|  |  |  |  |
| --- | --- | --- | --- |
| Ratio of Expansion. | Percentage of Water present | | Consumption of Steam per Indi­cated Horse- Power per Hour. |
| At End of Admission. | At End of Expansion. |
| 7∙3 | 24∙2 | 17∙8 | lb  17∙8 |
| 9∙4 | 30·8 | 18∙6 | 17∙6 |
| 15·1 | 37∙5 | 20∙8 | 17·7 |

Table IV.

|  |  |
| --- | --- |
| Ratio of Total Expansion. | Consumption of Steam per I.H.P. per Hour. |
| 4∙2 | lb  21∙2 |
| 5·7 | 20· |
| 7∙0 | 20∙3 |
| 9∙2 | 20·7 |
| 16∙8 | 25·1 |

Here a maximum of efficiency lies between the extreme grades of expansion to which the test extends. In the American experi­ments the best results were ob­

tained with even more moderate ratios of expansion. The com­pound engines of the United States revenue steamer “ Bache,” when tested with steam in the jacket of the large cylinder, with the boiler pressure nearly uni­form at 80 lb by gauge, or 95 lb per square inch absolute, and the speed not greatly varied, gave the results shown in Table IV. Here the efficiency is very

little affected by a large variation in the cut-off, but when the ratio of expansion becomes excessive a distinct loss is incurred.

Experiments with engines, in the conditions which hold in ordinary practice, show that it is not unusual to find 20 or 30 per cent. of the steam that comes over from the cylinder condensed during admission. In favourable cases the amount is less than this ; occasionally, on the other hand, the amount condensed is as much as half, or even more than half, the whole steam supply.

91. The action of the cylinder walls is reduced—(1) by jacketing, (2) by superheating, and (3) by using compound expansion. The advantage of the steam-jacket has been already mentioned. In high-speed engines its beneficial effect is necessarily small, and in certain cases the benefit may be even more than neutralized by the drawbacks which have been alluded to above (§ 88). In general, however, the steam-jacket forms a valuable means of reducing the wasteful action of the cylinder walls, especially when the ratio of expansion is considerable. Experiments made with and without a jacket, on the same engine, have shown that jacketing may increase the efficiency by 20 or 25 per cent. When a jacket is working pro­perly it uses, in a single-cylinder engine, 4 or 5 per cent., and in a compound engine 8 to 12 per cent., of the whole steam supply.

92. Superheating the steam before its admission reduces the amount of initial condensation, by lessening the quantity of steam needed to give up a specified amount of heat, and this in its turn lessens the subsequent cooling by re-evaporation. That it has a marked advantage in this respect has been experimentally demonstrated by Hirn. On general thermodynamic grounds superheating is good, because it extends the range of temperature through which the working substance is carried. In modern practice superheating (to any considerable extent) is seldom attempted. It occurs to a small extent whenever dry steam is throttled, and a slight superheating is occasionally given to steam in its passage from the high-pressure to the low-pressure cylinder of a compound engine. In former years superheated steam was a common feature of marine practice, but serious practical difficulties caused engineers to abandon its use and to seek economy rather by increasing the initial pressure and using compound expansion. In those days, however, the theoretical advantage of superheating was less understood than it is now. The economy of fuel which its employment would probably secure is so great as to warrant a fresh and energetic attempt to overcome the mechanical difficulties of construction and lubrication that have hitherto stood in the way.

93. The most important means of preventing cylinder condensa­tion from becoming excessive is the use of compound expansion. If the vessels were non-conductors of heat it would be, from the thermodynamic point of view, a matter of indifference whether expansion was completed in a single vessel or divided between two or more, provided the passage of steam from one to the other was performed without introducing unresisted expansion (§ 51). But with actual materials the compound system has the important merit that it subjects each cylinder to a greatly reduced range of temperature variation. For this reason the amount initially condensed in the high-pressure cylinder is greatly less than if admission were to take place at once into the low-pressure cylinder and the whole expansion were to be performed there. Further, the steam which is re-evaporated from tho first cylinder during its exhaust does work in the second, and it is only the re-evaporation that occurs during the exhaust from the second cylinder that is absolutely wasteful. The exact advantage of this division of range, as compared with expansion (through the same ratio) in a single cylinder, would be hard to calculate ; but it is easy to see in a general way that an advantage is to be anticipated, and (though there are

isolated instances to the contrary) experience bears out this con­clusion. In large engines, working with high pressure, much expansion, and a slow stroke, the fact that compound engines are in general more efficient than single engines cannot be doubted. Additional evidence to the same effect is furnished when a com­pound engine is tested first with compound expansion and then as a simple engine with the same grade of expansion in the large cylinder alone. Thus in the American experiments the compound engine of the “Bache” when worked as a simple engine used 24 lb of steam per I.H.P. per hour, as compared with about 20 lb when the engine worked compound, with the same boiler pressure, the same total expansion, and steam in the jacket in both cases. The necessity’ for compounding, if efficiency is to be secured, becomes greater with every increase of boiler pressure. So long as the initial pres­sure is less than about 100 lb per square inch (absolute) it suffices to reduce the range of temperature into two parts by employing two-cylinder compound engines ; with the higher pressures now common in marine practice triple and even quadruple expansion is being introduced.

The action of the cylinder walls would be greatly reduced if it were practicable to use a non-conducting material as an internal lining to the cylinder and to the exposed surfaces of the piston. No cure for the evils of initial condensation would be so effectual as this ; and in view of the economy of heat which would result, it is a matter of some surprise that the use of a non-conducting lining has not received more serious attention.

94. The principal reasons have now been named which make the actual results of engine performance differ from the results which would be obtained if the steam conformed in every respect to the simple theory stated in chap. III. It remains to state, very shortly, a few of the results of recent practice as to the actual efficiency of steam-engines considered as heat-engines.

The performance of a steam-engine, as regards economy in its consumption of heat, may be stated in a number of ways. In some of these the engine alone is treated as an independent machine ; in others the engine, boiler, and furnace are considered as a whole.

The performance of the engine alone is best expressed by stating either (1) the thermodynamic “efficiency” or (2) the number of thermal units used per horse-power per minute. These terms re­quire a short explanation. The “efficiency” of a heat-engine has already been defined as the ratio of the work done to the heat sup­plied. The “ work done ” ought in strictness to be reckoned as the net work done by the working substance in passing through a complete cycle of operations ; it should therefore be determined by subtracting from the work which the substance does in the cylin­der the work which is spent upon the substance in the feed-pump. The latter is a comparatively small quantity, and engineers gene­rally neglect it in their calculations of thermodynamic efficiency. In making comparison, however, between the efficiency which is actually realized and the efficiency of a perfect engine or of an engine working under any assumed conditions, account should be taken of the negative work done in the feed-pump. Account should also in strictness be taken of that part of the work spent in driving the air-pump which is done upon the working substance, as dis­tinguished from the water of injection. The “ heat supplied ” is the total heat of the steam delivered to the engine, less the heat con­tained in the corresponding amount of feed-water. This quantity depends on the amount of steam used, on the temperature of the feed, on the boiler pressure, and on the extent to which the boiler “primes.” Priming is the delivery by the boiler of water mixed with the steam. Except where there is actual superheating the steam supply is always more or less wet ; in a badly designed or overworked boiler large volumes of water may be carried over with the steam, but in a good boiler of adequate size the amount of priming is less (often much less) than 5 per cent. of the whole supply. The effect of priming is, of course, to reduce the supply of heat per lb of the working substance.

One horse-power is the mechanical equivalent of 42·75 thermal units per minute. The relation between the above two methods of stating engine performance is therefore expressed by the equation

Efficiency=42·75/Number of T.U. per I.H.P. per minute·

Another very common mode is to give the number of pounds of steam supplied per horse-power per hour. This is unsatisfactory’, even as a method of stating the comparative economy of different engines, or of one engine in different conditions, for several reasons. It ignores variations in boiler pressure, in feed-water temperature, and in the dryness of the supply’, although each of these things affects the amount of heat required for the production of a pound of steam. But the total heat of production of dry steam does not vary greatly within the limits of practical pressures ; moreover, since (in condensing engines) feed-water is generally taken from the hot-well, its temperature does not differ much from that of the air-pump discharge, or (say·), 100o F. Finally, in many comparative trials the amount of priming is nearly if not quite constant. Hence it happens that this mode of statement often furnishes a fairly accurate test of the economy of engines, and it