IV. Actual Behaviour of Steam in the Cylinder.

76. In fig. 18 we have what may be called a first approximation to the theoretical indicator diagram of a steam-engine. In the action then described it was assumed—(1) that the steam supplied was dry and saturated, and had during admission the full (uniform) pressure of the boiler P1 ; (2) that there was no transfer of heat to or from the steam except in the boiler and in the condenser ;

(3) that after more or less complete expansion all the steam was discharged by the return stroke of the piston, during which the back pressure was the (uniform) pressure in the condenser P2 ; (4) that the whole volume of the cylinder was swept through by the piston. It remains to be seen how far these assumptions are un­true in practice, and how far the efficiency is affected in

consequence.

The actual conditions of working differ from these in the following main respects, some of which are illustrated by the practical indicator diagram of fig. 19, which is taken from an actual engine.

77. Owing to the resistance of the ports and passages, and to the inertia of the steam, the pressure within the cylinder is less than P1 during admission and greater than P2 during exhaust.

Moreover P1 and P2 are themselves not absolutely uniform, and P2 is greater than the pressure of steam at the temperature of the condenser, on account of the presence of air in the condenser.

During admission the pressure of steam in the cylinder is less than the boiler pressure by an amount which increases as the piston advances, on account of the increased velocity of the piston’s motion and the consequent increased demand for steam. When the ports and passages offer much resistance the steam is expres­sively said to be throttled or “wire-drawn.” Wire-drawing of steam is in fact a case of imperfectly-resisted expansion (§ 51). The steam is dried by the process to a small extent, and if initially dry it becomes superheated. In an indicator diagram wire-drawing causes the line of admission to lie below a line drawn at the boiler pressure, and to slope downwards. In fairly good practical instances the mean absolute pressure during admission is about nine-tenths of the pressure in the boiler.

In the same way, during the exhaust the actual back pressure exceeds the pressure in the condenser (shown by a dotted line in fig. 19) by an amount depending on the freedom with which the steam makes its exit from the cylinder. In condensing engines with a good vacuum the actual back pressure is from 3 to 5 lb per square inch, and in non-condensing engines it is 16 to 18 lb in place of the mere 14·7 lb which is the pressure of the atmosphere. The excess of back pressure may be greatly increased by the pre­sence of water in the cylinder. The effects of wire-drawing do not stop here. The valves open and close more or less slowly; the points of cut-off and release are therefore not absolutely sharp, aud the diagram has rounded corners at *b* and *c* in place of the sharp angles which mark those events in fig. 18. For this reason release is allowed in practice to occur a little before the end of the forward stroke, hence the toe of the diagram takes a form like that shown in fig. 19. The sharpness of the cut-off, and to a less extent the sharpness of the release, depends greatly on the kind of valves and valve-gear used; valves of the Corliss type (to be described later), which are noted for the suddenness with which admission of steam is stopped, have the merit amongst others of producing a very sharply defined diagram.

78. When the piston is at either end of its stroke there is a small space left between it and the cylinder cover. This space, together with the volume of the passage or passages leading thence to the steam and exhaust valves, is called the *clearance.* It con­stitutes a volume through which the piston does not sweep, but which is nevertheless filled with steam when admission occurs,

and the steam in the clearance forms a part of the whole steam which expands after the supply from the boiler is cut-off. If AC be the volume swept through by the piston up to re­lease, OA the volume of the clearance, and AB the volume swept through during admission, the apparent ratio of expansion is AC∕AB, but the real

ratio is (OA + AC)∕ (OA + AB).

Clearance must obviously be taken

account of in any calculation of curves of expansion. It is conveniently al­lowed for in indicator diagrams by shifting the line of no volume back through a distance corresponding to the clearance (fig. 20). In actual engines OA is from 1/10 to 1/50 of the volume of the cylinder.

79. Clearance affects the thermodynamic efficiency of the engine chiefly by altering the consumption of steam per stroke, and its influence depends materially on the *compression* (§ 72). If during

the back stroke the process of exhaust is discontinued before the end, and the remaining steam is compressed, this cushion of steam will finally fill the volume of the clearance ; and by a proper selection of the point at which compression begins the pressure of the cushion may be made to rise just up to the pressure at which steam is admitted when the valve opens. This may be called complete compression, and when it occurs the existence of clearance has no direct effect on the consumption of steam nor on the efficiency ; the whole fluid in the cylinder may then be thought of as consisting of two parts,—a permanent cushion which is alternately expanded and compressed without net gain or loss of work, and the working part proper, which on admission fills the volume AB (fig. 20), and which enters and leaves the cylinder in each stroke. But if com­pression be incomplete or absent there is, on the opening of the admission valve, an inrush of steam to fill up the clearance space. This increases the consumption to an extent which is only partly counterbalanced by the increased area of the diagram, and the result is that the efficiency is reduced. The action is, in fact, a case of unresisted expansion (§ 51), and consequently tends, so far as its direct effects go, to make the engine less than ever reversible. It is to be noted, however, that by such unresisted expansion the entering steam is dried to some extent, and this helps in a measure to counteract the cause of loss which will be described below. Compression has the mechanical advantage that it obviates the shock which the admission of steam would otherwise cause, and that by giving the piston work to do while its velocity is being rapidly reduced it reduces those stresses in the mechanism which are due to the inertia of the reciprocating parts.

80. The third and generally by far the most important element of difference between the action of a real engine and that of our hypothetical engine is that alluded to at the end of chap. I., the difference which proceeds from the fact that the cylinder and piston are not non-conductors. As the steam fluctuates in temperature there is a complex give-and-take of heat between it and the metal it touches, and the effects of this, though not very conspicuous on the indicator diagram, have an enormous influence in reducing the efficiency by increasing the consumption of steam. Attention was drawn to this action by Mr D. K. Clark as early as 1855 (*Railway Machinery,* or art. Steam-Engine, *Ency. Brit.,* 8th edition@@1), and the results of his experiments on locomotives were confirmed some years later by Mr Isherwood’s trials of the engines of the United States steamer “ Michigan.” Rankine in his classical work on the steam-engine notices the subject only very briefly, and takes no account of the action of the cylinder walls in his calculations. Its importance has now been established beyond dispute, notably by the experiments of Messrs Loring and Emery on the engines of certain revenue steamers of the United States,@@2 and by a protracted series of investigations carried out by M. Hallauer aud other Alsatian engineers under the direction of Him,@@3 whose name should be specially associated with the rational analysis of engine tests. In the next chapter some account will be given of how steam- engines are experimentally examined and how (following Him) we may deduce the exchanges of heat which occur between the steam and the cylinder throughout the stroke. The following is, in gene­ral terms, what experiments with actual engines show to take place.

81. When steam is admitted at the beginning of the stroke, it finds the metallic surfaces of the cylinder and piston chilled by having been in contact with low-pressure steam during the exhaust of the previous stroke. A portion of it is therefore liquefied, and, as the piston advances, more and more of the chilled cylinder surface is exposed and more and more of the hot steam is con­densed. At the end of the admission, when communication with the boiler is eut off, the cylinder consequently contains a film of water spread over the exposed surface, in addition to saturated steam. The boiler has therefore been drawn upon for a supply greater than that corresponding to the volume of steam in the admission space. The importance of this will be obvious from the fact, demonstrated by experiment, that the steam which is thus condensed during admission frequently amounts to 30 and even 50 per cent. of the whole quantity that comes over from the boiler.

82. Then, as expansion begins, more cold metal is uncovered,

and some of the remaining steam is condensed upon it. But the pressure of the steam now falls, and the layer of water which has been previously deposited begins to be re-evaporated as soon as the temperature of the expanding steam falls below that of the liquid layer. On the whole, then, the amount of water present will increase during the earliest part of the expansion, but a stage will soon be reached when the condensation which occurs on the newly exposed metal is balanced by re-evaporation of older portions of the layer. The percentage of water present is then a maximum ; and from this point onwards the steam becomes more and more dried by re-evaporation of the layer.

83. If the amount of initial condensation has been small this

@@@1 See also *Min. Proc. Inst. C.E.,* vol. lxxii. p. 275.

@@@2 A useful abstract of Messrs Loring and Emery's reports is given in *Engineer­*

*ing* vols. xix. and xxi., and in Mr Maw’s *Recent Practice in Marine Engineering.*

@@@3 *Bull. Soc. Industr. de Mulhouse,* from 1877. For other references, see chap. V.