has the advantage of putting results in a way that is easy to under­stand and remember.

95. None of these modes of statement include the efficiency of the boiler and furnace. The performance of a boiler is most usually expressed by giving the number of pounds of water at a stated temperature converted into steam at a stated pressure by the combustion of 1 lb of coal. The temperature commonly chosen is 212° F., and the water is supposed to be evaporated under atmo­spheric pressure; the result may then be stated as so many pounds of water evaporated from and at 212° F. per 1 lb of coal. But the term “efficiency” may also be applied to a boiler and furnace (considered as one apparatus) in the sense of the ratio between the heat that is utilized and the potential energy that is contained in the fuel. This ratio is, in good boilers, about 0·7. Thus, for example, 1 lb of Welsh coal contains about 15,500 thermal units of potential energy, an amount which is equal to the heat of pro­duction (L) of about 16 lb of steam from and at 212°. In practice, however, 1 lb of coal serves to evaporate only about 11 lb of water under these conditions, or about 9·5 lb when the feed-water enters at 100° F. and the absolute pressure is 100 lb per square inch.

The efficiency of the engine multiplied by that of the furnace and boiler gives a number which expresses the ratio between the heat converted into work and the potential energy of the fuel,—a number which is, in other words, the efficiency of the system of engine, boiler, and furnace considered as a whole. Instead, how­ever, of expressing this idea by the use of the term efficiency, engineers are more usually in the habit of stating the performance of the complete system by giving the number of pounds of coal consumed per horse-power per hour. It must be borne in mind that this quantity depends on the performance of the boiler as much as on that of the engine, and that the difference in thermal value between one kind of coal and another makes it, at the best, a rough way of specifying economy. It is, however, an easy quantity to measure ; and to most users of engines the size of the coal-bill is a matter of greater interest than any results of thermodynamic ana­lysis. Still another expression for engine performance, similar to this last, is the now nearly obsolete term “duty,” or number of foot-pounds of work done for every 1 cwt. of coal consumed. Its relation to the pounds of coal per horse-power per hour is this—

Duty= 112 × 33000 × 60/Number of lbs. of coal per I.H.P. per hour·

A good condensing engine of large size, supplied by good boilers, consumes about 2 lb of coal per horse-power per hour ; its duty is then about 110 millions.

96. To illustrate the subject of this chapter more fully the follow­ing summary is given of the results of tests of pumping engines by Mr J. G. Mair, described in two excellent papers in *Min. Pro. Inst. Civ. Eng.* (vols. lxx. and lxxix.). The first group (Table V.) refers to single cylinder beam rotative engines, all of the same type, working at about 120 horse-power (in all except the last trial there were steam-jackets in use) :—

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Boiler  Pressure  (Abs.). | Total  Ratio of Expansion. | Percentage of Water Present at Cut-off. | Lbs. of Dry Steam per I.H.P. per  Hour. | Efficiency. |
| 48 | 6∙8 | 44 | 22·1 | 0·099 |
| 57 | 4∙3 | 29 | 22·1 | 0∙099 |
| 59 | 3·2 | 22 | 21∙3 | 0·102 |
| 59 | 1∙9 | 15 | 23∙6 | 0∙093 |
| 56 | 3·8 | 37 | 26∙5 | 0·083 |

In these engines, which ran at the slow speed of about 20 revolu­tions per minute, the influence of steam jacketing was very marked. In the trials made with jackets in action, the percentage of water present at cut-off’, when plotted in relation to the ratio of expan­sion, gives a diagram which is sensibly a straight line ; by drawing this line it may be seen that with an expansion of 3·8 in a similar jacketed cylinder there would be about 25 per cent. of initial con­densation instead of the much greater amount (37 per cent.) which the absence of a jacket caused in the last trial.

The next group of tests (Table VI. ) refer to compound engines, of the types named (for explanation of the terms see chap. VI. ):@@1—

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Type. | Boiler Pressure  Abs. | Total Ratio of Expansion. | Number of Revolutions per Minute. | Percentage of Water present at Cut-off. | Lbs. of Dry Steam per  I. H. P. per Hour. | Efficiency. |
| Woolf beam, without jackets.. | 58 | 9∙3 | 18 | 51 | 26·6 | 0 082 |
| ,, with jackets | 62 | 15∙8 | 20 | 41 | 17∙3 | 0∙126 |
| ,, without jackets.. | 89 | 7∙8 | 34 | 34 | 19∙2 | 0∙113 |
| „ with jackets | 88 | 9∙6 | 34 | 38 | 17∙4 | 0∙125 |
|  | 68 | 11·9 | 18 | 25 | 15∙6 | 0∙139 |
|  | 78 | 16∙5 | 23 | 31 | 15∙5 | 0·140 |
| ,, .... | 75 | 13∙2 | 27 | 29 | 15∙1 | 0·144 |
| Woolf tandem, without jackets | 86 | 11∙5 | 80 | 43 | 21∙6 | 0∙101 |
| Receiver beam, with jackets... | 76 | 13∙6 | 24 | 34 | 14∙8 | 0∙147 |

V. The Testing of Steam-Engines.

97. Under this head we may include experiments made to determine—(*a*) the horse-power of an engine; (*b*) the thermody­namic efficiency, or some more or less nearly equivalent quantity, such as the relation of power to steam supply or to coal consump­tion (§ 95); (*c*) the distribution of steam, that is, the relation which the several events of steam-admission, expansion, exhaust, and compression bear to the stroke of the piston ; *(d)* the amount of initial condensation, the wetness of the steam throughout the stroke, and the transfer of heat between it and the cylinder walls ; (*e*) the efficiency of the mechanism, or the ratio which the work done by the engine on the machinery it drives bears to the work done by the steam in the cylinder.

Tests *(a)* and (c) are of common application ; test *(b),* in the simple form of a comparison of horse-power with coal burnt per hour, is not unusual. The actual measurement of efficiency, whether thermodynamic *(b)* or mechanical (e), and the analysis involved in *(d)* have been carried out in comparatively few instances.

98. In all these operations the taking of indicator diagrams forms a principal part. The indicator, invented by Watt and improved by M‘Naught and by Richards, consists of a small steam cylinder, fitted with a piston which slides easily within it and is pressed down by a spiral spring of steel wire. The cylinder of the indicator is connected by a pipe below this piston to one or other end of the cylinder of the engine, so that the piston of the indicator rises and falls in response to the fluctuations of pressure which occur in the engine cylinder. The indicator piston actuates a pencil, which rises and. falls with it and traces the diagram on a sheet of paper fixed to a drum that is caused to rotate back and forth through a certain arc, in unison with the motion of the engine piston. In M''Naught's indicator the pencil is directly attached to the indicator piston, in Richards’s the pencil is moved by means of a system of links so that it copies the motion of the piston on a magnified scale. This has the advantage that an equally large diagram is drawn with much less movement of the piston, and errors which are caused by the piston’s inertia are consequently reduced. In high-speed engines especially it is important to minimize the inertia of the indicator piston and the parts con­nected with it. In Richards’s indicator the linkage employed to multiply the piston’s motion is an arrangement similar to the parallel motion introduced by Watt as a means of guiding the piston-rod in beam engines (see § 188). In several recent forms of indicator lighter linkages are adopted, and other changes have been made with the object of fitting the instrument better for high­speed work. One of these modified forms of Richards’s indicator (the Crosby) is shown in fig. 21. The pressure of steam in the engine cylinder raises the piston P,

compressing the spring S and causing

the pencil Q to rise in a nearly straight

line through a distance proportional,

on a magnified scale, to the com­

pression of the spring and therefore

to the pressure of the steam. At the same time the drum D, which carries the paper, receives motion through the cord C from the crosshead of the en­

gine. Inside this drum there is a spiral spring which becomes wound up when the cord is pulled, and serves to turn the drum in the reverse direction during the back stroke. The cap of the indi­cator cylinder has holes in it which admit air freely to the top of the piston, aud the piston has room to descend, extending the spring S, when the pressure of the steam is less than that of the atmosphere. The spring is easily taken out and replaced by a more or less stiff one when higher or lower pressures have to be dealt with.

99. To register correctly, an indicator must satisfy two conditions : (1) the motion of the piston must be proportional to the change of steam pressure in the engine cylinder ; and (2) the motion of the drum must be proportional to that of the engine piston.

The first of these requires that the pipe which connects the

@@@1 For other comparative trials, see Hallauer’s papers, especially *Bull. Soc. Ind. de Mulhouse,* Dec. 30, 1878, and May 26, 1880.