TABLES OF THE PROPERTIES OF SATURATED STEAM AND OTHER VAPORS

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BY

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FOURTH EDITION.

SATURATED STEAM, AND OTHER VAPORS.

A COMPARISON of the several tables of the properties of saturated steam, expressed in English units, reveals discrepancies of considerable magnitude; and investigation shows that, while all are in some manner founded on the experiments of Regnault, various methods of calculation have been used, and in some cases other experimental data have been employed. A review of the whole subject, in connection with the preparation of notes on thermodynamics for the use of the students of the Massachusetts Institute of Technology, made it seem important to calculate a set of tables, to accompany those notes, founded on the best and most recent data.

In presenting the tables for general use, it appears proper to state in full the data and the methods of calculation employed, so that each one may see the degree of accuracy and correctness of the tables, and the reliance to be placed on them.

Tables of the properties of other vapors have been added, which will be discussed hereafter.

Pressure of Saturated Steam. — As a conclusion from all the experiments on the tension of saturated steam, Regnault gives, in the *Mémoires de l'Institut de France, etc., Tome XXI.*, the following data : —

TEMPERATURE C.	PRESSURE MM. OF MERCURY.
−32	0.32
−16	1.29
0	4.60
25	23.55
50	91.98
75	288.50
100	760.00
130	2030.0
160	4651.6
190	9426.
220	17390.
−20	0.91
+40	54.91

From these data he calculated, by the aid of seven-place logarithms, the following formulæ, which give the pressure in millimetres of mercury for any temperature in degrees Centigrade : —

A.   For steam from $-32°$ to $0°$ C.

$$p = a + ba^n.$$
$$a = -0.08038.$$
$$\log b = 9.6024724 - 10.$$
$$\log a = 0.033398.$$
$$n = 32° - t.$$

B.   For steam from $0°$ to $100°$ C.

$$\log p = a - ba^n + c\beta^n.$$
$$a = 4.7384380.$$
$$\log b = 0.6116485.$$
$$\log c = 8.1340339 - 10.$$
$$\log a = 9.9967249 - 10.$$
$$\log \beta = 0.006865036.$$
$$n = t.$$

C.   For steam from $100°$ to $220°$ C.

$$\log p = a - ba^n + c\beta^n.$$
$$a = 5.4583895.$$
$$\log b = 0.4121470.$$
$$\log c = 7.7448901 - 10.$$
$$\log a = 9.997412127 - 10.$$
$$\log \beta = 0.007590697.$$
$$n = t - 100.$$

D.   For steam from $-20°$ to $220°$ C.

$$\log p = a - ba^n - c\beta^n.$$
$$a = 6.2640348.$$
$$\log b = 0.1397743.$$
$$\log c = 0.6924351.$$
$$\log a = 9.994049292 - 10.$$
$$\log \beta = 9.998343862 - 10.$$
$$n = t + 20.$$

By aid of the formulæ A and B, Regnault calculated and recorded tables of the pressures of saturated steam for temperatures from $-32°$ to $100°$ C. The formula D was calculated from the data given above for the temperatures $-20°$, $+40°$, $100°$, $160°$, and $220°$ C., and was intended to represent the whole range of experiments. By this formula, instead of formula C, he calculated the pressures set down in his tables for temperatures from $100°$ C. to $220°$ C.

Wishing to obtain greater accuracy for meteorological work, Moritz re-calculated Equation B, using ten-place logarithms, and obtained constants

that differ but little from those that will be given later. Some of the more recent tables in the French system were calculated by his equations.

Equations for the Pressure of Steam at Paris. — In view of the preceding statements, it appeared desirable to re-calculate the constants for Equations *B* and *C*, with a degree of accuracy that should exclude any doubt as to the reliability of the results. Accordingly, the logarithms required were taken from Vega's ten-place table, and then the remainder of the calculations were carried on with natural numbers, checking by independent methods, with the following results : —

$B.$ For steam from $0°$ to $100°$ C.

$$\log p = a - ba^n + c\beta^n.$$
$$a = 4.7393622142.$$
$$\log b = 0.6117400190.$$
$$\log c = 8.1320378383 - 10.$$
$$\log a = 9.996725532820 - 10.$$
$$\log \beta = 0.006864675924.$$
$$n = t.$$

$C.$ For steam from $100°$ to $220°$ C.

$$\log p = a - ba^n + c\beta^n.$$
$$a = 5.4574301234.$$
$$\log b = 0.4119787931.$$
$$\log c = 7.7417476470 - 10.$$
$$\log a = 9.99741106346 - 10.$$
$$\log \beta = 0.007642489113.$$
$$n = t - 100.$$

To show the degree of accuracy attained, the following tables are given : —

EQUATION $B.$

$t.$	$p.$	LOG p FROM TABLE OF LOGARITHMS.	LOG p CALCULATED BY EQUATION.
0	4.60	0.6627578317	. . . . . .
25	23.55	1.3719909115	1.37199097
50	91.98	1.9636934052	1.96369346
75	288.50	2.4601458175	2.46014587
100	760	2.8808135923	2.88081365

EQUATION $C.$

$t.$	$p.$	LOG p FROM TABLE OF LOGARITHMS.	LOG p CALCULATED BY EQUATION.
100	760.00	2.8808135923	. . . .
130	2030.0	3.3074960379	3.307496036
160	4651.6	3.6676023618	3.667602359
190	9426	3.9743274354	3.974327428
220	17390	4.2402995820	4.240299575

The results from Equation C are quite satisfactory; for the errors come in the ninth place of decimals, and one place of decimals is unavoidably lost in the application of the formula. Equation B was calculated after Equation C and the numerical work was not carried to so large a number of decimal places. For the calculation of tables, the constants are carried to seven places of significant figures only; this gives six significant figures in the result, of which five are recorded in the table.

Pressure of Steam at Latitude 45°. — **French System.** — It is customary to reduce all measurements to the latitude of 45°, and to sea-level. The standard thermometer should then have its boiling and freezing points determined under, or reduced to such conditions. The value of g, the acceleration due to gravity, is, at Paris, latitude 48° 50′ 14″ and 60 metres above sea-level, 9.809218 metres; and at 45°, and at sea-level, it is 9.806056 metres. Consequently, 760 mm. of mercury at 45° gives a pressure equal to that of 759.755 mm. at Paris; and this corresponds to a temperature of 99.°991 C.

In other words, the thermometer which is standard at 45° has each degree 0.99991 of the length of the degree of a thermometer standard at Paris.

To reduce Equation B to 45° latitude, we have

$$\log p = a + \log \frac{980.9218}{980.6056} - ba^{0.99991t} + c\beta^{0.99991t};$$

and for Equation C,

$$\log p = a + \log \frac{980.9218}{980.6056} - ba^{(0.99991t - 100)} + c\beta^{(0.99991t - 100)}$$

$$= a + \log \frac{980.9218}{980.6056} - ba^{-0.009} a^{0.00991\,(t - 100)} + c\beta^{-0.008} \beta^{0.99991\,(t - 100)}.$$

The resulting equations which were used in calculating Table III are

$B.$ For steam from 0° to 100° C. at 45° latitude.

$$\log p = a_1 - ba_1{}^n + c\beta_1{}^n.$$
$$a_1 = 4.739502.$$
$$\log b = 0.6117400.$$
$$\log c = 8.13204 - 10.$$
$$\log a_1 = 9.996725828 - 10.$$
$$\log \beta_1 = 0.0068641.$$
$$n = t.$$

$C.$ For steam from 100° to 220° C. at 45° latitude.

$$\log p = a_1 - b_1 a_1{}^n + c_1 \beta_1{}^n.$$
$$a_1 = 5.457570.$$
$$\log b_1 = 0.4120021.$$
$$\log c_1 = 7.74168 - 10.$$
$$\log a_1 = 9.997411296 - 10.$$
$$\log \beta_1 = 0.0076418.$$
$$n = t - 100.$$

Pressure of Steam at Latitude 45°. — English System. — To reduce the equations for the pressure of steam, so that they will give the pressures in pounds on the square inch for degrees Fahrenheit, there are required the comparison of measures of length, and of weight, the comparison of the scales of the thermometers, and the specific gravity of mercury.

Professor Rogers (*Proceedings of the Am. Acad. of Arts and Sciences, 1882–83*, also *Additional Observations*, etc.) gives for the length of the metre, 39.3702 inches. This differs from the value given by Capt. Clarke (*Proceedings of the Royal Society, vol. xv., 1866*), by an amount that does not affect the values in the tables ; his value being 39.370432 inches.

Professor Miller (*Phil. Transactions, cxlvi., 1856*) gives for the weight of one kilogram, 2.20462125 pounds.

Regnault gives, for the weight of one litre of mercury, 13.5959 kilograms.

The degree Fahrenheit is $\frac{5}{9}$ of the length of the degree Centigrade.

Let
$$k = \frac{13.5959 \times 2.204621}{39.3702^2} ;$$

then the equations B and C have for the reduction to degrees Fahrenheit, and pounds on the square inch,

$$\log p = a_1 + \log k - ba^{\frac{5}{9}n} + c\beta^{\frac{5}{9}n},$$
$$\log p = a_1 + \log k - b_1 a_1^{\frac{5}{9}n} + c_1 \beta_1^{\frac{5}{9}n}.$$

The resulting equations, which were used in calculating Tables I and II, are : —

$B.$ For steam from 32° to 212° F., in pounds on the square inch.
$$\log p = a_2 - ba_q^n + c\beta_2^n.$$
$$a_2 = 3.025908.$$
$$\log b = 0.6117400.$$
$$\log c = 8.13204 - 10.$$
$$\log a_2 = 9.998181015 - 10.$$
$$\log \beta_2 = 0.0038134.$$
$$n = t - 32.$$

$C.$ For steam from 212° to 428° F., in pounds on the square inch.
$$\log p = a_2 - b_1 a_2^n + c_1 \beta_2^n.$$
$$a_2 = 3.743976.$$
$$\log b_1 = 0.4120021.$$
$$\log c_1 = 7.74168 - 10.$$
$$\log a_2 = 9.998561831 - 10.$$
$$\log \beta_2 = 0.0042454.$$
$$n = t - 212.$$

All of the foregoing equations make the pressure a function of the temperature on the scale of the air-thermometer. It will be assumed that the difference between that scale and the absolute scale may be neglected.