of tubes, generally of brass, about 3/4 of an inch in diameter. Through these cold sea-water is made to circulate, while the steam is brought into contact with their outside surfaces. In some cases, especially in Admiralty practice, cold water circulates outside the tubes and the steam passes inside.

226. The ordinary marine engine has four pumps:—the air-pump, which is made large enough to serve in case injection instead of surface-condensation should at any time be resorted to; the feed­pump; the circulating-pump, which maintains a current of sea­water through the

tubes of the condenser;

and the bilge-pump,

which discharges any

water accumulated by

leakage or otherwise

in the bilge of the

ship. The pumps are

so arranged that in the

event of a serious leak

the circulating-pump

can also draw its sup­

ply from the bilge. In

most engines, especi­

ally those of less re­

cent construction, the

four pumps are placed

behind the condenser,

and are worked by a

single crosshead driven

by a lever, the other

end of which is con­

nected by a short link

with one of the cross­

heads of the engine.

It is now becoming

common to use a small

engine, distinct from

the main engine, to

drive the feed-pump,

and to supply circulat­

ing water by a centri­

fugal pump also driven

by a separate engine.

227. In the improve­ment of the marine en­gine two points are note­worthy,—reduction in the rate of consump­tion of coal per horse­power, and reduction in the weight of the machine (comprising the engine proper anti the boilers) per horse­power. The second consideration is in some cases of even more moment than the first, especially in war-ships.

Progress has been made, in both respects, by increase of steam pressure, and, in the second respect espe­cially, by increase of piston speed. Fifty years ago the boilers of marine engines made steam at a pressure of about 5 lb per square inch above that of the atmosphere. By 1860 compound engines were in use with pressures ranging from 25 to 40 lb. In 1872 statistics collected for nineteen ocean steamers showed that the average con­sumption of coal was then 2·11 lb per H.P. per hour, the boiler- pressure 45 to 60 lb, and the mean piston speed about 375 feet per minute.@@1 These were for the most part two-cylinder compound engines of the vertical inverted type. Nine years later statistics for thirty engines of the same type showed a consumption of 1·83 lb of coal, a mean boiler pressure of 771/2 lb, and a mean piston speed of 467 feet per minute.@@2 In recent triple-expansion engines the pressure is as high as 165 lb ; a piston speed of 700 or 800 feet per minute is not uncommon in naval engines, aud in some cases it has risen to

over 1000 feet per minute.@@3 The economy in coal consumption brought about by the change from double-expansion engines work­ing at (say) 80 lb to triple engines at 160 lb or more is variously estimated at from 18 to 25 per cent. Much of this is due simply to the increased range of temperature through which the working substance is carried ; but it appears that the actual performance of the triple engine is better than that of the double compound in a ratio greater than that by which its ideal efficiency—as an engine using a wider range of temperature—exceeds that of the other; and this is to be ascribed to the same causes as have been already dis­cussed in speaking of the advantage of the compound over the simple engine. Apart from its greater eco­nomy of coal, the triple engine owes some of its practical success to the mechanical superiority of three driving cranks

over two.

228. The relation of weight of machinery to power developed, and the causes which affect this ratio, have recently been discussed by Messrs Marshall and Weighton,4 from whose paper the following figures are taken. Be­fore the introduction of triple expansion and forced draught the weight of engines in the mercantile marine, including the boilers and the water in them, was 480 lb per I.H. P. In the navy this was reduced, chiefly by the use of lighter framing, with the object of minimizing weight, to 360 lb. Triple-engines of the merchant type, without forced draught, are only slightly lighter than double engines ; but in naval practice, where forced draught, greatly increased speed, and the use of steel for frames and working parts have combined to reduce the ratio of weight to power, a marked reduction in weight is apparent. A recent set of vertical triple engines, which with natural draught indicate 2200 H.P., and with a draught forced by pressure in the stokehole equal to 2 inches of water indi­cate 4000 H. P., weigh under the latter condi­tion (along with the boilers) only 155 lb per

I.H.P. In another set, in which the draught is forced by a pres­sure of 3 inches, and the cylinders are only 151/2, 24, and 37 inches in diameter, with a stroke of 16 inches, the indicated horse-power is 4200, and the weight of engines and boilers is 136 lb per I.H.P. In these the boilers are of the locomotive type, and the mean piston speed is 1066 feet per minute. Even these light weights are sur­passed in smaller engines, such as those of torpedo boats. In so far as this immense development of power from a small weight o machinery is due to high piston speed it is secured without loss —indeed with some gain—of thermodynamic efficiency , forced draught, however, without a corresponding extension of the heating

@@@1 Sir F. J. Bramwell, *Proc. Inst. Mech. Eng.*,1872.

@@@2 F. C. Marshall, *Proc. Inst. Mech. Eng.,* 1881.

@@@3 Marshall and Weighton, *Proc. North-East Coast Inst. Engineers and Ship­builders,* 1886. *Loc. cit.*