made.@@1 The relation of P to V may be approximately expressed by the formula@@2

PV17/16 = constant = 68500 (nearly), when P is stated in lb per sq. ft. and V in cub. ft. per lb.

Table II.—*Properties of Saturated Steam.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Temperature. | Pressure. | Volume of 1 tb. | Heat of Formation. | |
| II. | Λ. |
| Degrees F. | lb per sq. in. | Cub. Ft. | Thermal Units. | Thermal Units. |
| 32 | 0∙085 | 3390 | 1091∙8 | 0 |
| 41 | 0∙122 | 2406 | 1094∙5 | 9∙0 |
| 50 | 0∙173 | 1732 | 1097∙3 | 18∙0 |
| 59 | 0∙241 | 1264 | 1100∙0 | 27∙0 |
| 68 | 0∙333 | 935 | 1102∙8 | 36∙0 |
| 77 | 0∙452 | 699 | 1105∙5 | 45∙0 |
| 86 | 0∙607 | 529 | 1108∙2 | 54∙0 |
| 95 | 0∙806 | 405 | 1111∙0 | 63∙0 |
| 104 | 1∙06 | 313 | 1113∙7 | 72∙0 |
| 113 | 1∙38 | 244 | 1116∙5 | 81∙0 |
| 122 | 1∙78 | 192 | 1119∙2 | 90∙1 |
| 131 | 2∙27 | 152∙4 | 1121∙9 | 99∙1 |
| 140 | 2∙88 | 122∙0 | 1124∙7 | 108∙1 |
| 149 | 3∙62 | 98∙45 | 1127∙4 | 117∙1 |
| 158 | 4∙51 | 80∙02 | 1130∙2 | 126·2 |
| 167 | 5∙58 | 65∙47 | 1132∙9 | 135∙2 |
| 176 | 6∙87 | 53∙92 | 1135∙6 | 144∙3 |
| 185 | 8∙38 | 44∙70 | 1138∙4 | 153∙3 |
| 194 | 10∙16 | 37∙26 | 1141∙1 | 162∙4 |
| 203 | 12∙26 | 31∙26 | 1143∙9 | 171∙4 |
| 212 | 14∙70 | 26∙36 | 1146∙6 | 180∙5 |
| 221 | 17∙53 | 22∙34 | 1149∙3 | 189∙6 |
| 230 | 20∙80 | 19∙03 | 1152∙1 | 198∙7 |
| 239 | 24∙54 | 16∙28 | 1154∙8 | 207∙8 |
| 248 | 28∙83 | 14∙00 | 1157∙6 | 216∙9 |
| 257 | 33∙71 | 12∙09 | 1160∙3 | 226∙0 |
| 266 | 39∙25 | 10∙48 | 1163∙1 | 235∙2 |
| 275 | 45∙49 | 9∙124 | 1165∙8 | 244∙3 |
| 284 | 52∙52 | 7∙973 | 1168∙6 | 253∙5 |
| 293 | 60∙40 | 6∙992 | 1171∙3 | 262∙7 |
| 302 | 69∙21 | 6∙153 | 1174∙1 | 271∙9 |
| 311 | 79∙03 | 5∙433 | 1176∙8 | 281∙1 |
| 320 | 89∙86 | 4∙816 | 1179∙5 | 290∙3 |
| 329 | 101∙9 | 4∙280 | 1182∙2 | 299∙5 |
| 338 | 115∙1 | 3∙814 | 1185∙0 | 308∙7 |
| 347 | 129∙8 | 3∙410 | 1187∙7 | 318∙0 |
| 356 | 145∙8 | 3∙057 | 1190∙4 | 327∙3 |
| 365 | 163∙3 | 2∙748 | 1193∙2 | 336∙6 |
| 374 | 182∙4 | 2∙476 | 1195∙9 | 345∙9 |
| 383 | 203∙3 | 2∙236 | 1198∙6 | 352∙2 |
| 392 | 225∙9 | 2∙025 | 1201∙4 | 364∙5 |
| 401 | 250∙3 | 1∙838 | 1204∙1 | 373∙9 |
| 410 | 276∙9 | 1∙672 | 1206∙9 | 383∙2 |
| 419 | 305∙5 | 1∙525 | 1209∙6 | 392∙6 |
| 428 | 336∙3 | 1∙393 | 1212∙4 | 402∙0 |

59. We have next to consider the supply of heat. During the first stage, until the temperature rises from its initial value *t0* to *t,* the temperature at which steam begins to form under the given pressure, heat is required only to warm the water. Since the specific heat of water is nearly constant, the amount of heat taken in during the first stage is approximately *t-t0* thermal units or J(*t*-*t*0) foot-pounds, J being Joule’s equivalent (§ 23), and this expression for it will generally serve with sufficient accuracy in practical calculations. More exactly, however, the heat taken in is somewhat greater than this, for Regnault's experiments show that the specific heat of water increases slightly as the temperature rises. In stating the amount of heat required for this first stage, *t0* must be taken as a known temperature; for convenience in numerical statement the temperature 32° F. is usually chosen as an arbitrary starting-point from which the reception of heat is to be reckoned. We shall employ the symbol *h* to designate the heat required to raise 1 lb of water from 32° F. to the temperature *t* at which steam begins to form. The value of *h* in thermal units is given, approximately, by the equation

*h*=*t*-32.

More exact values, which take account of the variation in the specific heat of water, will be found in the last column of Table II. During the first stage, sensibly all the heat supplied goes to increase the stock of internal energy which the fluid possesses, the amount of external work which is done by the expansion of the fluid being negligible.

60. The heat taken in during the second stage is what is called the *latent heat* of steam, and is denoted by L. Of it a part is spent

in doing external work,—namely, P multiplied by the excess of the volume of the steam over the volume of the water,—and the remainder is the difference of internal energy between 1 lb of steam at *t* and 1 lb of water at *t.* The volume of 1 lb of water, at such temperatures as are usual in steam-engines, is nearly 0∙017 cubic feet. We may therefore write the external work (in foot-pounds) done during the production of 1 lb of steam under constant pressure P,—

External work = P(V-0∙017).

61. Adding together the heat taken in during the first and second stages we have a quantity designated by H and called the *total heat* of 1 lb of saturated steam:—

H=*h* + L.

Regnault’s values of H are very accurately expressed (in thermal units) by the formula

H = 1082 + 0∙305*t*.

They are given in the fourth column of Table II. A similar for­mula gives approximate values of L, exact enough for use in prac­tical calculations,—

L=1114-0∙7*t*.

The total heat of formation of 1 lb of steam, when formed under constant pressure from water at any temperature *t*0, is of course H - *h0,* where *h0* corresponds to *t0,*

62. Of the whole latent heat of steam, L, the part Γ(V -0∙017) is, as has been said above, spent in doing external work. The remainder (in foot-pounds)—

JL-P(V-0∙0l7)—

is the change of internal energy which the substance undergoes during evaporation. This quantity, for which it is convenient to have a separate symbol, will be denoted by *ρ* in thermal units, or J*ρ* in foot-pounds. In dealing with the heat required to produce steam we adopted the state of water at 32° F. as an arbitrary start­ing-point from which to reckon the reception of heat. In the same way it is convenient to use this arbitrary starting-point in reckoning what may be called the *internal energy* of the substance, which is the excess of the heat taken in over the external work done by the substance during its reception of heat. Thus the internal energy I of 1 lb of saturated steam at pressure P is equal to the total heat H, less that part of the total heat which is spent in doing external work, or (in foot-pounds)

JI = JH-P(V-0∙0I7),

or I = L + *h*- P(V-0∙017)∕J = *h* + *ρ*.

The notion of internal energy is useful in calculating the heat taken in or rejected by steam during any stage of its expansion or compression in an engine. When a working substance passes from one condition to another, its gain or loss of heat is determined by the equation

Heat taken in = increase of internal energy + external work.

Any of the terms of this equation may be negative ; the last term is negative when work is done, not by, but upon the substance.

63. The same equation gives the means of finding the amount of heat required to form steam under any assigned conditions, in place of the condition assumed at the beginning of this chapter, where the formation of steam under constant pressure was con­sidered. Whatever be the condition as to pressure under which the process of formation is carried on, the total heat required is the sum of the internal energy of the steam when formed and the work done by the substance during the process. Thus in general

Heat of formation = I + J-1∫P*d*V, the limits of integration being the final volume of the steam and the original volume of the water. When steam is formed in a closed vessel of constant volume no external work is done ; the heat of formation is then equal to the internal energy, and is less than the total heat of formation (H) of steam, when formed at a constant pressure equal to the pressure reached in the vessel, by the quantity P(V-0·017).

64. In calculations which relate to the action of steam in engines we have generally to deal, not with *dry* saturated steam, but with *wet* steam, or steam whieh either carries in suspension, or is otherwise mixed with, a greater or less proportion of water. In every such mixture the steam and water have the same temperature, and the steam is saturated. The dryness of wet steam is measured by the proportion *q* of dry steam in each pound of the mixed substance. When that is known it is easy to determine the other physical constants : thus—

Latent heat of 1 lb of wet steam *= qL ;*

Total heat of 1 lb of wet steam *=h + q*L*∙,*

Volume of 1 lb of wet steam = *q*V + (1 -*q)*0·017

= *q*V very nearly,

unless the steam is so wet as to consist mainly of water ; Internal energy of 1 lb of wet steam*=h+qρ.*

65. Steam is superheated when its temperature is raised, in any manner, above the temperature corresponding to saturation at the actual pressure. When much superheated, steam behaves like a

@@@1 See Fairbairn and Tate, “On the Density of Steam at Different Temperatures,” *Phil. Trans.,* vol. cl., 1860.

@@@2 This is Rankine’s formula. Zeuner gives PV1·0646=constant.