In place of the ordinary indicator an apparatus is occasionally used which integrates the two coordinates which it is the business of the indicator diagram to represent, and exhibits the power developed from stroke to stroke by the progressive movement of an index round a dial.

102. In tests of thermodynamic efficiency we may measure either the heat supplied or the heat rejected, and compare it with the work done. The heat supplied is on the whole capable of more exact measurement, but in any case a determination of the heat rejected furnishes a valuable check on the accuracy of the result. The trial must be continued for a period of some hours at least, during which the engine and boiler are to be kept working as uniformly as possible in all respects. The power is determined by taking indicator diagrams at short intervals. The heat supplied is found by noting the amount of feed-water required to keep the water- level in the boiler constant during the trial, the temperature of the feed, aud the pressure of the steam. The only uncertainty which attaches to the measurement of heat-supply is due to priming. Every pound of water that passes over unevaporated to the engine takes less heat by the amount L (§ 60) than if it went over in the state of steam. To measure the degree of wetness in steam is a matter of some difficulty ; it may be done by passing the steam into a known quantity of cold water, so as to condense it, and observing the rise of temperature which has taken place when the whole quantity of water present has increased by a measured amount.

If L1 be the latent heat of steam at the boiler pressure, *h*0 the heat in the feed-water per lb, *h*1 the heat in the boiler water per lb, and *q* the dryness of the steam as it leaves the boiler, the heat taken in per lb of the substance supplied to the cylinder is

*q*L1 + *h*1 — *h*0 *.*

To this must be added, in the case of a jacketed engine, the heat supplied to the jacket, a quantity which depends on the amount of steam condensed there, and also on whether the water that gathers in the jacket is drained back into the boiler or allowed to escape into the hot-well.

The heat rejected by an engine fitted with an injection condenser is made up of the following parts :—(*a*) heat rejected in the con­densed water, less the heat returned to the boiler in the feed (if the feed is directly drawn from the hot-well without giving the water time to cool sensibly, this quantity vanishes ; in a jacketed engine this item must include the heat rejected in the jacket drains) ; (ό) heat used in warming the condenser water from the temperature of injection to the temperature of the air-pump discharge ; (c) heat rejected in air and vapour from the air-pump ; (*d*) heat lost by radiation, conduction to supports, and aerial convection,—or, more properly, the excess of this heat over the heat developed within the engine by the friction of piston, valves, &c. Of these quanti­ties, (*a*) is found without difficulty from a knowledge of the amount of the feed-water, its temperature, the temperature of the air-pump discharge, and amount and temperature of water drained from the jacket ; (5) is measured by gauging the whole discharge from the pump, deducting from it the amount returned to the boiler as feed­water, and measuring its temperature and that of the injection water ; (*c*) does not admit of direct measurement ; (*d*) may be approximately estimated for a jacketed engine by filling the jacket with steam while the engine is out of action, and observing the amount of steam condensed in the jacket during a long interval, through radiation, &c., from the external surface.

In calculating the supply of heat by the boiler it is convenient to take the temperature 32° F. as a starting point from which to reckon what may be termed the gross supply, and then to deduct from this the heat which is restored to the boiler in the feed-water. The difference, which may be called the net supply, is the true consumption of heat, and is to be used in calculating the efficiency of the engine. A similar convention may be followed in dealing with the heat rejected.

103. This subject is most easily made intelligible by help of a numerical example. For this purpose the following data of an actual engine-test have been taken from one of Mr Mair’s papers@@1 ; the data have been independently reduced, with results that differ only to a small and unimportant extent from those stated by Mr Mair. The engine under trial was a compound beam engine, steam- jacketed, with an intermediate receiver between the cylinders. The cylinders were 21 inches and 36 inches in diameter, and the stroke 51/2 feet. The total ratio of expansion was 13·6.

*Data.*

Boiler pressure, absolute, 76 lb per sq. in.

Time of trial 6 hours.

Revolutions 8632, or 24·0 per min.

I.H.P 127 4.

Feed-water 12,032 lb, or 1∙394 lb per rev. (M.).

Air-pump discharge 1226 lb per min., or 51-1 lb per rev

Water drained from jackets 1605 lb, or 0·186 lb per rev. (M*j*).

Percentage of priming 4.

Temperature of feed, *t*059°

Temperature of injection, *t*2 50°.

Temperature of air-pump discharge, *t*3...73°∙4.

*Results.*

Dryness of boiler steam, *q*=0∙96.

Supply to cylinder, M*c* =M—M*j*=∙l∙028 lb per rev.

Injection water per rev. = 51·1—1·208 = 49∙9 lb.

L1 = 898, *h*1 = 278, *h*2*=18*, *h*3 = 41∙4, *h*0 = 27.

Gross supply of heat from boiler to cylinder per revolution = M*c* (qL1+h1)

= l∙208 (0∙96 × 898+278) = 1377 T.U.

Gross supply of heat from boiler to jackets per revolution

=M (*q*L1+h1)

= 0∙186 (0·96 X 898+278)=212 T.U.

Total gross supply per revolution=1377+212 = 1589 T.U.

Heat restored to boiler per revolution,

By feed water=M*h*0=l∙394×27 = 38 T.U By jacket drains = 0.

*Net* supply of heat per revolution = 1589—38 = 1551 T.U.

Heat converted into work, per revolution

= I.H.P. ×42∙75/24=227 T.U.

Total heat rejected per revolution = 1551—227 = 1324 T.U.

The rejected heat is accounted for as follows :—

Net heat rejected in air-pump discharge = Gross heat rejected in air-pump dis­charge-heat in injection water—heat restored to the boiler by the feed

= 51∙1 ×41∙4-49∙9×18-38 = 1179 T.U.

Heat rejected in jacket drains = Mj*h*1 = 0·186×278 = 52 T.U.

These two items account for 1231 units of rejected heat and leave a balance of 93 units unaccounted for. The balance is made up of heat rejected in air and vapour by the air-pump, heat lost by radiation, &c., and errors of experiment. In the example con­sidered the loss by radiation was estimated at 45 thermal units, which reduces the discrepancy between the two sides of the account to 48 units, or only about 3 per cent. of the whole heat supplied.

The efficiency of the engine is 227/1551 or 0·146. The efficiency of a perfect engine working between the same limits of temperature, 308° F. and 50° F., would be 0·335.

104. When it is desired to deduce from the test of an engine not only the thermodynamic efficiency but also the amount of initial condensation and the subsequent changes of wetness which the working fluid undergoes during expansion, it is necessary to know, in addition to the above data, the volume of cylinder and clearance, the relation of pressure to volume during the several stages of the stroke, and the whole amount of working substance present in the cylinder. This last is a quantity whose precise value is not easily ascertained. Assuming that the point at which compression begins can be distinguished on the diagram, we have the pressure and the volume of the steam that is afterwards compressed into the clear­ance space. From its pressure and volume we can infer its amount, if only its degree of dryness be known. The assumption usually made is that at the beginning of compression the steam shut up in the cylinder is dry. This assumption is to a certain extent supported by the fact that re-evaporation has been going on during expansion and exhaust ; in good engines it is probably not far from the truth, though there are cases where, owing to excessive initial condensa­tion and to the exhaust ports being badly situated for draining the cylinder, water may accumulate in considerable quantities. Except in extreme cases of this kind, however, the assumption that the steam is dry when compression begins does not introduce an error which can seriously affect the subsequent calculations. Hav­ing found the quantity shut up in the clearance, we add to it the quantity delivered from the boiler per single stroke, to find the whole quantity of working substance in the cylinder. The sub­stance is, and continues, a mixture in varying proportions of steam and water. Its volume may practically be taken as the volume of the dry steam it contains, the volume of the water being compara­tively small. Taking any point of the stroke, and measuring the pressure and the volume there, we can say how much steam (at that pressure) would be required to fill the volume which the mix­ture then occupies. This quantity will always be less than the actual amount of the mixture ; and the difference between them is the amount of water that is present. This calculation is of special interest at two places in the stroke—the point of cut-off and the point of release.

105. To illustrate it we may continue the numerical example quoted above. In the high-pressure cylinder of the engine to which the test refers the volume at the beginning of com­pression (including clearance) was 1·52 cubic feet. The pressure, just before compression began, is shown by the indicator diagram (of which fig. 28 is a copy) to have been 14·8 lb per square inch. At this pres­

sure the density (or mass of 1 cubic foot)

of steam is 0·038 lb. Hence (on the above

assumption that the steam was then dry)

the quantity shut up in the clearance was

l∙52×0∙038 = 0∙058 lb.

The amount delivered to the cylinder per single stroke (or half revolution) was 0·604 lb). The whole quantity of working substance present from the end of the admission to the beginning of the exhaust was therefore 0·662 lb.

At the point of cut-off the pressure is shown by the diagram to have been 64 lb per square inch (absolute), and the volume, includ­ing clearance, was 2·92 cubic feet. The density of steam for this

@@@1 *Min. Proc. Inst. C. E.,* vol. lxx.