pressure is 0·151 lb per cubic foot. Hence, out of the whole mixture, the amount of steam was 2·92 × 0·151 = 0·440 lb. The water present at the point of cut-off was therefore 0·662 - 0·440 or 0·222 lb. This is 33·5 per cent. of the whole amount of the mix­ture, and shows (after allowing for the priming water) that about 32 per cent. of the steam admitted was condensed on admission.

Next, to find the amount of water present at the end of the expansion. The diagram shows that at this point the pressure was 15·2 lb per square inch and the volume 13·235 cubic feet. Steam of this pressure has a density of 0·0392 lb per cubic foot. The quan­tity of steam at release was therefore 13·235 × 0·0392, or 0·519 lb, and the quantity of water 0·662 - 0·519 = 0·143 lb. It appears therefore that re-evaporation from the cylinder walls during ex­pansion reduced the amount of water present by 0·079 lb, so that the percentage of water fell from 33·5 at the point of cut-off to 21·6 at the point of release. The same method of calculation can obviously be applied to any other point in the expansion curve, and can be extended to the low-pressure cylinder of an engine which (like the one in this example) is compound. The amount of dry steam present at the point of release is sometimes spoken of as the “steam accounted for by the indicator diagram.”

106. Having completed this analysis of the working-substance, we may proceed to find the quantity of heat whieh it gives to or takes from the walls of the cylinder during any stage of its action, by considering the changes of internal energy whieh the working substance undergoes, along with the external work done, from stage to stage. If we write *m* for the amount of steam and *m'* for the amount of water present in the cylinder at any one stage, the internal energy of the mixture is (§ 62)

(*m* + *m'*)*h* + *mp .*

Let the value of this quantity be denoted by IA at any one stage in the expansion or compression of the mixture, such as the point of cut-off A, and by Ib at a later stage, such as the point of release B, the corresponding volumes of the whole mixture being Va and Vb respectively. Then in passing from the first condition to the second the substance loses Ia - Ib of internal energy. It also does

V

an amount of external work Wab measured by ∕ P*d*V, or the area Va

of the figure AB*ab*. If Wab is equal to Ia-Ib the process is adiabatic ; otherwise the amount of heat taken up (from the cylinder walls) during the process is

Qab = Wab-(Ia- Ib).

If A is the point of cut-off and B that of release, the quantity so calculated is the heat taken up from the cylinder walls during the whole process of expansion. The calculation applies equally, how­ever, in determining the heat taken up during any stage of the process. When this has a negative value heat has been given up by the substance to the cylinder walls. In the numerical example which has been cited above the internal energy of the mixture at the beginning of expansion was 540 thermal units. At the end of expansion the internal energy was 584 thermal units. Between these points the indicator diagram (fig. 28) shows that the work done was equivalent to 55 thermal units. 44 + 55 = 99 units of heat were therefore taken from the cylinder walls during the process of expansion. A similar calculation, applied to the compression curve, shows that in that part of the operation heat was given up to the cylinder walls. During compression W is of course nega­tive, since work is then spent upon the steam.

107. During admission and also during exhaust another item enters into the account,—the amount of the working substance is then undergoing change. To find the heat given up by the steam during admission we have first to calculate (by the method already described) the internal energy of the mixed steam and water that is shut into the clearance space at the end of the previous stroke ; this may be called Id. The steam which then enters brings with it an additional amount of internal energy which we may calculate from a knowledge of the quantity of steam, its pressure at admission, and its dryness. Let Io denote this additional supply of internal energy. At the end of admission the state of the mixture is known from the indicator diagram ; hence its internal energy Ia may be found. The work done during admission, Wda, is also determined from the diagram. Then we have, for the heat given up by the steam during admission,

Qda = Id + Io - Ia - Wda.

In attempting to apply the same method of calculation to de­termine the heat taken up from the cylinder walls during exhaust (Qbc), we are met by the difficulty that we do not know the state, as regards dryness, of the mixture during its expulsion from the cylinder. We may, however, estimate the value of Qbc as follows. Let Qcd and Qda be, as before, the heat given up by the steam to the cylinder walls during compression and admission respectively, and let Qab be the heat taken from the cylinder walls during ex­haust ; also let Qr be the heat which the cylinder loses (per single stroke) by radiation (less the heat produced by piston and valve friction), and QJ the heat which it gains by condensation of steam

in the jacket, if there is one. Then, as the cylinder neither gains nor loses heat on the whole, after a uniform régime has been arrived at, we have qbc = Qcd + QDA + QJ - QR

The quantity Qbc may also be calculated directly from a know­ledge of the gross heat rejected to the condenser, since the gross heat rejected is

Ib + Wbc + Qbc,

Ib being the internal energy of the mixture at release aud Wbc being the work done upon the steam in expelling it from the cylinder.

108. This heat Qbc, which is taken up by the steam from the cylinder walls during exhaust, is a part of the heat deposited there during admission. It has passed through the cylinder without con­tributing in the smallest degree to the work of the engine. Prob­ably for this reason it is treated by some writers as a quantity whieh measures the wasteful influence of the cylinder walls. This, however, is not strictly the case. The magnitude of Qbc is certainly in some sense an index of the extent to which the alternate heating and cooling of the metal causes inefficiency ; it is so much heat absolutely lost, and lost by the action of the walls. [In the high- pressure cylinder of a compound engine this loss is, of course, absolute only as regards that cylinder ; the heat represented by QBC assists in the work of the low-pressure cylinder.] But besides this loss there is another which the walls cause by taking heat from the steam on admission and restoring it during the later stages of expansion. That part of the heat abstracted during admission which is restored before the point of release does not appear in Qbc ; nevertheless it is a source of inefficiency. With steam that is dry at the end of the expansion the value of Qbc is almost negligible ; still the cylinder walls may cause a very sensible loss by abstracting heat from the hot steam as it enters and restoring it as the mixture expands. The quantity which has been denoted here by Qbc— that heat, namely, which the steam takes up from the cylinder walls after release and during exhaust—appears in the writings of Hirn and his followers under the symbol R*c*. He terms it “ le re­froidissement au condenseur,” and refers to it, somewhat inexactly, as “l’effet réel des parois.”@@1 Prof. Cotterill applies the name “exhaust waste” to the sum of the two quantities Qbc and Qr.@@2

109. It is obvious that the above analysis depends fundament­ally on the strict accuracy with which the indicator diagram not only gives a measure of the work done by the engine under test, but shows the relation of pressure to volume at each stage in the process. Engine tests of a complete kind have now been made and discussed by a number of independent observers, working with widely different data. The results are in good general agreement. They demonstrate the influence of the sides beyond question, show­ing that 30 per cent. is no unusual amount of water to be present in the mixture at the point of cut-off, even in compound engines of the best types ; that half of this water, or even more, is frequently found at the end of expansion ; and that the heat denoted above by Qbc ranges from about 10 to 20 per cent. of the whole heat supplied.@@3

110. An engine employed to drive other machinery delivers to it an amount of power less than the indicated power by an amount which is wasted in overcoming the friction of piston and piston- rod, slides, valves, journals, &c. The efficiency of the mechanism is the ratio of the “effective” or “brake” horse-power to the indicated horse-power. It may be tested by measuring the power delivered by the engine when at work, either by using a transmission dynamometer or by substituting an absorption dynamometer for the mechanism usually driven. In the case of a pumping engine the efficiency of the engine and pumps together may be determined by observing the actual work done in raising water or in delivering a measured volume against a known pressure. Attempts are sometimes made to find the amount of power wasted in engine friction by testing the indicated power needed to drive the engine against no other resistance than its own friction. This, however, fails to show the power which will be spent in overcoming friction when the engine runs under ordinary conditions, since the pressures at the slides, the journals, and elsewhere are then widely different from what they are when the engine is running without load. Experiments with large engines show that the efficiency of the mechanism may, in favourable cases, be 0·85 or even 0·9 *; in* small engines, or in large engines running under light loads, it is generally much less than this.

@@@1 *Bull. Soc. Ind. de Mulhouse,* 1881.

@@@2 *The Steam Engine considered as a Heat Engine,* p. 54.

@@@3 In this connexion reference should be made to the data supplied by the American experiments (of Messrs Emery and Loring), some of which are dis­cussed fully by Prof. Cotterill ; also to the writings of Hirn and the extensive researches of the Alsatian engineers alluded to in chap. IV. ; also to Mr Mair's paper (§ 96) and to Mr M. Longridge’s *Reports,* as engineer to the Engine, Boiler, and Employers Liability Association, for 1880, 1881, and 1884. The *Report* for 1884 especially exhibits the results of a test with unique fulness and clearness. The *Journal* of the Franklin Institute for 1885 contains an account of experiments by Messrs Gately and Kletzsch on one engine, under varied conditions of boiler pressure, expansion, and speed; these, so far as they go, confirm the conclusions stated, on general grounds, in chap. IV. For a synopsis of Hirn s method of ana­lysis reference should be made to a paper by M. Poupardin, *Bull. Soc. Ind. de Mul­house,* March 31, 1875.