first cylinder. The equation to the curve may then be taken as PV10/9 = constant (§ 67). In the absence of data regarding the wet­ness of the steam this assumption may be considered fair.

122. Lastly, fig. 38 shows a pair of diagrams, treated in the same manner, for a two-cylinder compound engine with cranks at right angles to each other, the high-pressure crank being 90° in advance. During the back stroke of the high-pressure piston there is at first compression into the receiver until the large cylinder opens ; the high-pressure diagram consequently takes a peculiar form, which should be compared with the diagram already given for a tandem engine (§ 118). In this example there is a considerable amount of drop and also of loss between the two cylinders.

VII. The Production of Steam.—Boilers.

123. The first step in the production of steam is to convert the potential energy of fuel into actual heat ; the second step is to transfer the heat to water in the boiler. The efficiency of furnace and boiler is the ratio which the amount of heat taken up by the water bears to the whole potential energy of the fuel. In good boilers this efficiency is about 0·7. The loss is due partly to incomplete combustion of the fuel and partly to incomplete trans­fer of heat from the products of combustion to the boiler water. Under the first head may be classed—(1) waste of fuel in the solid state by bad stoking, and (2) waste of fuel in the gaseous and smoky states by imperfect combustion. Under the second head are comprised—(1) waste by external radiation and conduction, and (2) waste by heat contained in the hot gases which escape by the chim­ney, due *(a)* to their still high temperature and (*b*) to the fact that they contain as one of the products of combustion steam-gas which passes away uncondensed. Loss of heat by the hot gases is the most important source of waste. Not only are the actual products of combustion rejected at a high temperature, but along with them goes the nitrogen of the air whose oxygen has been used, and also a quantity of additional air which is needed to dilute the products in order that combustion may be fairly complete. Roughly speak­ing, about 12 lb of air are required to supply oxygen enough for the combustion of 1 lb of coal. Over and above this quantity, about 12 lb more generally pass through the furnace as air of dilution. In furnaces with forced draught, in which the consumption of coal per square foot of grate surface is much more rapid, the air of dilu­tion may be reduced to half or less than half of this quantity, though to some extent at the expense of completeness in the combustion.

124. The extent to which heat is taken from the hot gases depends on the *heating surface* through which heat passes into the water. The heating surface is made up of the surface of the fur­nace or combustion-chamber, so far as that is brought into con­tact with the water, and of the flues or tubes through which the hot gases pass on their way to the chimney. Its efficiency depends on the conductivity of the metal, on the difference in temperature between the gases on one side and the water on the other, and on the freedom with which steam, when formed, can escape from the surface. Differences in specific conductivity and in thickness of metal affect the result less than might be expected, on account of the resistance which is offered to the passage of heat through the film of scale and also through the film of water vapour which forms on the metallic surface.

By extending the heating surface sufficiently the hot gases may be deprived of heat to an extent which is only limited by the tempera­ture of the boiler water. This temperature, however, need not form a limit, for after leaving the boiler the gases may be further cooled by being brought into contact with a vessel termed a feed-water heater, through whieh the feed-water passes on its way to the boiler. Even with a feed-water heater, however, the temperature of the hot gases is never, in practice, reduced so low as that of the boiler.

125. In nearly all land engines and most marine engines the draught is produced by means of a chimney, which acts in virtue of the column of air within it being specifically lighter than the air outside, so that the pressure within the chimney at its base is less than the atmospheric pressure at the same level outside. The composition of tire chimney gases is such that they are heavier than air at the same temperature, and to make them sufficiently lighter to cause a draught they must retain a certain considerable portion of their heat. On the other hand, if they are left too hot the mass of air drawn through the furnace is actually diminished, since then the chimney gases are so much expanded that the increased volume of the draught does not compensate for its diminished density. With a given chimney and furnace the maximum draught is obtained when the gases escape at a tempera­ture about that of melting lead ; by making the chimney more capacious a lower temperature will suffice to give the same draught, and this will of course increase the efficiency of the boiler.

126. In place of using a chimney draught depending merely on the temperature of the rejected hot gases, the air required for com­bustion and dilution may be forced through the furnace either by producing a partial vacuum in the chimney or by supplying air to the grate at a pressure higher than that of the atmosphere. In

locomotives, for example, a partial vacuum is produced in the chimney by means of a blast of exhaust steam from the engine ; aud in many naval and a few mercantile steamers a forced draught is produced by having a closed stokehole or a closed ashpit, whieh is supplied with air at a pressure above that of the atmosphere by the use of a blowing fan.

If heat were thoroughly extracted from the products of com­bustion, a forced draught would be more efficient, from the thermo­dynamic point of view, than a chimney draught, for a chimney is in fact an extremely inefficient heat-engine, and requires a very large amount of heat to be expended in order to effect the comparatively trifling work of maintaining the draught. But where forced draught has been substituted for chimney draught this has hitherto been done for the purpose of increasing not the efficiency but the *power* of boilers. The motive has been to burn more coal per square foot of grate surface and so to evaporate more water with a boiler of given weight. This is incompatible with very high efficiency. When more coal is burnt by forcing the draught it is true that the products of combustion have a higher temperature (since less air is required for dilution) and the effective­ness of the heating surface is therefore increased. But the heat­ing surface has more hot gas to deal with, and the result is that the boiler is less efficient than when the draught is not forced. The same efficiency could be secured, with forced draught, by increasing the heating surface to a sufficient extent ; and a still greater efficiency could be realized if the heating surface were still further enlarged so that the gases left the flues at a temperature lower than would be needful if the draught depended on the light­ness of the chimney’s contents. The most efficient boiler would be one in which the draught was forced by mechanical means, and the gases were then cooled as far as possible by contact with a very extensive heating surface, first in the boiler itself and then in a feed-water heater. None of the forced draught boilers that have hitherto been introduced have a heating surface so large as to make them more efficient than good chimney-draught boilers (in which the rate of combustion is much slower), although the heating surface bears a much larger ratio to the grate area than is usual with chimney draughts.

127. Most modern boilers are internally fired ; that is to say, the furnaces are more or less completely enclosed within the boiler. Externally fired boilers are for the most part much less efficient than internally fired boilers ; they are, however, used to a consider­able extent where fuel is specially cheap or where the waste heat of other furnaces is to be utilized. Their usual form is that of a horizontal cylinder with convex ends ; the strength both of the main shell and the ends is derived from their curvature, and no

staying is necessary. The heating surface is entirely external and is of very limited extent.

In large stationary boilers the forms known as the “ Lancashire ” (or double flue) and the “ Cor­nish” (or sin­gle flue) are most common.

Figs. 39 and

40 show in

section a Cor­

nish boiler by

Messrs Gallo­

way, and fig.

41 a Lanca­

shire boiler by

the same mak­

ers. In both

the shell is a

round horizon­

tal cylinder

with flat ends.

In the Cornish

boiler there is

one internal

flue, at the

front end of

which is the furnace. The hot gases pass through the flue to the back ; they then return to the front end by two external side flues