole pumps and was of comparatively small size. No. 11 was therefore the only example of the type described in the Paper, and even Mr. Thwaites's amended figure for this was only 0·34*d.* per water horse-power-hour. With regard to the electrically-driven plants, the last on the list, the only one which could compare with the above figures had a very exceptionally high lift and, though included in the comparative list as the most efficient electric waterworks plant known to the Author, worked under conditions hardly comparable with those at Lea Bridge. Nevertheless Mr. Thwaites's figures undoubtedly showed that under certain circumstances electric driving could compete with certain forms of steam driving, though unlikely seriously to menace the Lea Bridge type in its own domain.

Regarding Mr. Smith's comparison of the Lea Bridge type with

The Author.

The Author. an electrically-driven set of the same capacity, it should be remembered that the speed of the pumps was determined by the size of the pumps themselves, not by the driving agent. The steam-engine at Lea Bridge could easily have been made to run more quickly—and in fact would then have been both cheaper and more efficient; but the pumps, however driven, must for purposes of fair comparison be limited to their actual speed. Moreover, the power costs deduced by Mr. Smith appeared to be based on an overall (motor, gearing, and pump) efficiency of 89 per cent., which was unusually high.

With regard to the initial cost of foundations and buildings and to the additional running-costs due to extra labour, rates, and taxes, those were undoubtedly factors which militated against the steam plant as compared with electric driving. Taking current at 0·6*d.* per unit, and the overall efficiency of the electrically-driven plant at 85 per cent., he had calculated the excess which could be spent on the foundations of a plant of the size of that at Lea Bridge, so as to bring the total fuel and capital costs up to the same amount as the combined power and capital costs of the corresponding electrically-driven plant. This amount, on the assumptions of Table IV, was just less than £80,000, or, allowing also three additional shifts, each of three stokers and three cleaners at £3 a week, about £60,000, sums far exceeding the additional building costs. The above calculation did not take into account rates and taxes. Even taking the figure of 0·4*d.* per unit, the corresponding excess expenditures allowable would be about £35,000 and £15,000 respectively.

Mr. Honeysett's estimates of the number of running-hours per year necessary to justify the expense of installing a triple-expansion pumping-engine were exceedingly interesting, and the Author would like to thank him for showing up the matter in that new light.

He quite appreciated Mr. Fairley's objection to his somewhat hasty dismissal of town gas. He had never intended to suggest that town gas could not compete with electric driving.

Regarding the objection that many of the figures in Table IV were based not on actual tests but on estimated efficiencies, that was done because only in very rare cases were two plants of different types to be found working under the same conditions. It had therefore been thought better to contrast projected installations which were strictly comparable than to attempt to make all the allowances necessary to bring into accord the varying conditions of actual tested plants. In that connection it was of interest to note that the

consumption of coal of the Lea Bridge station over a period The Author. in actual working was 1.87 lb. per pump horse-power-hour. Since this included a compound engine besides the triple, it would appear that the 10 per cent. and 20 per cent. allowance was in this case ample.

Mr. Key's figures of relative costs at Alexandria of steam and Diesel pumping were of great interest. The steam-engines in this case appeared to be much less efficient than that at Lea Bridge, while the coal appeared to be much dearer and of inferior quality. Under such conditions Diesel pumping would appear to be the more economical, though the maintenance and repair bills told their own story as to relative reliability. The constant replacements which went to swell the repairs costs of oil and high-speed steam-engine drives virtually provided a new plant as often as needed, so that, except for obsolescence, the plant would be virtually everlasting. On the other hand the heaviness of the repairs costs and the unreliability inseparable from frequent repairing had to be taken into account.

As regarded the flexibility of the Diesel engines referred to by Mr. Key, the Author was much interested in the wide range of speed obtainable, which, in a type of engine giving only one working stroke per cylinder every two revolutions, must have necessitated very ample fly-wheel effect.

Mr. Maude had suggested that a longer life than 10 years should have been taken for the high-speed machinery. Perhaps the life assumed was on the short side, but in fixing it the Author had had in mind that the plant was assumed to be running almost continuously, and also that the life was to be comparable with the figure of 25 years for the slow-running plant, which, as pointed out in the Paper, was a very conservative estimate. As to the life of the Lea Bridge type, what figures could be more striking than those given by Mr. Stilgoe, although the older examples cited were not, of course, capable of the economy demanded of modern plant?

With regard to Mr. Hider's point as to the maintenance of the efficiency of the Corliss valves, the valves in the Lea Bridge engine were made in two parts—the valve proper and the cap, the two being urged apart by suitable springs. Any wear which took place was taken up by the springs, with the result that the valves, having once made for themselves a "skin," kept permanently tight. That had been confirmed by consumption tests taken after years of work.

The Author. He had noted with much interest the suggestions of Mr. Hider and Mr. Maude for the more efficient utilization of the exhaust end of the heat-drop. As pointed out by Mr. Mawson, this was undoubtedly the most hopeful direction in which to attack the deficit between the existing and the Rankine-cycle engine. The exhaust-steam turbine especially was an attractive proposition, but it was usually necessary to steer quite clear of increased complication. The Author could not at all agree with Mr. Roger Smith that it was probably not worth while to employ a vacuum higher than 26 inches, owing to the size of low-pressure cylinder involved. Even if the steam was not expanded below, say, 18 inches of mercury, as at Lea Bridge, the work obtained owing to relief of back pressure alone was well worth the small expenditure on an efficient condenser and air-pump. At Lea Bridge it was approximately 20 per cent. of the indicated horsepower, or nearly 5 per cent. per pound of pressure-relief below release. As Mr. Smith pointed out, the possibility of easily obtaining high vacua was an intrinsic economy of the steam pumping-engine for waterworks purposes.

Turning to the other end of the heat-drop, doubt had been expressed as to whether the lower fuel-consumption was worth the troubles in the boiler-house, etc., introduced by the adoption of higher pressures. The Author was emphatically of opinion that higher pressures were the road to progress, and power-station design certainly gave the lead in this direction. The President's remarks as to the behaviour of steel at high temperatures (up to 700° F.) confirmed the Author in this opinion, since the highest temperature advocated was 700° F., which was well below the critical region to which the President had drawn attention. Lubrication also was easily practicable up to this temperature, provided it was carefully applied.

Concerning the engines at Hamburg mentioned by Mr. Cotterell, the Author would not claim that all engines using a large thermal range must have a low steam-consumption, but only that a wide range was a necessary condition for the highest efficiencies.

With regard to Mr. Cotterell's point concerning the overlapping of the combined indicator-diagrams of Fig. 3, Plate 4, this was due to inaccuracy of the indicators. The Author had corrected it in transferring to the  $I\phi$  diagram, where points G and H were shown at the same pressure.

He was much interested in Mr. Hider's surmise that jacketing and reheating was excessive. He was inclined to think that Mr. Hider's doubts were very probably justified, but more experiments were required. The vacuum jacket used in some

instances by Mr. Henry Davey, M. Inst. C.E., might, under certain conditions, help towards economy. The Author.

With regard to Mr. Mawson's point as to the driving of the boiler feed-pump, the usual practice of the Author's firm was to drive this pump direct from one of the main pump crossheads, and the fuel-consumptions taken on p. 216 for the Lea Bridge type of engine mostly provided for the small extra work of driving it. In the case under review, however, the boilers and accessories were provided under a separate contract. For that reason also the Author could not comment upon the economizer efficiency.

As regarded the slip, it was true that the indicator diagrams alone would not detect leakage. They could only indicate the punctual opening and closing of the valves, without which slipless running would be impossible.

With regard to Mr. Clark's communication, the Author quite appreciated Mr. Clark's division of the efficiency into three factors. The last two of these the Author had intended to separate at the bottom of p. 222, but he was much indebted to Mr. Clark for the separate characterization of them, which he agreed might with advantage be adopted universally. To the boiler efficiency the Author feared he had not devoted much space. In this connection he realized, of course, that more fuel was necessary to evaporate the higher grades of steam, and he ought perhaps to have drawn attention to the fact on p. 224. But the percentage increase was small—in fact, almost negligible, when compared with the corresponding percentage gain in availability.

The concept of "mean effective temperature" was new to the Author, but he agreed with Mr. Clark it would often be a convenient one. The Author thought it was important in this connection to emphasize that the averaging was on an entropy basis.

He noted that Mr. Clark stated that "the efficiency of the engine would be improved by making the steam conditions worse." In the case of the triple-expansion engine working between the limits at present usual, the Author very much doubted this as far as extension towards *higher* pressures and temperatures was concerned, though he agreed in the matter of improved vacua, and he had in fact attempted to convey this converse impression by the statement on p. 224 to the effect that it was the high-pressure end of the heat-drop which was most efficiently utilized by the reciprocating engine. That was perhaps best visualized by considering what was the mechanical effect, in a given engine, of moving the "starting-point" of the steam up its adiabatic, that was, using

The Author steam slightly hotter and at a slightly higher pressure. Neglecting condensation losses, such steam could be cut off slightly earlier than before, and yet when the piston reached its former cut-off position it would have attained its former "starting-point" conditions. Up to this point its mean effective pressure would have been higher than previously and therefore the work done greater, while afterwards it would be precisely as before. Thus the engine had done further work with very little additional loss—less, at any rate, than the average loss on the whole heat-drop, since this average loss was swelled by the large "toe" loss at low-pressure release. Hence its efficiency was increased.

In conclusion, the Author, having attempted to present a fair comparison, would like to record his entire agreement with Mr. Mawson that the considerations advanced could only cover part of the field to be traversed when a choice as to the type of pumping-plant had to be made in any particular circumstances.

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