Discussion.

Sir B. Baker.

Sir BENJAMIN BAKER, K.C.M.G., President, said in his Presidential Address[1] he had suggested that the Institution might do useful work in securing uniformity, if possible, in engineering problems of different kinds. He thought the Paper was a distinct advance in that direction, because, no doubt, considerable inconvenience was occasioned and a great amount of time wasted in consequence of there being no standard for comparison in experimental investigations of steam-engines. If, as a result of the Author's very able Paper and the discussion upon it, some standard could be agreed upon by the members, to be known as the Institution Standard, he was sure the Author would think the trouble he had bestowed on his Paper would be amply justified. He had great pleasure in proposing a vote of thanks to the Author.

Capt. Sankey.

Captain H. RIALL SANKEY thanked the President for his kind remarks and the members for their reception of the Paper. He

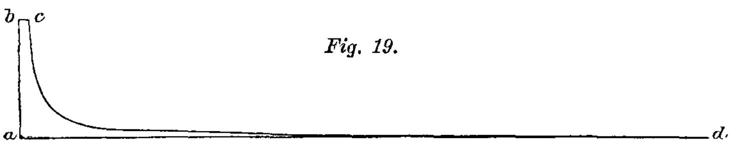


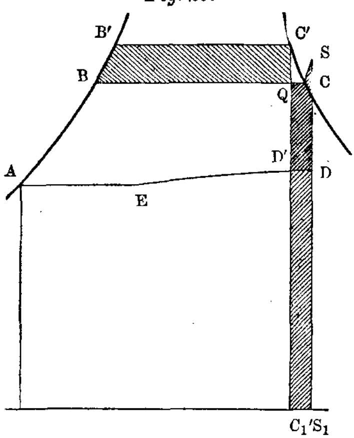
Fig. 19.

wished to call attention to the $p\,v$ diagram, *Fig. 19*, which was *Fig. 3* drawn out to full length. The point at which he proposed to cut off the toe of the diagram was at 0·15 atmosphere above the back-pressure. Looking at this diagram, one was tempted to think that it would be almost better to cut off more of the toe, and as there was a certain advantage in round numbers he suggested that it should be cut off at 0·2 atmosphere above the back-pressure. The obvious reason for choosing a fraction of an atmosphere instead of so many pounds per square inch was to make the standard universally applicable. The shaded part of *Fig. 19*, *i.e.*, from r to d, corresponded in area to the shaded part of *Fig. 10*. Although probably unnecessary, he thought it well to mention that the shaded areas on the various $\theta\,\phi$ diagrams were no indication of the efficiency of the corresponding ideal engines. For instance the area L in *Fig. 4* was less than K + L in *Fig. 2*. Nevertheless,

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 1.

Capt. Sankey. the latter was the less efficient engine because it was a matter of the ratio of the heat converted into work to the heat supplied. In the first case this ratio was $\frac{L}{N}$, and in the second case it was $\frac{K + L}{K + M + L + N}$. It was stated in the Paper that the standard superheated steam-engine did not make so good a use of the heat as the standard saturated steam-engine. A further diagram, *Fig. 20,* had been prepared to show that point more clearly. The area A_1 A B C S S_1 represented the heat given to the standard superheated steam-engine, and A_1 A B′ C′ C_1' an equal quantity of heat given to the standard saturated steam-engine; hence the shaded areas B B′ C′ Q and Q C S S_1 C_1' were equal. The work done by the superheated steam-engine was A B C S D E, and that by the saturated steam-engine was A B′ C′ D′ E, which was obviously greater than the former.[1] Some terms were used in the Paper that he would like to define a little more closely to prevent confusion. He had used the expression "ideal engine" in the sense of a theoretical engine, that gave any desired indicator or $p\,v$ diagram, and he had not used it in the sense of a perfect engine; it might be applied to any heat-engine whatever, not only to a steam-engine.

Fig. 20.



The perfect steam-engine was the particular ideal steam-engine which utilized the greatest amount of the heat supplied; it was also known as the "Clausius steam-engine." He had used the term "standard engine" in the special sense of the particular ideal engine, which, he hoped, might be chosen as the standard of comparison. At p. 200 there was a formula, in which, it would be observed, he had used 778 as the Joule equivalent, in accordance with the latest determinations of Messrs. Griffiths, Clark, and others. Corresponding to that, he had used 42·4 B.T.U. as the equivalent of 1 HP. per minute, instead of the more usual figure, 42·75.

Mr. Mair-Rumley. Mr. J. G. MAIR-RUMLEY had great pleasure in listening to the Paper and looking at the diagrams, which conveyed in the

[1] D E and D′ E′ are not shown separate in this figure as they nearly coincide (see *Fig. 14*).

Mr. Mair-Rumley.

Author's best manner the absolute inwardness of the $\theta\phi$ diagram. The $\theta\phi$ diagram was well known from the work of Mr. Macfarlane Gray and the late Mr. Willans, but he thought the Paper showed more clearly the applicability of the diagram to a standard steam-engine than anything that had yet appeared in the Proceedings of the Institution. Engines had been compared with the Clausius standard by Mr. Willans, and the standard now adopted by the Author was the Clausius standard with the toe taken off. He believed there would be not only in England, but in all parts of the world, a good deal of discussion as to the right amount of toe to be taken off, and whether any should be taken off at all. For comparison he believed it was better to take, as Mr. Willans had done, the entire Clausius standard by itself, or, better still, the Carnot cycle. In the Clausius standard, or in the standard of Carnot, there was the curious fact that the smaller the number of expansions the more nearly the standard was approached, so that an engine that was not really economical with regard to the amount of steam it used might approach more nearly to the Clausius or the Carnot cycle than if it were an engine with a higher rate of expansion and a better rate of duty. For that reason it seemed that the best basis for comparison was to compare the heat-unit expended per HP. with the thermal equivalent of work done. Having this efficiency it was only necessary to divide the number 42·75 (the thermal equivalent of 1 HP.) by the efficiency to obtain the heat used, and therefore the lbs. of steam, and from that could be obtained the amount of fuel if it was known what heat the fuel would give. It appeared much better to have the absolute efficiency of the engine on that basis than to have it in a form based on an assumption of cutting off so much of the toe of a theoretical diagram. In making engine trials with several rates of expansion according to the basis laid down by the Author, the lower the rate of expansion the better the engine would appear in regard to efficiency. It was necessary for users to know when a certain efficiency was given, how the exact amount of heat and steam, and if desired also the amount of coal used, could be calculated from it without trouble. That could not be done with an ideal standard because it was not known what an ideal standard was. It was best, therefore, for practical purposes, to compare the amount of heat used by the engine with the thermal equivalent of the indicated work; and for theoretical purposes the Carnot cycle should be adopted.

Mr. Davey.

Mr. Henry Davey thought the Author had rendered great service to the Institution by his lucid Paper. The subject

Mr. Davey. was an important one, and although many engineers, with Mr. Mair-Rumley, considered that one standard was sufficient, he was not himself of that opinion, and he would give a practical example illustrating his view. He had in mind two engines, one working with 30 lbs. or 35 lbs. per square inch and expanding to a very moderate amount, and another working with 140 lbs., both engines exhausting at the same pressure. The economy was practically the same if judged by the absolute standard—the units of work produced per unit of heat. Why was the pressure not maintained at 35 lbs. per square inch instead of increasing it to the 140 lbs. per square inch? It was simply because there was a difference in the use of the steam, and in the steam distribution. To judge accurately of those two engines, he must know their possibilities in the conditions under which they were working. It was clear that an engine working at low pressure had not the same physical possibility of producing work economically as an engine at high pressure; he therefore thought something more was wanted than the absolute standard of efficiency. He admitted that for the purpose of calculating the amount of the coal bill the units of work per unit of heat were sufficient, and all it was necessary to aim at was to obtain an engine which would give the greatest number of work-units for the least number of heat-units. But engines had to be designed and built, and it had to be discovered how to make steam of a given pressure expanded to a given extent produce the greatest amount of work. It was when questions of that kind were considered that something more was required to be known than the absolute thermal efficiency. It was within certain limits practically immaterial, when dealing with efficiency considered in relation to the possibilities of pressure and expansion, whether the ideal engine was what a physicist might consider a perfect steam-engine or not. A datum line was required, and he had no doubt there would be a great deal of discussion on the question where that line should be drawn. The Clausius perfect steam-engine had a non-conducting cylinder. There were no steam-engines with a non-conducting cylinder, and as far as was known that standard was impossible of realisation. He questioned whether any of the standards that had been proposed could be considered as standards of a perfect steam-engine. All that could be done was to approximate to what might be considered a perfect steam-engine. He therefore thought that the Author had elaborated the question too highly. An indicator diagram with an expansion line $p\,v =$ constant provided a standard which, though not very different in result from that proposed by the Author, would be very much simpler. He would assume the steam to be expanded to a terminal pressure of 1 lb. per square inch. To compare the efficiency of a condensing engine working under the condition of 100 lbs. per square inch pressure, its theoretical diagram would be a diagram with a small portion of the toe cut off. Enclosed within this figure was the actual engine diagram, and taking the mean pressure of this enclosed diagram and multiplying it by the number of expansions, supposing it to come to 20, and taking the mean pressure of the enclosing diagram multiplied into its number of expansions, and supposing it to come to 40, it was evident that the efficiency on this basis was 50 per cent. It was true this would show a different efficiency from that calculated in the way given by the Author, but he questioned whether it could be said that the ideal steam-engine the Author had prepared was much nearer the actual perfect engine than the engine indicated by the enclosing diagram. Three standards of comparison were adopted by the Author, the one with a small portion of the toe cut off, the absolute thermal efficiency, and also the one necessary to determine whether the engine being experimented with gave the best results in the conditions under which it was working, that was with the toe cut off to the point of release on the engine diagram. As he had said, that was a comparison which ought to be made by engine designers if they wished thoroughly to understand what their engines were doing and what they were capable of doing, supposing improvements to be possible. Mr. Davey.

Mr. Bryan Donkin.

Mr. BRYAN DONKIN remarked the subject which the Author had so well brought before the Institution was a difficult one, and the members ought to be grateful to him for bringing it forward in such a graphic and interesting manner. The practical question of the best standard to use in comparing different engines was most important, and well worthy of full discussion. After discussion, however, it was one that might perhaps be better decided by a committee of scientific men. It could, of course, never be final, as any standard adopted by the Author or anyone else would have necessarily to advance with scientific progress and research. It was certainly very desirable that some uniform method, such as that before them, should be adopted and agreed upon by engineers, but such a standard should be as simple and as practical as possible to suit all motors. If a standard were adopted, it should not only be applicable to steam, but also to gas, air and oil, so that all classes of engines could be readily compared with steam, either saturated or superheated. That, he thought, was very important. The different standards of thermal

Mr. Bryan Donkin. efficiency of steam-engines proposed by the Author appeared to have many good points. From a thermodynamic point of view it would be necessary to base any standard upon the highest and lowest temperature limits for any motor working between them; but from a practical commercial standpoint there was much to be said in favour of giving the results of experiments in thermal units per brake HP. hour. On this point he agreed with Mr. Mair-Rumley that the latter standard was very practical, easy and correct; it was also much used in the United States. Thermal units were actually paid for in the shape of coal, oil or gas, and mill-owners cared less for the temperature limits than for their weekly coal- or gas-bills. In comparing lbs. of steam per B.HP. in steam-engines it was certainly not strictly correct, as mentioned in the Paper, to take the lbs. per B.HP. when the pressures of steam were not the same, especially when superheated steam was used. With regard to the interesting $\theta\,\phi$ diagrams, they formed to his mind a most elegant and useful method of delineating the amount of heat in an engine, and represented the quantities very clearly. He was glad to see that the Author had used them so much in the Paper. The $\theta\,\phi$ or entropy diagrams have rather a frightening effect upon engineers as a rule, but if it were remembered that the area between the water-line and the saturated line simply represented thermal units, he thought engineers would take to them more kindly.

Mr. Beaumont. Mr. W. WORBY BEAUMONT congratulated the Author upon having thrown over the old bogey, the mis-used Carnot function. He had stated why he objected to the use of the so-called Clausius ideal engine, and preferred to work out a diagram into which he imported what might be called a limitation. But it appeared to be questionable whether the Author was quite right when he said that engineers were in so little agreement as to what the standard should be. He thought it might be said that at least eight out of ten of any reports of experiments would show that engineers were using the standard that Mr. Mair-Rumley had mentioned. They had in that what he should call an ideal standard; not an imaginary one founded on a so-called ideal engine evolved in the study, but a standard which judged the steam-engine exactly as it would be judged whether a business was a paying one or whether it was not; that was, an engine had given to it so much heat, of which the engine had returned in work so many units converted into foot-pounds. As far as he could see, it was impossible to imagine a more truly ideal standard of efficiency, and it was an exceedingly simple one; it was, Mr. Beaumont.

however, only a standard for comparison. The Author was endeavouring to find a standard that would take into consideration some of the differences that must occur as a result of difference in temperatures, and in conditions of working. If it were possible to obtain a combination of standard of comparison, and of what might be called ideal efficiency, it would be worth a great deal. At the same time, as far as the thermal efficiency of engines was concerned, he admitted that up to the present the Clausius and other standards had not made it possible to predicate an economic improvement, it had not been found how to improve engines except from the results of seeing how much of the heat given to an engine was returned in the form of work. It was to the ingenuity and experience of designers and experimenters, guided by the main facts as to the difference between the heat supplied and the heat given out in the form of work, that all the great improvements were to be attributed, even including those brought out at the Thames Ditton Works, which had been the home of so many useful investigations, and amongst them those that had led up to the conclusions recorded in the Paper.

Mr. Schönheyder.

Mr. W. Schönheyder entirely agreed with Mr. Mair-Rumley that there ought to be only one standard of efficiency, and that the one he had mentioned was the right one. Without wishing to be considered frivolous or irrelevant he would ask whether it would be right to measure the height of a British soldier with an ordinary yard standard, and the height of a round-backed or knock-kneed soldier with a shorter standard? Or would it be reasonable to measure the work of an ordinary British sailor by ordinary foot-pounds, and the work of a lascar, with a different constitution, by a smaller measure? Again, if a steward to whom a cheque for £100 was given to buy a horse, wasted £80, and bought a horse for £20, would it be said that he had utilized 100 per cent. of the money entrusted to him? Obviously, he had only utilised 20 per cent. And the same thing applied to a steam-engine.

Mr. Tremlett Carter.

Mr. E. Tremlett Carter remarked that, in presenting a standard of measurement of thermal efficiency based purely on the action of the steam-engine, the Author had separated the steam-engines from other heat-engines, and had introduced a method of arriving at a standard which was not directly applicable in the same way to gas-engines and explosion engines. He had also introduced an element of empiricism which must, at any rate from the logical point of view, destroy the scientific beauty of his standard. The clipping of the toe destroyed the figure, and a mutilated standard

Mr. Tremlett Carter. was not strictly artistic. He could not see how the Author's method could be applied to a gas-engine, either to one exploding at constant volume or one exploding at constant pressure. Nor did he see how the method was to be applied to the important class of steam-engines of the rotary type—say a steam-turbine. The practical method which had been strongly supported by several speakers was an admirable one when dealing with practical tests. The ratio of the number of foot-pounds to the dynamical value of the heat supplied, always appeared a very small ratio—say 0·1 or under 0·2. Before it could be understood why 0·9 or 0·99, or unity, could not be obtained, a conception of some such standard as the Author had put forward was necessary. In other words, in order to understand the distinction between avoidable and unavoidable losses, some visualized standard, the Carnot, or the Clausius, or the clipped Clausius standard, if it might be so termed, was required.

Capt. Sankey. Captain SANKEY, in reply, observed that he had, in the Paper, referred to the method advocated by Mr. Mair-Rumley as the commercial criterion of engine economy, and from that point of view he agreed with Mr. Mair-Rumley. It was only the absolute thermal efficiency expressed in a form more intelligible to people who were not engineers. But the object of the standard of comparison advocated in the Paper was to have some means of ascertaining how nearly a particular engine approached what was possible taking account of the conditions under which it was working. The use of such a standard was exemplified in the experiments made by the late Mr. Willans, who had worked the same engine under different conditions of admission temperature and exhaust temperature, and calculated in each case how nearly the actual engine approached to perfection. In stating that the proposed standard of comparison did not take into consideration a rotary engine or a steam-turbine, Mr. Tremlett Carter was mistaken, because such a steam-engine could not give a greater return than the corresponding Clausius perfect engine; that was the absolute limit, no matter what might be the type of the engine. He had referred in the Paper to the use of what he had called the "type standard"; he did not know what this type standard would be for a steam-turbine, as he had not gone into the matter; but when worked out and compared with the Clausius cycle it would give the relation between the thermal efficiency of the turbine and of the Clausius cycle; and further, the comparison with the "type standard" of a reciprocating engine would give an idea of the thermal relation which steam-turbines bore to reciprocating engines. It was thought by Mr. Davey that one thermal efficiency was insufficient, and so far he agreed with the Paper; but he proposed another standard of comparison, in which $p\,v$=constant was the expansion line. Such an ideal engine had been considered in the Paper, and its $\theta\,\phi$ diagram was given in *Fig. 9*, and for reasons there discussed he thought that $p\,v$ = constant was not a suitable expansion line to take for a standard. Capt. Sankey.

Mr. Davey said he had in his mind a jacketed engine. He had proposed $p\,v$ = constant for ease of calculation, and because the error was not very great. Mr. Davey.

Captain Sankey said for the type standard of a jacketed engine the saturation line should be taken as the expansion line, and not $p\,v$ = constant. The $p\,v$ = constant was proposed by Mr. Davey merely for simplicity in calculation. Certainly in this respect Mr. Davey's formula had the advantage of the formula given in the Paper, which was of considerable length, and was really worse than it appeared; it would have to be worked out by trial and error, which would be a long process, or by means of the $\theta\,\phi$ chart. But this difficulty was overcome at once by using a prepared set of curves, as shown in *Fig. 13*, from which the absolute thermal efficiency of the standard engine could be obtained by mere inspection when the limiting temperatures were given. Only a few curves were shown in the *Fig.* to illustrate the method; but if, in accordance with the President's suggestion, there should be an Institution standard established, these curves could be worked out in greater detail. After making a trial of an engine, it would be found that a certain number of heat-units were required per I.HP. per hour, and that gave the absolute thermal efficiency of the engine, and this divided by the absolute thermal efficiency of the standard engine gave the standard thermal efficiency. A numerical example was given in the Paper at p. 201. He thought this method was at least as simple as Mr. Davey's calculation, which required hyperbolic logarithms. It has also been remarked by Mr. Davey that the Clausius cycle necessitated a non-conducting cylinder, and there was no such thing in existence. Unfortunately, there was not; but the effect of a conducting cylinder might be taken account of in a "type standard." On the other hand, the loss occasioned by a conducting cylinder was one of the losses which the standard was appointed to try. He thought many engineers would agree that a portion of the toe should be cut off, but the question was how much. A standard that would include every kind of engine—steam, gas, oil, air, etc., was required by Mr. Donkin. But that was precisely Capt. Sankey.

Capt. Sankey. what absolute thermal efficiency did, as mentioned on the first page of the Paper. The standard thermal efficiency was useful for quite a different purpose, and the standard engine discussed in the Paper had reference only to steam-engines; but a gas-engine could be compared with its $\theta\ \phi$ diagram, as shown in *Fig. 1*, in an exactly similar manner, and the standard thermal efficiency of a gas-engine obtained. That there ought to be two thermal efficiencies, one to compare the absolute conversion into work by an engine, and the other to ascertain the degree of perfection under the conditions in which the engine was placed, Mr. Beaumont appeared to be in agreement with the Paper. He had laid on the Table a few copies of the $\theta\ \phi$ chart, which was a graphic representation of the properties of steam. This chart showed the temperatures, pressures, and volumes of saturated steam and also the volumes of 1 lb. of H_2O under various conditions (using that term to mean a mixture of steam and water); also the total heat expressed in British thermal units required to evaporate water at constant pressure from 32° F.

Correspondence.

Prof. Dwelshauvers-Dery. Professor V. Dwelshauvers-Dery remarked that the ideal steam-engine should have cylinder-walls absolutely impervious to heat; but its cycle would show the breaks due to the exhaust of the working fluid and its replacement in the boiler. There would thus be:—1st, admission at constant pressure p equal to that of the boiler, during which r thermal units per lb. of steam would be furnished, r being the latent heat of the lb. of steam; 2nd, adiabatic expansion prolonged until the pressure became equal to that of the condenser p' (or a higher one as proposed by the Author, but this would complicate the formulas), during which there was condensation, so that the dryness of the steam, which was unity, fell to a value x' which depended upon p'; 3rd, expulsion of the steam at constant pressure p', with consequent negative work taking place during the entire return stroke; 4th, restitution of the lb. of steam in the boiler and elevation of its temperature from that of saturation t', corresponding to p', to that of saturation t, corresponding to the initial pressure p. The quantity of heat expended in this operation was represented by $(q - q')$ thermal units per lb. of water, if by q be represented the heat of the lb. of saturated water at the temperature t, and by q' that of the lb. of water at the temperature t'. It would result that $q + r - q'$