Correspondence.

Professor Dwelshauvers.

Professor V. DWELSHAUVERS DERY observed that in his view the Author's experiments were unexceptionable, and made under conditions which gave them considerable importance. It was so much the more to be regretted that they were insufficiently detailed. In fact, to study them, and to investigate the bearing of the walls of the cylinders after the method of Hirn, it would be necessary to have for each cylinder separately the volume of the dead space, and the volume occupied by the steam at the commencement of each of the phases of admission, expansion, exhaust, and compression; the pressure of the steam at each of these periods; the work of this pressure during each of these phases; the mean diagram for each side of the piston; the external radiation of each cylinder and of each receiver; the quantity of heat transferred by the steam in each jacket. In fact, the data ought to be sufficiently complete to allow of the application of the six equations of the practical theory. With the information supplied in the Tables, only the first equation could be established, the equation of control, the balance-sheet of the trial. Without doubt, some conclusions relative to the facts might be deduced from it; but it was not clearly elucidated either in respect of the reason of, or of the method of the economies realized. He had applied so far as possible his method of investigation to these experiments. It consisted in bringing into account all the quantities of total heat expended, and in expressing them as fractions of this total heat. This was composed of two parts; first, the heat brought to the cylinder by the steam, Q, reckoning from 32° Fahrenheit; secondly, the heat Q' of the jacket steam, total $Q + Q'$. This heat ought to be found again (1) in the external work accomplished, represented by T thermal units; (2) in the external radiation E; (3) in the heat given up to the condenser composed of two parts, namely, that which had been furnished to the cold water, C, and that which the condensed steam possessed above 32° Fahrenheit, c; and for the sum $(C + c)$.

There then was: $Q + Q' = T + E + (C + c)$,

and $$1 = \frac{T}{Q + Q'} + \frac{E}{Q + Q'} + \frac{(C + c)}{Q + Q'}.$$

Professor Dwelshauvers.

In the six trials given there were—

—	44	33	56	41	35	40
$\frac{Q}{Q+Q'}$	0·749	0·789	0·817	0·870	0·893	0·905
$\frac{Q'}{Q+Q'}$	0·251	0·211	0·183	0·130	0·107	0·095
$\frac{T}{Q+Q'}$	0·152	0·164	0·170	0·124	0·135	0·136
$\frac{E}{Q+Q'}$	0 132	0·096	0·065	0·047	0·058	0·050
$\frac{(C+c)}{Q+Q'}$	0·716	0·741	0·764	0·828	0·807	0·814
$\frac{Q'-E}{Q+Q'}$	0·119	0·115	0·119	0·083	0·048	0·045

By this process, it would be seen clearly that No. 56 gave the highest efficiency; that for some unexplained reason the external radiation E was in that case very feeble; that the heat $Q' - E$ supplied to the steam in the first three trials was very nearly the same. The reason then of a greater efficiency in trial 56 was not apparent; but it was, however, a question which deserved to be cleared up. The Paper contained sufficient data to determine the thermal efficiency, f_1, that of the fluid, f_2, that of the mechanism, f_3, and consequently the ultimate efficiency $f_1\ f_2\ f_3 = f$. By thermal efficiency he meant the fraction $\frac{\tau - \tau^1}{\tau}$ in which τ was the absolute temperature of the source of heat (of the steam in the boiler), and τ^1 was the absolute temperature of the cold condensation water, of the cold body. The temperature of the cold water varied greatly from one trial to another, insomuch that the possible fall and the thermal efficiency varied for the highest and the lowest as much as 5·5 per cent. from the mean. He called f_2, fluid efficiency, the relation between the work indicated and that which should be obtained from a Carnot ideal motor with the same expenditure of heat and the same fall of temperature. Lastly, f_3 was the relation between the brake HP. and the indicated HP. From the highest to the lowest the difference varied about 5 per cent. from the mean of this efficiency, but the reason for this variation was not very apparent. In each of the two series, with and without steam in the jackets, the efficiency of the mechanism was greatest at mean speed. With steam in the jacket it was least for the highest speed, and without steam for the lowest speed. If, therefore, it

Professor Dwelshauvers. were desired to determine either the benefit due to the jacket, or that due to the influence of the speed, it would be necessary to disregard f_1 and f, and consider only f_2. At the outset he would consider the efficiencies deduced from the data in the Paper:—

—	1	2	3	4	5	6
	44	33	56	41	35	40
	With Steam in the Jacket.			Without Steam in the Jacket.		
f_1	0·3944	0·3732	0·3904	0·3936	0·3795	0·3918
f_2	0·3864	0·4389	0·4360	0·3290	0·3802	0·3766
f_3	0·7921	0·8128	0·7649	0·7869	0·8266	0·7969
f	0·1207	0·1331	0·1302	0·0978	0·1114	0·1080
$f_1\ f_2$	0·1524	0·1638	0·1702	0·1243	0·1347	0·1356

The last line, the product of $f_1 f_2$ represented the relation between the heat equivalent to the indicated work and the total heat expended. The economical effect of the jacket was shown by a comparison of the trials, made at approximately the same speed, 1 and 4, 2 and 5, 3 and 6, with respect to the value of f_2 only:—

$$\text{Trials 1 and 4} \quad \frac{3{,}864 - 3{,}158}{3{,}864} = 0\cdot183,$$

$$\text{,, 2 and 5} \quad \frac{4{,}389 - 3{,}549}{4{,}389} = 0\cdot191,$$

$$\text{,, 3 and 6} \quad \frac{4{,}360 - 3{,}455}{4{,}360} = 0\cdot208.$$

The mean advantage was 0·194, or 19·4 per cent., the highest being in respect of the highest speed. To find the advantage resulting from high speeds, he would compare in the same way trials 1 and 2, 2 and 3, 1 and 3 with the jacket, and trials 4 and 5, 5 and 6, 4 and 6 without the jacket. This would give:—

Trials 1 and 2, advantage	0·1196	Trials 4 and 5, advantage	0·1102
,, 2 and 3, ,,	0·0067	,, 5 and 6, ,,	0·0272
,, 1 and 3, ,,	0·1138	,, 4 and 6, ,,	0·0860

The maximum efficiency of the fluid was therefore obtained at mean speed; but the highest speed gave greater efficiency than the lowest. He hoped that the data in the Paper would be extended, so as to allow of a more thorough analysis of the thermal phenomena observable in the experiments. Professor Dwelshauvers.

Mr. Donkin. Mr. BRYAN DONKIN, Jun., said he would like to know how the radiation experiments had been made. It would much increase the interest of the Paper if the Author could add any experiments giving the result of each set of steam-jackets separately, so as to determine their relative effect; also if he could divide in the same way the returns of the total weights of jacket-water. If an experiment could be made with the three engines coupled in the usual way, as in mill and marine engines, it would be of great value. His new hydraulic brake dynamometer was especially interesting and complete, and was likely to be much used in similar experiments on account of its small size and its easy application. The great difference between the feed-water into the boiler and out of the air-pump was startling; but no doubt the Author would be able to reduce this in future experiments, or determine the reason for the differences. As the balance-sheet system of heat in and heat out had been used in this Paper, as in many other similar trials, and had been so largely adopted of late years by engineers, it might be of interest to state that, after some trouble, Mr. Donkin had succeeded in tracing when and by whom it originated. Professor Dwelshauvers Dery, of Liége, informed him that it was first employed by Mr. Hirn in the following Paper:—"Mémoire sur l'utilité des Enveloppes à Vapeur."[1]

Mr. Kirk. Mr. A. C. KIRK could not refrain from a note of warning, that results got from a model, however carefully and correctly the trials might be carried out, should not by any means be implicitly accepted as applicable to a large engine. As an illustration, the late Mr. Froude's observations on the behaviour of ship models towed in a suitable tank, while they might in any case have been of some interest, would have been of little value had not that illustrious experimenter found a law of comparison between the results from the models and those of the full-sized ship, and been able to prove by experiment that the law held true. It might, perhaps, be said that so far as the action of the walls of the cylinder was concerned, the law of comparison was simply that (under the same conditions of temperature, of expansion, &c.), while the weight of steam used in the cylinder would be as its cubic capacity, the action of the sides of the cylinder would be in proportion to the surface exposed to the working steam. But this should by no means be hastily assumed, and it might possibly be

[1] Bulletin de la Société Industrielle de Mulhouse, vol. xxvii. (1855), p. 105.

Mr. Kirk. a considerable way from representing the truth. Without investigating the hypothetical conditions that might prevent the application of such a law, one obvious condition would probably modify it materially, namely, that the steam acting inside the cylinder was not at rest, expanding quiescently, but was, on the contrary, in a state of violent agitation and movement. Under these conditions how much of the steam came in contact with the sides of the cylinder no one, perhaps, would venture to guess. His feeling was that, while these experiments were of value, the results obtained were only applicable to small engines. On the Paper itself he would make a few remarks. In engines where the steam was worked through a considerable range of expansion in one cylinder, experience had proved beyond doubt that the use of a steam-jacket effected economy, that, in fact, the steam condensed in the jacket produced more power than the same steam would do if admitted to the cylinder as an addition to the working steam. Unfortunately the Author seemed to ignore this essential condition. As formerly practised in single-expansion engines, Mr. Kirk would not venture to assert that the interior of the cylinder was kept absolutely dry by the action of the jacket, as the steam in the jacket did not exceed in temperature the working steam admitted to the cylinder. About eighteen years ago, the idea took strong hold of many engineers, that much higher economy could be attained in the compound engine by keeping the inside of the cylinders dry. Not only was much attention given to steam-jackets in cylinders and covers, and an attempt was even made to keep the pistons hot by steam inside them; but further, to make sure that the working steam was dry before it entered the engine, it was passed through a steam receiver and separator heated by the waste heat of the chimney. There was little doubt that dry steam was in this way obtained, and that the inside of the cylinders was kept dry during the passage of the steam through them; but, in consequence, the cylinders and valves often cut badly, and the enginemen used so much oil inside the engine that harm was done otherwise. It came to be recognized that it was objectionable in practice to work a cylinder without some moisture to act as a lubricator. Thus the Author's condition of working with the low-pressure cylinder, kept so hot as to act as a powerful evaporator, however interesting it might be in some ways, was a matter outside practical engineering. Glancing, now, briefly at the combined indicator diagrams, there seemed to be anomalies needing explanation. The diagrams having been reduced so as to correspond to an engine with all the pistons working on one crank-shaft, and consuming 1 lb. of steam per stroke, a curve of dry saturated steam was drawn for the sake of comparison. The quantity of steam was deduced from the water discharged from the air-pump, the capacity of the low-pressure cylinder being taken so as to contain 1 lb. of steam at the pressure of release. In the case of the unjacketed cylinder, the steam shown by the diagram was not sufficient to fill this cylinder, and there was a quantity missing, represented by the shaded belt between the actual diagram and the curve of saturation. In the case of the jacketed trials this belt in the low-pressure cylinder, and partly in the intermediate cylinder, had all but vanished. From this it must be inferred that water passed into the engine had been evaporated chiefly in the low-pressure cylinder, and had filled it with dry saturated steam, which then had passed out of the cylinder into the condenser. But, looking at the high-pressure diagram, it did not seem that this amount of dry saturated steam discharged from the engine ever got into the engine. It could hardly be assumed that, with the precautions taken, and the high-pressure cylinder steam-jacketed, all this missing steam was due to condensation of dry saturated steam entering the high-pressure cylinder, amounting as it did to about 50 per cent. of the actual working steam. It would seem rather as if a considerable quantity of water had passed from the boiler, in the first place along with the steam, which on its way through the engine was gradually evaporated by the action of the jackets, and chiefly so in the low-pressure cylinder, where the temperature of the jackets was much above that of the working steam and the water which accompanied it. The use of boiler-steam, at 200 lbs. pressure per square inch, to evaporate water in the low-pressure cylinder and generate steam in it of about 25 lbs., which, after doing some work there, escaped direct to the condenser, could not be economical. It would be better if this steam at boiler-pressure were admitted as working steam to the high-pressure cylinder. There seemed to be a slight mistake in not setting back the low-pressure diagrams in trials 40, 41, and 44 to zero line. When this was done in trial 40 it would be found that the diagrams followed very closely the line of adiabatic expansion, as the diagrams of the trials of the triple-expansion engines of the steamship "Aberdeen" were found to do.[1] Mr. Kirk's view was that, seeing the presence of water in a steam- Mr. Kirk.

[1] For further information on these triple-expansion engine-trials and the method of setting out a continuous diagram, see Mr. Kirk's Paper in the Transactions of the Institution of Naval Architects, vol. xxiii. (1882), p. 33.

Mr. Kirk. cylinder was unavoidable, it was better to divide expansion into successive stages in cylinders of graduated temperatures than to trust to the action of the steam-jacket.

Professor Ryan. Professor J. RYAN observed that the Author said (p. 178): "The steam in the cylinder at release expands down to the pressure of the condenser. The expansion takes place partly in the cylinder, partly in the passages, and will be attended by liquefaction similar to that which results from ordinary expansion." But liquefaction could scarely be expected here, inasmuch as the steam in passing to the condenser would have but little work to do. Since the "total heat" of saturated steam diminished with diminishing pressure, it might be expected that the steam, if dry at release, would become superheated on expanding into a chamber where the pressure was initially much lower than its own. The Author, p. 177, pointed out that at release the steam was "dry saturated steam." The tendency should therefore be for the steam to become superheated on passing to the condenser, not merely "by the hot walls," but by its own intrinsic excess as pressure and temperature fell. But the Author put on record the fact that the temperature as noted in the pipe was not greater than that which would correspond with the pressure in the condenser. This was what might be expected; for the superfluous heat, which would superheat the steam if it were enclosed in a dry chamber, mainly served in the actual circumstances to increase the energy of translation of the issuing steam, and ultimately to evaporate some of the water in the condenser, instead of raising the temperature of the steam very sensibly. But except in cases where the pipes were narrow, and much friction opposed the expansion, liquefaction was not likely to occur at the cylinder end. On p. 186, the Author directed attention to the "great excess of condensation in the intermediate cylinder over the high-pressure, and in the low-pressure cylinder over the intermediate." These observations discredited the views of some authorities, who persistently maintained the contrary. To recall some theoretical reasons, which he had put forward once before, why the condensation should be worse in the successive cylinders as usually constructed:—

(1) In the high-pressure cylinder the fall of temperature took place in less time, as it occurred during a portion only of the stroke. This was also a reason why a steam-jacket must be less effective on the high-pressure than on the other cylinders.

(2) The ratio of exposed metallic surface to weight of steam increased in each successive cylinder.

(3) The faces of the piston and of the cylinder-cover formed a

larger percentage of the total surface exposed to steam during the stroke in the larger cylinders; and these two faces were wholly exposed from the very commencement. At the outset, a certain weight of steam was brought into contact with larger condensing surfaces in the successive cylinders. Professor Ryan.

(4) The weight of metal involved in the thermal changes was greater in the cylinders which exposed the larger surface.

(5) The steam became wetter and wetter as it passed on, doing work.

These considerations showed why steam-jackets were more effective on the intermediate and low than on the high-pressure cylinder; as did also the greater gradient of temperature where boiler-steam was used in all the jackets, as the Author indicated. The Author calculated, p. 185, that a difference of temperature of 38° Fahrenheit would be required to cause a flow of "22,000 T.U. per square foot per hour" through the walls of the cylinder. According to the results of Forbes for iron, a difference of temperature of about 19°·7 Fahrenheit would suffice, and, according to Tait's careful work, 15°·6 Fahrenheit would be sufficient at a mean temperature of 342° Fahrenheit. Ångström's conclusions pointed to 30° Fahrenheit, but he used the highest temperature correction of the classical experimentalists. Modern results led to lower values. This was of course on the supposition that the only obstacle to the passage of the heat was the iron itself, whose conductivity was in question. He imagined, however, that the greatest obstacle was the difficulty of intercommunication of heat between steam and iron.

Mr. W. Schönheyder remarked that having shown, as early as 1871, how to correctly combine indicator diagrams of compound engines, so as to take proper account of the compression steam, he should like to state that though his method had been followed by many engineers, it was of course not the only correct one. Professor Unwin had a plan of his own, which, however, did not seem to be very convenient, as neither the compression curves nor the expansion curves were made to meet, and the relative proportions of the cards were therefore not made as apparent to the eye as they might have been. The Author had adopted a third method, which also was correct, and which had the great value of giving a clear oversight of the diagrams, and of showing the total losses very distinctly; but it had the disadvantage that the cards were more or less mutilated, and hence it was necessary to refer back to the original ones for information on many points. In the diagrams of trials 40, 35 and 41, the dark-shaded portions, representing the losses, Mr. Schönheyder.

Mr. Schönheyder. had been carried beyond the length of the actual diagrams; this gave a great increase to the area of losses, for which there did not appear to be any just reason. The method adopted of measuring the jacket-water could only give approximate results, and it would seem from the diagram of the steam-pipes that the water so measured must have included some of the condensation from the main steam-pipes. He could not see the reason why the Author should have fixed the indicators vertically, as this necessitated a bend (apparently quite sharp) in the passage for the steam to the indicator, and also a bend of the string over an extra pulley; these were all large factors in producing unreliable diagrams, and totally unnecessary evils. As the engines were claimed (p. 152) to represent "good examples of steam-engine design," he begged to say that it was not good design to bring the cylinders in line with the cross-head guides by means of set-screws, which were always liable to serious abuse; when the same end (that of securing small heat-conducting surfaces) could have been reached by providing narrow but solid strips cast on either piece and properly tooled, so that when the cylinder and guide were once made true they would always be so. Neither was it good design for valves of such abnormal dimensions, working under such high pressures, and at such high speeds, to have their rods connected to the eccentric rods by such diminutive pins as shown, and without the provision of means for taking up wear. In order to "cause the governor to close the expansion valve" (p. 162) a "Meyer" gear had been provided, several bevel-wheels, lay-shafts, friction-clutches and other gear; the same result could have been obtained in a much simpler manner, with probably one-quarter the number of parts, by a judicious use of the "Bodmer" gear, often erroneously called the "Rider" gear. The use of running joints was very properly condemned (p. 160); they were convenient appliances for jointing gas pipes or for similar light purposes, where pressures were low, where no heat prevailed, and where vibrations were absent. On p. 161 it was stated that "the air-pump . . . . is designed to work up to 400 revolutions per minute." This pump did not appear to differ in construction from air-pumps in use twenty-five or thirty years ago, and intended for quite moderate speeds; it would be interesting to have it more fully described, so as to show in what particular it was so well suited for high speeds. It might no doubt be reciprocated up and down at the rate mentioned, but he doubted if it would "work," that was, produce a good vacuum at even one-half or one-quarter of that speed.

17 December, 1889.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion upon the Paper by Professor Osborne Reynolds, "On the Triple-Expansion Engines and Engine-Trials at the Whitworth Engineering Laboratory, Owens College, Manchester," occupied the evening.