by Professors Callendar and Nicolson *(Proc. Inst. C.E.* cxxxi. 147), who studied the cyclic variations of temperature throughout the metal by means of thermo-electric junctions set at various depths. They found that the range of temperature through which the surface of the metal fluctuates is much less than the range of temperature passed through by the steam; the processes of condensation and re-evaporation are slow, and the time is too short to bring the surface of the metal into anything like equilibrium with the steam. The amount of condensation up to the point of cut-off, as inferred from the heat which the metal takes up, may be much less than the “ missing quantity ” or difference between the steam supplied per stroke and the dry steam then present. According to their experiments, this discrepancy is accounted for by leakage of steam past the valve, direct from the steam chest to the exhaust, and they suggest that this source of error may have been present in many estimates of initial condensation based on determinations of the missing quantity. This may explain cases in which the initial condensation has apparently been excessive, but large amounts of initial condensation certainly do occur, and constitute the most potent factor in making the real performance of the engine fall short of the ideal standard.@@1

In the alternate condensation and re-evaporation of steam in the cylinder more heat is given to the metal by each pound of steam that is condensed than is taken from the metal by each pound of steam that is re-evaporated, the temperature of condensation being higher than that of re-evaporation. The quantity H1-H2, namely, the difference in the heat of formation at the two temperatures, repre­sents this excess of heat. Unless this is in some way abstracted from the metal, the process cannot occur. Hence the action of the cylinder walls in causing alternate condensation and re-evaporation to occur may be limited by imposing conditions which prevent or reduce the abstraction of heat. By the use of a steam jacket the metal may be prevented from losing heat externally, and may even be made to take up heat. Under these conditions the action depends on the fact that more water is re-evaporated than is con­densed. To some extent this is a necessary result of the work done during expansion, which (in an adiabatic process) would make the steam become wetter as expansion proceeds, and would therefore leave more water to be evaporated than is initially condensed by the action of the cylinder walls. But it is important to notice that any water which is introduced into the cylinder along with the steam will be an important factor in supplying the means by which this thermal balance is maintained. With steam that is. perfectly dry before admission, the action of the walls takes its limit from the condensation which expansion brings about; with steam that is wet before admission no such limit applies. Hence the importance of having steam that is initially dry. To secure this, no method is so certain as to give some initial superheat to the steam, and hence arises the practical advantage which even a small amount of superheating is found to bring about.

47. *Influence of the Slide-Valve.—*To a considerable extent the slide-valve itself promotes initial condensation, for it requires that the hot steam shall enter the cylinder, through a passage which, immediately before, was chilled by being used for the escape of exhaust steam. The use of entirely distinct admission and exhaust ports and valves tends towards economy of steam, partly for this reason and partly because it allows the clearance spaces to be reduced. Accordingly, we find that many of the best recorded results of tests relate to engines in which each cylinder has four separate valves of the Corliss or of the drop type. By using hori­zontal cylinders with admission valves on the top and exhaust valves below, the further advantage of drainage through the exhaust valves is secured. Water which is present at release has then the chance of escaping without being re-evaporated, a circumstance which contributes largely to reduce the exchange of heat between the working substance and the metal. Thus a horizontal triple­expansion engine with drop valves, by Messrs Sulzer, using saturated steam at an absolute pressure of 160 lb per sq. in., and indicat­ing not much more than 200 h.p., is reported, in a test by Professor Stodola, to have used only 11∙52 lb of steam per indicated horse-power-hour (see *Engineer,* July 1, 1898; also\* summary of trials by B. Donkin, ibid., Oct. 13, 1899). The performance in this test is equivalent to nearly 69% of the ideal, an exceptionally high figure. In one or two trials of larger engines even this performance has been surpassed, 11∙2 and 11∙3 lb per horse-power-hour having been recorded. In other particularly favourable records of trials the consumption of steam with triple-expansion engines has been found to lie between 12 and 13 ft) per horse-power-hour. Some of the best results relate to slow-running pumping engines fitted with steam jackets on the barrels and on the covers of the cylinders, and may be taken as showing how. influential, in a long-period engine, the jacket may prove in reducing the evils of initial condensation. In the mean of several apparently authoritative trials by different observers on different engines the consumption of steam was 12∙2 ìb per horse-power-hour, at an absolute pressure of about 140 lb per sq. in., which corresponds to 66% of the ideal performance.

It should be added that these figures are exceptional. A consump­tion of 13 or 14 lb of steam per horse-power-hour is much more usual even in large and well-designed triple-expansion engines; and with two-cylinder compound engines, using steam with an absolute pressure of 100 or 120 lb per sq. in., anything from 14 to 15 lb may be reckoned a good performance.

48. *Superheated Steam —*The advantage of superheated steam, which arises mainly from its influence in reducing the exchange of heat between the steam and cylinder walls, was demonstrated by the experiments of Hirn, and as early as i860 it was not unusual to supply superheaters with marine engines. But the practice of superheating was soon abandoned, chiefly on account of difficulties in regard to lubrication. By the introduction of heavy mineral oils this objection has been removed, and a revival in the use of super­heating has taken place, with striking effect on the thermodynamic economy of engines. Experiments made in 1892. by the Alsatian Society of Steam Users on a large number of engines showed that superheating effected an average saving in coal to the extent of about 20%, when the superheater was simply placed in the boiler flue, so that it utilized what would otherwise be waste heat, and about 12% when the superheater was separately fired. In those cases the steam was superheated only about 30° to 45° C. above the temperature of saturation, but in more recent practice much greater amounts of superheat have been successfully applied. Professor Schröter has tested a factorý engine of 1000 h.p.., using steam super­heated by some 50° C., and has shown that this amount of super­heat is not sufficient to prevent some of the steam from becoming condensed on the walls during admission to the cylinder *(Zeitschrift des Vereins deutscher Ingenieure,* vol. xl., 1896). It follows that still larger amounts of superheat will be thermodynamically advantageous. That this is the case has been demonstrated by the remarkable results which have been obtained with highly superheated steam by W. Schmidt in stationary engines and locomotives. Using a somewhat special design, Schmidt has shown that it is perfectly practicable to employ steam superheated to a temperature of 400° C., and that an efficiency not attainable from steam in any other way is thereby reached. In several authentic trials of Schmidt engines the consump­tion of steam has been considerably less than 10 lb per indicated horse-power-hour—a figure which, after allowance is made for the heat taken up during the process of superheating, represents a better performance than that of the best engines using saturated or slightly superheated steam. It has been found that the consumption of coal, in the boiler and superheater together, need not exceed 11/3 lb per indicated horse-power even with engines of small power. To attain this remarkable result it is of course necessary that, after the hot gases from the furnace have passed the superheater, a further extraction of heat from them should take place. This is done by an economizer or feed-water heater of peculiar form, consisting of a long coil of small pipes which maintain a circulation of hot distilled water through a closed system containing an external coil, which forms the heater of a tank through which the feed-water passes on its way to the boiler. Some of the Schmidt engines adopt the principle of single action, to escape the necessity of having a piston-rod and gland on the side which is exposed to contact with high-temperature steam ; but it is found that this precaution is not essential, and that with glands of suitable design a double-acting piston may be used without inconvenience, and without risk of undue wear. In some instances Schmidt transfers to the partially expanded steam in the interme­diate receiver a portion of the heat which is conveyed to the engine by the highly superheated steam ; and when this is done, the steam may properly receive a still higher degree of initial superheat. Accordingly, though the initial temperature of the steam may be 400° C. or more, this is reduced to about 320° by transfer to steam in the superheater before the high-pressure steam is admitted to the cylinder. In tests by the present writer of a Schmidt plant indica­ting 180 h.p., in which this device was employed, the steam was superheated to 397° C. and 10∙4 lb were used per horse-power- hour. In this trial the temperature of the chimney gases was reduced, by the use of Schmidt’s feed-water heater, to 175° C., and the consumption of coal was 1∙31 lb per indicated horse-power-hour. In another trial, of a larger engine with steam superheated to 425° C., the consumption of steam per horse-power-hour was only 9∙0 lb.

49. *The Indicator.—*The actual behaviour of steam in the cylinder of a steam engine is studied by means of the indicator, which serves not only to measure the work done but to examine the operation of the valves and generally to give much useful information regarding the action of the engine. The indicator, which was invented by Watt, and improved by Richards, is a device for automatically drawing a diagram showing the pressure at all points of the piston’s stroke. In its most usual form it consists of. a small steam cylinder fitted with a piston which slides easily within it and is pressed down by a spiral spring of steel wire. The cylinder of the indicator is connected by a pipe below this piston to one or other end of the cylinder of the engine, so that the piston of the indicator rises and falls in response to the fluctuations of pressure which occur in the engine cylinder. The indicator piston actuates a pencil, which rises and falls with it and traces the diagram on a sheet of paper fixed to a drum that is caused to rotate back and forth through a certain arc, in unison with the motion of the engine piston. In

@@@1 See also “ Report of Steam Engine Research Committee,” *Inst. Mech. Eng.* (1905).