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New Equation of Saturation Pressure for Water as a Function of Temperature*

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New equation of the saturation pressure for water is formulated and compared with the standard values of the new Skeleton Tables established by the Sixth International Conference on the Properties of Steam (1963).

This new equation has a form of the simple fractional expression which can be easily calculated by an electronic computer, and covers the whole range of temperatures between 0 °C and 374.15 °C with a single equation.

This equation has been adopted as a part of the internationally agreed 1967 IFC Formulation for Industrial Use which are the basic equations for the new International Steam Table.

Also reported are values of the heat of vaporization for water calculated from the new equation of the saturation pressure.

1. Introduction

In 1963, the 6th International Conference on the Properties of Steam (ICPS) adopted the new International Skeleton Tables (1963) of specific volume and enthalpy for ordinary water substance for temperatures up to 800°C and pressures up to 1 000 bar together with those of saturation pressures at the temperatures between 0°C and 371.15°C, summarizing experimental studies performed in many countries in decades. For the industrial purpose, it is necessary to formulate the numerical data in these tables to reproduce the standard values within the quoted tolerances. And also this formulation should be an international one, otherwise troubles may occur in international trading activities between countries using different formulations and steam tables. The 6th ICPS organized the International Formulation Committee (IFC) consisting of delegates from six countries, namely Czechoslovakia, Germany, Japan, UK, U.S.A. and U.S.S.R., to test and choose one best formulation from those proposed by many countries.

At Keio University, three equations of state for the water region, the superheated steam region and the critical region, and an equation of the saturation pressure were formulated and presented at the second IFC meeting held in Glasgow in 1966⁽¹⁾. Of these four equations, the equation for the critical region

and the equation for the saturation pressure have been chosen and approved as sub-formulations of the internationally recognized formulation for industrial use⁽²⁾, which is composed of two Japanese equations and two German equations. Here reported is the equation for the saturation pressure formulated at Keio University.

Most of previously published equations for the saturation pressure for water represent the whole range by two separate expressions. But in 1950, one of the authors, I. Tanishita⁽³⁾, made an equation which represents the whole range of the saturation curve 0°C ~ 374.15°C by a single equation within the tolerances of the Skeleton Table of 1934. The equation shown in this report has the same form as Tanishita's original equation, while constants are modified to agree with the new Skeleton Table of 1963. Also presented are calculated results, as well as comparisons with other investigations, of the heat of vaporization of water using this equation for the saturation pressure.

2. Units and symbols

Units and symbols used in this report are as follows.

$$A: \frac{1}{10} \frac{\text{J}}{\text{bar cm}^3}$$

P : pressure bar (except otherwise stated)

$$R: \text{gas constant for steam } 4.6151 \frac{\text{cm}^3 \text{bar}}{\text{g}^\circ \text{K}}$$

r : heat of vaporization J/g

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T : Kelvin temperature °K

t : temperature in centigrade °C

v' : specific volume of saturated water cm³/g

v'' : specific volume of saturated steam cm³/g

β : reduced pressure P/P_c

θ : reduced temperature T/T_c

Subscripts

c : critical, s : saturated

3. Review of previous investigations

Precise experimental investigations on the relation between saturation pressure and temperature for water were performed by Henning⁽⁴⁾, Egerton and Callender⁽⁵⁾, Osborne and his co-workers⁽⁶⁾, Smith and his co-workers⁽⁷⁾ and others. The Skeleton Table drawn up by the Third International Steam Table Conference in 1934 was based on these investigations, and most of steam tables published in industrial countries later on have used the standard values of the Skeleton Table (1934) as basic data. Among those workers, Osborne and his co-workers made an empirical equation in 1934⁽⁸⁾. And, after further investigations, they published a set of equations for the saturation pressure including Gerry's equation in 1939⁽⁹⁾. Since then this study had been supposed to be most reliable and the 6th ICPS in 1963 adopted the values of this study, except at the critical point, as the standard values of the International Skeleton Table (1963). But as shown later, Osborne's formulation consists of two independent equations dividing the whole region at 100°C. This type of formulation has a disadvantage for industrial purposes and may have a discontinuity on the boundary.

Also for the heat of vaporization, experimental investigations^{(10)~(13)} and a summarizing paper⁽⁹⁾ by Osborne and his co-workers have been considered the most reliable one up to the present. Most of steam tables published thereafter are based on their values. But Osborne's experimental values are expected to have larger errors in the region very close to the critical point. Nowak and Grosh⁽¹⁴⁾ estimated the error of Osborne's values to be about 10% at a region within 1 or 2°C from the critical temperature.

The saturation curve for water which shows the relation between the saturation pressure and temperature, has the form shown in Fig. 1. Although this curve seems to be very simple, it is not easy to express precisely the whole region with a single equation.

If steam is assumed to behave as ideal gas in the low pressure region, we can take $v=RT/P$, and the specific volume of saturated water may be assumed to be negligibly small comparing with that of

saturated steam. Then from Clapeyron's equation, we can obtain the following equation:

$$\ln \frac{P_c}{P} = \frac{r}{ART_c} \frac{T_c - T}{T} \dots\dots\dots (1)$$

Van der Waals found this relation experimentally and wrote the equation as:

$$\ln \frac{P_c}{P} = a \left(\frac{T_c}{T} - 1 \right) \dots\dots\dots (2)$$

Where a is a constant

Equations (1) and (2) are only approximations and a more precise equation can be obtained by, for example, considering the heat of vaporization as a function of temperature.

Smith, Keyes and Gerry⁽⁷⁾ divided the whole region into two sub-regions and gave two equations: one for temperatures from 10°C to 150°C and the other for those from 50°C to the critical temperature. To get good consistency on the boundary, the overlapping range of temperatures is made comparatively wide. These equations have the fractional form.

Osborne and Meyers⁽⁸⁾ also divided the whole region into two sub-regions and used for temperatures below 100°C Gerry's equation:

$$\log_{10} P = -3.142305 \left\{ \frac{10^3}{T} - \frac{10^3}{373.16} \right\} + 8.2 \log_{10} \left(\frac{373.16}{T} \right) - 0.0024804(373.16 - T)$$

and for temperatures above 100°C used the following equation made by themselves:

$$\log_{10} P = A + \frac{B}{T} + \frac{Cx}{T} (10^{2x} - 1) + E(10^{Fy^{3/4}})$$

Fig. 1 The vapor pressure curve for water

where $x = T^2 - K$, $y = 374.11 - t$, and A, B, C, D, E, F and K are constants. Pressure in above two equations is expressed in kp/cm^2 . Gerry's equation has a term of logarithm and the equation by Osborne and Meyers has terms of 10 to the power of the function of temperature.

As already stated the calculated values of Osborne and Meyers have been considered the most reliable one and are adopted as the standard values of the Skeleton Table (1963) except the value at the critical point. The Skeleton Table (1963) gives 221.2 bar as the critical pressure, while the table by Osborne and Meyers gives 225.65 kp/cm^2 (221.29 bar). Later we shall discuss about this matter.

Sugawara⁽¹⁵⁾ also divided the whole region into two sub-regions. His equation has the following form:

$$\ln \frac{P_c}{P} = [7.21379 + (a + bT + cT^n)(T - 483.16)^2] \times \frac{T_c - T}{T}$$

where constants a, b, c and n have two different sets of values for below and for above 210 °C. This equation has been used as one of the basic equations for the Japanese Steam Tables of 1950⁽¹⁶⁾.

All equations stated above need two equations to express the whole region from 0 °C to the critical temperature. This subdivision is not favorable for industrial use and may induce a discontinuity at the boundary.

One of the authors, I. Tanishita, have previously made an equation which could express the whole region with a following single equation:

$$\log_{10} \frac{P_c}{P} = \frac{x}{T} \left(\frac{a + bx + cx^2 + dx^3 + ex^4}{1 + fx + gx^2} \right)$$

where $x = T_c - T$ and $a \sim g$ are constants.

This equation seems to be the first one which reproduced the all values of the saturation pressure in the Skeleton Table of 1934 with a single equation.

Schmidt and his co-workers⁽¹⁷⁾ made the equation,

$$\beta = \exp M - K_1(\theta - k_1)(\theta - k_2)\exp(-12\theta^4)$$

$$\text{where } M = k_0 - k_3\theta^{-1} + k_4\theta^{-1}m \{ \exp(k_6m^2) - 1 \} + k_7\exp\{-43(k_8 - \theta)^{5/4}\}$$

$$m = \theta^2 - k_5$$

and k_i are constants. This equation was first made as part of the German formulation and had a com-

paratively complicated form.

Bridgeman and Aldrich⁽¹⁸⁾ made a comparatively complicated equation as follows:

$$\log_{10} P = A + Y_1 - B(1 + Ct)Y_2$$

where Y_1 and Y_2 have more than 10 constants. Unit of P is atm.

Equation by Gibson and Bruges⁽¹⁹⁾ is,

$$\ln \beta = \sum_{r=0}^{11} a_r T_r(x)$$

where $x = \{2(1/\theta - 0.95)^{0.4} - A - B\}/(B - A)$ and $T_r(x)$ are the Chebyshev polynomials of the r -th order. This equation fits the standard values so closely that it reproduces the irregularities of the Skeleton Table (1963) too, which lead to an unnatural tendency of derivatives.

Equation by Sato and his co-workers⁽²⁰⁾ has the form:

$$\ln P = \sum_{\nu=0}^{10} a_{\nu} t_1^{\nu}$$

where $t_1 = (T - T_0)/100$ and a_{ν} are constants.

4. New equation and its calculated results

4.1 New equation

The following equation of the same form as Tanishita's original equation was adopted:

$$\log_{10} \frac{P_c}{P} = \frac{1}{T} \frac{K_1x + K_2x^2 + K_3x^3 + K_4x^4 + K_5x^5}{1 + K_6x + K_7x^2} \dots\dots\dots(3)$$

where $x = T_c - T$ and K_i are constants determined based upon the standard values of the International Skeleton Table (1963).

Purposes of adopting the fractional form are to reduce the number of constants and to get a larger number of effective figures when calculated by the computer of limited digits.

In the reduced form, Eq. (3) becomes,

$$\beta = \exp \left[\frac{1}{\theta} \frac{\sum_{\nu=1}^5 k_{\nu}(1-\theta)^{\nu}}{1 + k_6(1-\theta) + k_7(1-\theta)^2} \right] \dots\dots\dots(3 \cdot a)$$

Constants k_{ν} are shown in Table 1.

In order to calculate the heat of vaporization using Clapeyron's equation, it is necessary to derive dP/dT or $d\beta/d\theta$. From Eq. (3·a) $d\beta/d\theta$ is given as,

$$\frac{d\beta}{d\theta} = \frac{\beta}{\theta^2} \frac{-\sum_{\nu=1}^5 \nu k_{\nu}(1-\theta)^{\nu-1} \{1 + k_6(1-\theta) + k_7(1-\theta)^2\} - \sum_{\nu=1}^5 k_{\nu}(1-\theta)^{\nu} \{1 + k_6(1-2\theta) + k_7(1-4\theta + 3\theta^2)\}}{\{1 + k_6(1-\theta) + k_7(1-\theta)^2\}^2} \dots\dots\dots(4)$$

Table 1 Constants of Eq. (3·a)

k_1	$-7.691\,234\,564 \times 10^0$
k_2	$-2.608\,023\,696 \times 10^1$
k_3	$-1.681\,706\,546 \times 10^2$
k_4	$6.423\,285\,504 \times 10^1$
k_5	$-1.189\,646\,225 \times 10^2$
k_6	$4.167\,117\,320 \times 10^0$
k_7	$2.097\,506\,760 \times 10^1$

4.2 Calculated results of the saturation pressure

Calculated values of the saturation pressure are shown in Table 2 compared with the standard values of the Skeleton Table (1963). Fig. 2 shows the difference between the values of this report and

of the Skeleton Table (1963) divided by the tolerances of the Skeleton Table. Values 1.0 and -1.0 correspond to the upper and lower limits of the tolerances. At 100°C the Skeleton Table gives no tolerances. From Table 2 and Fig. 2, it is clear that the calculated results of this new equation agree fairly well with the Skeleton Table within tolerances. At temperatures over 200°C differences are larger.

Table 2 Comparison of the calculated saturation pressures with the Skeleton Table values

Temperature $t^\circ\text{C}$	Saturation Pressure P bar		
	Calculated values	Standard values	$\Delta P/\text{Tolerance}$
0	0.006 108 0	0.006 108	0/6
0.01	0.006 112 4	0.006 112	+0.4/6
10	0.012 269 9	0.012 271	-1.1/10
20	0.023 365 6	0.023 368	-2.4/20
30	0.042 414 9	0.042 418	-3.1/30
40	0.073 750 1	0.073 750	+0.1/38
50	0.123 353	0.123 35	+0.3/6
60	0.199 202	0.199 19	+1.2/10
70	0.311 620	0.311 61	+1.0/16
80	0.473 598	0.473 58	+1.8/24
90	0.701 088	0.701 09	-0.2/36
100	1.013 25	1.013 25	—
110	1.432 66	1.432 7	-0.4/10
120	1.985 43	1.985 4	+0.3/13
130	2.701 32	2.701 1	+2.2/16
140	3.613 79	3.613 6	+1.9/21
150	4.759 97	4.759 7	+2.7/32
160	6.180 65	6.180 4	+2.5/42
170	7.920 23	7.920 2	+0.3/53
180	10.026 6	10.027	-0.4/7
190	12.551 2	12.553	-1.8/8
200	15.548 8	15.550	-1.2/8
210	19.077 4	19.080	-2.6/8
220	23.198 3	23.202	-3.7/9
230	27.976 0	27.979	-3.0/10
240	33.476 3	33.480	-3.7/12
250	39.776 0	39.776	0/13
260	46.943 4	46.941	+2.4/15
270	55.058 1	55.052	+6.1/17
280	64.201 8	64.191	+9.8/20
290	74.460 7	74.449	+11.7/22
300	85.926 9	85.917	+9.1/24
310	98.700 1	98.694	+6.1/30
320	112.891	112.89	+0.1/3
330	128.625	128.64	-1.5/4
340	146.052	146.08	-2.8/4
350	165.351	165.37	-1.9/4
360	186.751	186.74	+1.1/5
370	210.540	210.53	+1.0/5
371	213.064	213.06	+0.4/10
372	215.616	215.63	-1.4/11
373	218.20	218.2	0/1
374	220.81	220.9	-0.9/1
374.15	221.20	221.2	0/1

$\Delta P = \text{Calculated value} - \text{Standard value}$

This is caused by adjusting the tendency of the equation for the saturation pressure to show better adaptability when combined with other sub-formulations for the steam, the water and the critical regions which were made at Keio University.

It seems to be meaningless to make an equation aimed only at the perfect reproduction of the Skeleton Table values, when the meaning of the tolerance is considered. Too faithful reproduction may lead to defects stated later. For the industrial purposes as in this case, it is preferable to make equations simpler.

Calculated results show that the Skeleton Table does not give reasonably smooth values near the critical point. Original equation by Osborne and his co-workers⁽⁸⁾ assumes the critical temperature as 374.11°C and Osborne's report of 1939 modified the critical temperature and the corresponding critical pressure as 374.15°C and 225.65 kp/cm^2 (221.29 bar) respectively. But, though for temperatures up to 374°C the values by Osborne are adopted as the standard values, only the critical pressure of the Skeleton Table is chosen as 221.2 bar . Most of equations made for the Skeleton Table (1963) show satisfactory agreement only at either 374°C or 374.15°C .

In the course of this investigation, it was found that better agreement could be obtained at 374°C if the critical temperature was chosen a little lower (about 374.12°C). But, the standard values are chosen at the critical point since it is preferable to express the reduced forms of other equations of state in terms of the critical quantities defined in the Skeleton Table. The defined critical pressure in other investigations is higher than 221.2 bar , for example 221.23 bar for Gibson and Bruges⁽¹⁹⁾, 221.25 bar for Bridgeman and Aldrich⁽¹⁸⁾ and 221.2645 bar for Miyabe and Yamagata⁽²⁵⁾. After all, the critical quantities should be as $T_c = 374.12^\circ\text{C}$ or $P_c = 221.25\text{ bar}$ for better smoothness. Recent investigations revealed that the critical temperature might be

Fig. 2 Comparison of the calculated saturation pressures with the Skeleton Table values

lower than 374.15 °C by more than 0.1 °C and proved the above conclusion.

Also in the region from 0 °C to 100 °C, it is said that the Skeleton Table values should be modified, because Osborne's values⁽⁹⁾ are based on the experimental values by Holborn and Henning⁽²²⁾ who used erroneous temperature scale for temperatures below 100 °C. Examples from the so called "Cragoe-Stimson correction"⁽²¹⁾ measured by Cragoe in 1942 and by Stimson in 1948 (both unpublished) are shown in Fig. 2. Equation by Bridgeman and Aldrich gives values very close to this correction. Furthermore in 1965

Fig. 3 Comparison of TdP/dT (below 370 °C)

Douslin and Osborn⁽²³⁾ measured at temperatures lower than 20 °C using an inclined piston manometer and obtained results different from the Skeleton Table values. These facts mean that the best formulation is not the one which is the most faithful reproduction of the Skeleton Table.

4.3 Results of the heat of vaporization

The term TdP/dT obtained by the new equation gives values shown in Fig. 3 and Fig. 4. Fig. 3 shows that below 300 °C values by various investigators agree quite well within 0.1 % with each other but values above 300 °C by Schmidt and his co-

Fig. 4 Comparison of TdP/dT (above 370 °C)

Table 3 Heat of vaporization for water

t °C	r J/g	t °C	r J/g	t °C	r J/g	t °C	r J/g	t °C	r J/g	t °C	r J/g
0	2 499.6	29	2 431.7	58	2 362.5	87	2 290.3	116	2 213.1	245	1 740.6
0.01	2 499.5	30	2 429.4	59	2 360.0	88	2 287.8	117	2 210.4	250	1 715.2
1	2 497.2	31	2 427.0	60	2 357.6	89	2 285.2	118	2 207.6	255	1 689.0
2	2 494.9	32	2 424.7	61	2 355.2	90	2 282.6	119	2 204.8	260	1 661.8
3	2 492.6	33	2 422.3	62	2 352.7	91	2 280.1	120	2 201.9	265	1 633.7
4	2 490.3	34	2 419.9	63	2 350.3	92	2 277.5	125	2 187.7	270	1 604.6
5	2 487.9	35	2 417.6	64	2 347.8	93	2 274.9	130	2 173.3	275	1 574.3
6	2 485.6	36	2 415.2	65	2 345.4	94	2 272.3	135	2 158.6	280	1 542.8
7	2 483.3	37	2 412.8	66	2 342.9	95	2 269.7	140	2 143.6	285	1 510.1
8	2 480.9	38	2 410.4	67	2 340.5	96	2 267.1	145	2 128.3	290	1 475.9
9	2 478.6	39	2 408.1	68	2 338.0	97	2 264.4	150	2 112.8	295	1 440.2
10	2 476.3	40	2 405.7	69	2 335.6	98	2 261.8	155	2 096.9	300	1 402.9
11	2 474.0	41	2 403.3	70	2 333.1	99	2 259.2	160	2 080.7	305	1 363.8
12	2 471.6	42	2 400.9	71	2 330.6	100	2 256.5	165	2 064.2	310	1 322.8
13	2 469.3	43	2 398.5	72	2 328.1	101	2 253.9	170	2 047.4	315	1 279.7
14	2 466.9	44	2 396.2	73	2 325.6	102	2 251.2	175	2 030.2	320	1 234.3
15	2 464.6	45	2 393.8	74	2 323.2	103	2 248.5	180	2 012.6	325	1 186.3
16	2 462.3	46	2 391.4	75	2 320.7	104	2 245.9	185	1 994.7	330	1 135.7
17	2 459.9	47	2 389.0	76	2 318.2	105	2 243.2	190	1 976.3	335	1 081.9
18	2 457.6	48	2 386.6	77	2 315.7	106	2 240.5	195	1 957.5	340	1 024.8
19	2 455.2	49	2 384.2	78	2 313.2	107	2 237.8	200	1 938.3	345	963.7
20	2 452.9	50	2 381.8	79	2 310.6	108	2 235.1	205	1 918.6	350	898.0
21	2 450.6	51	2 379.4	80	2 308.1	109	2 232.4	210	1 898.5	360	718.5
22	2 448.2	52	2 377.0	81	2 305.6	110	2 229.7	215	1 877.7	370	445.7
23	2 445.9	53	2 374.6	82	2 303.1	111	2 226.9	220	1 856.5	371	399.4
24	2 443.5	54	2 372.2	83	2 300.5	112	2 224.2	225	1 834.6	372	343.6
25	2 441.2	55	2 369.7	84	2 298.0	113	2 221.4	230	1 812.2	373	266.1
26	2 438.8	56	2 367.3	85	2 295.5	114	2 218.7	235	1 789.0	374	105.2
27	2 436.4	57	2 364.9	86	2 292.9	115	2 215.9	240	1 765.2		

workers tend to be higher. In the region near the critical point shown in Fig. 4, values in this report agree with those of other investigations except Schmidt and his co-workers whose values are higher by about 2%.

If the equation for the saturation pressure is made so as to reproduce small "ripples" or discontinuities of the values of the International Skeleton Table (1963) too, then errors are expected in values of dP/dT and of the heat of vaporization calculated from it.

The calculated results of the heat of vaporization are shown in Table 3; they were calculated by combining with the equations of state for the steam⁽²⁶⁾ and the water⁽²⁷⁾ and the critical regions⁽²⁸⁾. Results at every 10 °C are shown in Fig. 5, while details in critical region are shown in Fig. 6. Up to 300 °C, various investigations agree within 0.1 % with each other. Schmidt's values show higher trends, and Osborne's are higher below 340 °C and lower at higher temperatures. As shown in Fig. 6, calculated values of this report are close to the mean values of Schmid's and Osborne's up to 373 °C, and at 374 °C close to the value by Miyabe and Yamagata whose equation is made especially for the critical region. Osborne's value is higher by about 9 % at 374 °C. In his critical review of the critical region properties for water and steam, Nowak⁽¹⁴⁾ states that Osborne's values may include errors of up to 10 % in the region within 1 or 2 °C from the critical point. So 9 % difference can not be explained without more precise experimental values of future investigations.

By the way, the International Skeleton Table (1963) does not include the heat of vaporization and has only the enthalpy of saturated water and steam with tolerances. Then, for example, at 374 °C if the enthalpy of saturated steam is chosen at the upper limit of the tolerance and that of saturated water at the lower limit, the heat of vaporization becomes

164 J/g, while it becomes as low as 64 J/g in the other way.

4.4 Characteristics when combined with other sub-formulations

Calculated results of the specific volume, the enthalpy, the entropy, the specific heat and the isentropic exponent at saturation pressures have been shown in reports of sub-formulations^{(26) - (28)}.

The differences of the free enthalpy of saturated water and of saturated steam, which were calculated by combining with the equations of state for the water and the steam regions, are shown in Table 4. They are, for the whole region, well within the limit of 0.2 J/g recommended by the International Formulation Committee of ICPS⁽²⁴⁾.

5. Modification to combine with the equation for the critical region

Newly correlated Eq. (3) or Eq. (3-a) in such a simple form well agrees with the International Skeleton Table values and is considered a favorable one. But after the precise check calculations of the internationally recognized formulation, it was found that there was a very narrow region (374.09 ~ 374.15 °C) where the equation did not give the saturation pressure of steam side when combined with the equation for the critical region. If there is a thermodynamically consistent condition, the equation of state gives three solutions at every saturation pressure determined by the equation for the saturation pressure, where the largest and the smallest solutions correspond to the specific volume of the saturated steam and the saturated water respectively. But as shown in Fig. 7, for example, at 374.12 °C the saturation pressure of this report must be lowered by about 0.0007 bar, otherwise the equation of state for the critical region does not give the specific volume of the saturated steam.

Fig. 5 Comparison of the heat of vaporization (below 370 °C)

Fig. 6 Comparison of the heat of vaporization (above 370 °C)

To slightly modify the calculated values, the following small correction term is added to Eq. (3.a),

$$\beta = \exp \left[\frac{1}{\theta} \frac{\sum_{\nu=1}^5 k_{\nu}(1-\theta)^{\nu}}{1+k_8(1-\theta)+k_7(1-\theta)^2} - \frac{(1-\theta)}{k_8(1-\theta)^2+k_9} \right] \quad \text{.....(5)}$$

where the second term is the correction term and $k_8=1 \times 10^9$, $k_9=6$.

The calculated results by this modified Eq. (5) are shown in Table 5. Differences from Eq. (3) or Eq. (3.a) are small and may be neglected below 370°C.

The reason why such a correction is needed is mainly the fact that only the critical pressure in

Table 4 Free enthalpy of saturated water and saturated vapor

Temperature °C	Free enthalpy		
	Water g_1	Vapor g_2	$g_1 - g_2$
0	0.00	0.07	-0.07
0.01	0.00	0.02	-0.02
10	-0.76	-0.75	-0.01
20	-3.00	-3.03	0.03
30	-6.67	-6.72	0.05
40	-11.71	-11.79	0.08
50	-18.09	-18.18	0.09
60	-25.75	-25.85	0.10
70	-34.67	-34.77	0.10
80	-44.81	-44.91	0.10
90	-56.13	-56.21	0.08
100	-68.60	-68.66	0.06
110	-82.18	-82.23	0.05
120	-96.86	-96.89	0.03
130	-112.60	-112.62	0.02
140	-129.37	-129.38	0.01
150	-147.15	-147.15	0.00
160	-165.92	-165.92	0.00
170	-185.65	-185.65	0.00
180	-206.32	-206.32	0.00
190	-227.91	-227.91	0.00
200	-250.40	-250.39	-0.01
210	-273.76	-273.75	-0.01
220	-297.99	-297.96	-0.03
230	-323.06	-323.01	-0.05
240	-348.95	-348.88	-0.07
250	-375.65	-375.55	-0.10
260	-403.14	-403.00	-0.14
270	-431.40	-431.24	-0.16
280	-460.41	-460.24	-0.17
290	-490.17	-490.00	-0.17
300	-520.66	-520.51	-0.15
310	-551.87	-551.76	-0.11
320	-583.78	-583.73	-0.05
330	-616.39	-616.40	0.01
340	-649.65	-649.74	0.09
350	-683.56	-683.72	0.16

the International Skeleton Table (1963) differs from the Osborne's values, although at other temperatures Osborne's values are adopted as the standard values. If the critical temperature is lowered by 0.05 ~ 0.1°C as shown by recent investigations, no correction term is needed. Equation (3) or Eq. (3.a) does not have such a defect in its nature.

6. Conclusion

In this report the new equation for the saturation pressure for water is correlated and compared with the standard values of the International Skeleton Table (1963) of ICPS. This single equation in a simple form can represent the whole region from 0°C to the critical temperature, is suitable for the computer calculations and has the feature that the loss in the number of effective figures in course of

Fig. 7 An example of the saturation curve in the very vicinity of the critical point

Table 5 Calculated results by the modified equation (5)

Temperature °C	Saturation pressure	
	Eq. (5)	ΔP
374.15	221.200 00	0×10^{-6}
374.14	221.173 17	55
374.13	221.146 46	98
374.12	221.119 91	125
374.11	221.093 50	139
374.10	221.067 19	143
374.09	221.040 95	140
374.08	221.014 74	135
374.07	220.988 55	128
374.06	220.962 36	121
374.05	220.936 17	115
374.04	220.909 99	107
374.03	220.883 80	102
374.02	220.857 61	96
374.01	220.831 42	91
374.00	220.805 23	86
373.00	218.196 66	12
372.00	215.616 30	6
371.00	215.103 64	6
370.00	210.540 33	3
360.00	186.750 69	1
350.00	165.351 24	0

$$\Delta P = \{\text{Value by Eq. (3.a)}\} - \{\text{Value by Eq. (5)}\}$$

calculation is comparatively few.

The equation of this form still has flexibility for future modifications, and can be adopted with slightly modified constants when the Skeleton Table is revised in future.

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Note: Recently, Bradley⁽²⁹⁾ compared various formulations for the properties of steam from a programmer's point of view and showed that Eq. (5) by authors is calculated for quicker and takes less storage than other equations of saturation pressure.

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