which is formed is said to be *saturated.* The volume which the piston encloses at the end of this stage—the volume, namely, of 1 lb of saturated steam at pressure *p* (and temperature *t)—*will be denoted by *v* in cubic feet.

3. If after all the water is converted into steam more heat be allowed to enter, the volume will increase and the temperature will rise. The steam is then said to be *superheated.*

The difference between saturated and superheated steam may be expressed by saying that if water (at the temperature of the steam) be mixed with steam some of the water will be evaporated if the steam is superheated, but none if the steam is saturated.. Any vapour in contact with its liquid and in thermal equilibrium is necessarily saturated. When saturated its properties differ con­siderably, as a rule, from those of a perfect gas, especially at high pressures, but when superheated they approach those of a perfect gas more and more closely the further the process of superheating is carried, that is to say, the more the temperature is raised above *t*, the temperature of saturation corresponding to the given pressure *p.*

28. *Relation of Pressure and Temperature in Saturated Steam.—*The temperature *t* at which steam is formed depends on the value of *p.* Their relation was determined with great care by Regnault *(Mem. Inst. France,* vol. xxi.). The pressure of saturated steam rises with the temperature at a rate which increases rapidly in the upper regions of the scale. This will be apparent from the first and second columns of the following table. The first column gives the temperature on the Centigrade scale; the second gives the corresponding pressure in pounds per square inch.

29. *Relation of Volume and Temperature.—*The same table shows the volume *v* in cubic feet, occupied by 1 lb of saturated steam at each temperature. This is based on the investigations of H. L. Callendar who has shown (see Thermodynamics and Vaporization) that an equation of the form

*v =***Rτ**/*p*+*b*-*c*

is applicable to water vapour, whether saturated or superheated, within the limits of experimental error throughout the range of pressure that is important in engineering practice. In this equation *τ* is the absolute temperature, R and *b* are constants and *c* is a term varying inversely as a certain power of the temperature. By aid of this equation, in conjunction with the results of various experiments on the latent heat and other properties of steam, Callendar has shown that it is possible to frame expressions from which numerical values of all the important properties of steam may be derived throughout a range of saturation temperatures extending from 0° C. to 200° C. or so. The values so obtained arc thermo­dynamically consistent with one another, and are in good agree­ment with the most authoritative experimental results. They are accordingly to be accepted in lieu of those given in earlier steam tables which depended on measurements by Regnault, and are now known to be in some particulars erroneous. R. Mollier has applied Callendar's method with great completeness to the calculation of steam tables, and the figures given here are adapted from his results.@@1 In addition to the relation of. temperature, pressure and volume, the table shows other properties of steam which will be explained as we proceed.

30. *Supply of Heat in Formation of Steam under Constant Pressure.—* We have next to consider the supply of heat in the imaginary experiment of § 27. 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-t0*) foot-pounds, J being Joule’s equiva­lent, 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 at high temperatures, 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 0° C. 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 0°C. to the temperature *t* at which steam begins to form. 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.

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 *v* over the volume of the water w, and the remainder is the difference of internal energy between 1 lb of steam at *t* and 1 lb of water at *t.*

31. *Total Heat of Steam.*—Adding together the heat taken in during the first and second stages, we have a quantity designated

by H which may be called the heat of formation of 1 lb of saturated steam :—

H=*h*+L.

The heat of formation of 1 lb of steam, when formed under constant pressure from water at any temperature *t0* is H—*h0*, where *h0* corresponds to *t0*.

It has been pointed out by Mollier that for the purpose of calcula­tions in technical thermodynamics it is convenient to add to the heat of formation the quantity *pw/*J which represents the thermal equivalent of the work spent in introducing the water under the piston, against the constant pressure *p,* before the operation of heating imagined in § 27 begins, *w* being the volume of the water. We thus obtain a quantity which in its numerical values differs only very slightly from H, namely

I=H+*pw*/J.

We shall call this the *total heat* of saturated steam. Values of I are stated in the table. Since the volume of 1 lb of water is only

Properties of Saturated Steam.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Tempera­ture. Centigrade. | Pressure lb per sq. in. | Volume cub. ft. per ìb. | Total Heat. | | Entropy. | |
| Of Water. | Of Steam. | Of Water. | Of Steam. |
| 0 | 0∙089 | 3283∙ | 0 | 594∙7 | 0 | 2·178 |
| 5 | 0∙127 | 2354· | 5∙0 | 597∙1 | 0∙018 | 2·148 |
| 10 | 0∙178 | 1708· | 10∙0 | 599∙4 | 0∙036 | 2·119 |
| 15 | 0∙246 | 1253· | 15∙0 | 601∙8 | 0∙054 | 2·091 |
| 20 | 0∙336 | 931· | 20∙0 | 604∙1 | 0∙071 | 2·064 |
| 25 | 0∙455 | 699∙5 | 25∙0 | 606∙5 | 0∙088 | 2·039 |
| 30 | 0∙610 | 530∙7 | 30∙0 | 608∙8 | 0∙104 | 2·015 |
| 35 | 0∙809 | 406∙8 | 35∙0 | 611∙1 | 0∙121 | 1·991 |
| 40 | 1∙062 | 314∙8 | 40∙1 | 613∙5 | 0∙137 | 1·969 |
| 45 | 1∙381 | 245∙8 | 45∙1 | 615∙8 | 0∙153 | 1·947 |
| 50 | 1∙78 | 193∙7 | 50∙1 | 618∙0 | 0∙169 | 1∙927 |
| 55 | 2∙27 | 153∙9 | 55∙1 | 620∙3 | 0∙184 | 1·907 |
| 60 | 2∙88 | 123∙3 | 60∙1 | 622∙6 | 0∙199 | 1·888 |
| 65 | 3∙61 | 99∙5 | 65∙2 | 624∙8 | 0∙214 | 1∙870 |
| 70 | 4∙51 | 80∙9 | 70∙2 | 627∙0 | 0∙229 | 1·852 |
| 75 | 5∙58 | 66∙24 | 75∙3 | 629∙2 | 0∙244 | 1·835 |
| 80 | 6∙86 | 54∙60 | 80∙3 | 631∙3 | 0∙258 | 1·819 |
| 85 | 8∙38 | 45∙29 | 85∙3 | 633∙5 | 0∙272 | 1·803 |
| 90 | 10∙16 | 37∙79 | 90∙4 | 635∙6 | 0∙286 | 1·788 |
| 95 | 12∙26 | 31∙71 | 95∙5 | 637∙6 | 0∙300 | 1·773 |
| 100 | 14∙70 | 26∙75 | 100∙5 | 639∙7 | 0∙324 | 1·759 |
| 105 | 17∙52 | 22∙69 | 105∙6 | 641∙7 | 0∙327 | 1·745 |
| 110 | 20∙79 | 19∙34 | 110∙7 | 643∙6 | 0∙340 | 1·732 |
| 115 | 24∙55 | 16∙56 | 115∙8 | 645∙5 | 0∙354 | 1·719 |
| 120 | 28∙83 | 14∙25 | 120∙9 | 647∙4 | 0∙367 | 1·706 |
| 125 | 33∙72 | 12∙30 | 126∙0 | 649∙2 | 0∙379 | 1·694 |
| 130 | 39∙26 | 10∙67 | 131∙I | 651∙0 | 0∙392 | 1·682 |
| 135 | 45∙51 | 9∙29 | 136∙2 | 652∙8 | 0∙405 | 1·671 |
| 140 | 52∙56 | 8∙12 | 141∙3 | 654∙5 | 0∙417 | 1·660 |
| 145 | 60∙42 | 7∙13 | 146∙4 | 656∙1 | 0∙430 | 1·649 |
| 150 | 69∙24 | 6∙274 | 151∙6 | 657∙8 | 0∙442 | 1·638 |
| 155 | 79∙04 | 5∙542 | 156∙7 | 659∙3 | 0∙454 | 1·628 |
| 160 | 89∙93 | 4∙910 | 161∙9 | 660∙8 | 0∙466 | 1·618 |
| 165 | 101∙98 | 4∙363 | 167∙1 | 662∙3 | 0∙478 | 1·∙608 |
| 170 | 115∙27 | 3∙891 | 172∙2 | 663∙7 | 0∙489 | 1·599 |
| 175 | 129∙9 | 3∙478 | 177∙4 | 665∙0 | 0∙501 | 1·589 |
| 180 | 145∙9 | 3∙116 | 182∙6 | 666∙3 | 0∙512 | 1·580 |
| 185 | 163∙4 | 2∙800 | 187∙9 | 667∙6 | 0∙524 | 1·57i |
| 190 | 182∙6 | 2∙523 | 193∙1 | 668∙8 | 0∙535 | 1·563 |
| 195 | 203∙4 | 2∙279 | 190∙3 | 670∙0 | 0∙546 | 1·554 |
| 200 | 226∙0 | 2∙063 | 203∙6 | 671∙1 | 0∙557 | 1∙546 |
| 205 | 250∙5 | 1∙874 | 208∙9 | 672∙2 | 0∙568 | 1∙538 |
| 210 | 277∙2 | 1∙703 | 214∙1 | 673∙2 | 0∙579 | 1·530 |
| 215 | 306∙8 | 1∙546 | 219∙4 | 674∙1 | 0∙590 | 1·522 |

0 016 cub. ft. the term *pw*/J is numerically insignificant except at the highest pressures. Similarly, in reckoning the total heat of water Iw we add *pw*/J to *h*, and this quantity is also given in the table. The latent heat L is to be found from the table by sub­tracting Iw, the total heat of water, from the total heat of steam. We shall use the centigrade scale of temperature throughout this article, and accordingly the total heats are expressed in terms of a unit involving the centigrade degree, namely, the quantity of heat required to raise the temperature of unit mass of water through 1°.C. at 15° C. With this unit of heat the mechanical equivalent J is 1400 foot-pounds when the unit of mass is the lb, and is 427 kilogram-metres when the unit of mass is the kilogramme.

32. *Internal Energy.*—Of the heat of steam the part *pv*/J is spent in doing external work. The remainder has gone to increase the stock of internal energy which the substance possesses.

In dealing with the heat required to produce steam we adopted the state of water at o°C. as an arbitrary starting-point from which to reckon the reception of heat. In the same way it is convenient

@@@1 R. Mollier, *Neue Tabellen und Diagramme für Wasserdampf* (Berlin, 1906). See also Ewing’s *Steam Engine* (3rd ed., 1910).