re-evaporation may be complete before release occurs. Very usually, however, there is still an undried layer at the end of the forward stroke, and the process of re-evaporation continues during the return stroke, while exhaust is taking place. In extreme cases, if the amount of initial condensation has been very great, the cylinder walls may fail to become quite dry even during the exhaust, and a residue of the layer of condensed water may either be carried over as water into the condenser, or, if the exhaust valves are so badly arranged as to prevent its discharge, this unevaporated residue may gather in the cylinder, requiring perhaps the drain-cocks to be left open to allow of its escape. When any water is retained in this way the initial condensation is enormously increased, for the hot steam then meets not only cold metal but cold water. The latter causes much condensation, partly because of its high specific heat, and partly because it is brought into intimate mixture with the entering steam.

84. Apart, however, from this extreme case, whatever water is re-evaporated during expansion and exhaust takes heat from the metal of the cylinder, and so brings it into a state that makes con­densation inevitable when steam is next admitted from the boiler. Mere contact with low-pressure steam during the exhaust stroke would cool the metal but little ; the cooling which actually occurs is due mainly to the re-evaporation of the condensed water. Thus if an engine were set in action, after being heated beforehand to the boiler temperature, the cylinder would be only slightly cooled during the first exhaust stroke, and little condensation would occur during the next admission. But the metal would be more cooled in the subsequent expansion and exhaust, since it would part with heat in re-evaporating this water. In the third admission more still would be condensed, and so on, until a permanent régime would be established in which condensation and re-evapora­tion were exactly balanced. The same permanent régime is reached when the engine starts cold.

85. The wetness of the working fluid to which the action of the walls of the cylinder gives rise is essentially superficial. A film of water forms on the walls, but except for this the body of the steam remains dry, until (by adiabatic or nearly adiabatic expansion) it becomes wet throughout its volume. The water formed by the act of expansion takes form as a mist diffused throughout the steam, and on it the sides of the cylinder exert practically no influence. This latter wetness is in fact increasing while the substance, as a whole, is getting dried by the re-evapora­tion of the liquid film. During expansion the working substance may be regarded as made up of two parts,—a core of steam, which is expanding adiabatically but is at the same time receiving addi­tions to its amount in the form of saturated steam from the liquid layer, and a liquid layer which is turning into steam.

86. From a thermodynamic point of view all initial condensation of the steam is bad, for, however early the film be re-evaporated, this can take place only after its temperature has cooled below that of the boiler. The process consequently involves a misappli­cation of heat, since the substance, after parting with high tempera­ture heat, takes it up again at a temperature lower than the top of its range. This causes a loss of efficiency (chap. II.), and the loss is greater the later in the stroke re-evaporation occurs. The heat that is drawn from the cylinder by re-evaporation of the condensed film becomes less and less effective for doing work as the end of the expansion is approached, and finally, whatever evaporation continues during the back stroke is an unmitigated source of waste. The heat it takes from the cylinder does no work ; its only effect, indeed, is to increase the back pressure by augmenting the volume of steam to be expelled. A small amount of initial condensation reduces the efficiency of the engine but little; a large amount causes a much more than proportionally larger loss.

87. The action of the cylinder walls is increased by any loss of heat which the engine suffers by radiation and conduction from its external surface. The entering steam has then to give up enough heat to provide for this waste, as well as enough to produce the subsequent re-evaporation of the condensed film. The consequence is that more steam is initially condensed. The loss of efficiency due to this cause will therefore be greater in an unprotected cylinder than in one which is well lagged or covered with non­conducting material. On the other hand, if the engine have a steam-jacket the deleterious action of the walls is reduced. The working substance is then on the whole gaining instead of losing heat by conduction during its passage through the cylinder. The jacket accelerates the process of re-evaporation and tends to make it finish at a point in the stroke when the temperature of the steam is still comparatively high. When the process is complete the cylinder walls give up very little additional heat to the steam during the remainder of the expansion and exhaust, for conduction and radiation between dry steam and the metal of the cylinder are incompetent to cause any considerable exchange of heat. The earlier, therefore, that evaporation is complete the less is the metal chilled, and the less is the subsequent condensation. Moreover, after this stage in the stroke has passed, a steam-jacket continues

to give heat to the metal during the remainder of the double stroke, and so warms it to a temperature more nearly equal to that of the boiler steam before the next admission takes place.

88. Thus a steam-jacket, though in itself a thermodynamically imperfect contrivance, inasmuch as its object is to supply heat to the working substance at a temperature lower than the source, acts beneficially by counteracting, to some extent, the more serious misapplication of heat which occurs through the alternate cooling and heating of the cylinder walls. The heat which a jacket com­municates to working steam often increases the power of an engine to an extent far greater than corresponds to the extra supply of heat which the jacket itself requires. Besides its thermodynamic effect a jacket has the drawback that it increases waste by external radiation, since.it both enlarges the area of radiating surface and raises its temperature ; notwithstanding this, however, many ex­periments have shown that in large and especially in slow-running engines, the influence of a steam-jacket on the efficiency is, in general, good; and this is to be ascribed to the fact that it reduces, though it does not entirely remove, the evils of initial condensation. To be effective, however, jackets must be well drained and kept full of “ live ” steam, instead of being, as many are, traps for con­densed water or for air.

89. It is interesting to notice, in general terms, the effects which certain variations of the conditions of working may be expected to produce on the loss that occurs through the action of the cylinder walls. Initial condensation will be increased by anything that augments the range of temperature through which the inner surface of the cylinder fluctuates in each stroke, or that exposes a larger surface of metal to the action of a given quantity of steam, or that prolongs the contacts in which heat is exchanged. The influence of time is specially important; for it must be borne in mind that the whole action depends on the rate at which heat is conducted into the substance of the metal. The changes of temperature which the metal undergoes are in every case mainly superficial ; the alternate heating and cooling of the inner surface initiates waves of high and low temperature in the iron whose effects are sensible only to a small depth ; and the faster the alter­nate states succeed each other the more superficial are the effects. In an engine making an indefinitely large number of strokes per minute the cylinder sides would behave like non-conductors and the action of the working substance would be adiabatic.

We may conclude, then, that in general an engine running at a high speed will have a higher thermodynamic efficiency than the same engine running at a low speed, all the other conditions of working being the same in both cases.

Again, as regards range of temperature, the influence of the cylinder walls will be greater (other things being equal) with high than with low pressure steam, and in condensing than in non- condensing engines. On the other hand, high pressure has the good effect of reducing the surface of metal exposed to the action of each pound of steam.

In large engines the action of the walls will be less than in small engines, since the proportion of wall surface to cylinder volume is less. This conclusion agrees with the well-known fact that no small engines achieve the economy that is easily reached with larger forms, especially with large marine engines, which eclipse all others in the matter of size.

Cylinder condensation is increased when the ratio of expansion is increased, all the other circumstances of working being left unaltered. The metal is then brought into more prolonged contact with low-temperature steam. The volume of admission is reduced to a greater extent than the surface that is exposed to the entering steam, since that surface includes two constant quantities, the surface of the cylinder cover and of the piston. For these and perhaps other reasons, we may conclude that with an early cut- off the initial condensation is relatively large ; and this conclusion is amply borne out by experiment. An important result is that increase of expansion does not, beyond a certain limit, involve increase of thermodynamic efficiency ; when that limit is passed the augmentation of waste through the action of the cylinder walls more than balances the increased economy to which, on general principles, expansion should give rise, and the result is a net loss. With a given engine, boiler pressure, and speed, a certain ratio of expansion will give maximum efficiency. But the conditions on which this maximum depends are too complex to admit of theoretical solution ; the best ratio can be determined only by experiment. It may even happen that an engine which is required to work at a specified power will give better results, in point of efficiency, with moderate steam-pressure and moderate expansion, than with high steam-pressure and a *very* early cut-off.

90. The effect of increased expansion in augmenting the action of the sides and so reducing the efficiency, when carried beyond a certain moderate grade, is well illustrated by the American and Alsatian experiments alluded to above. The following figures (Table III. ), relating to a single-cylinder Corliss engine, are reduced from one of Hallauer’s papers:@@1—

@@@1 *Bull. Soc. Industr. de Mulhouse,* May 26, 1880.