IAPWS Equations for Transport Properties and Surface Tension of Water and Steam

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For details see http://www.cheresources.com/iapwsif97.shtml

Symbols

I, *J*	exponents
n	coefficient
p	pressure
R	specific gas constant, *R* = 0.461 526 kJ/(kg K)
T	temperature
Λ	reduced thermal conductivity
Ψ	reduced dynamic viscosity
δ	reduced density
ϕ	dimensionless Helmholtz free energy
γ	dimensionless Gibbs free energy
η	dynamic viscosity
λ	thermal conductivity
π	reduced pressure
θ	reduced temperature
ρ	density
σ	surface tension
τ	inverse reduced temperature

1. Dynamic Viscosity

Range of validity:

$273.15\text{ K} \le T \le 423.15\text{ K}$ and $p \le 500\text{ MPa}$
$423.15\text{ K} < T \le 873.15\text{ K}$ and $p \le 350\text{ MPa}$
$873.15\text{ K} < T \le 1173.15\text{ K}$ and $p \le 300\text{ MPa}$

Reduced dynamic viscosity:

$$\Psi(d,t) = \Psi_0(t)\Psi_1(d,t)$$

where

$\Psi = h/h^*$ with h^* = 55.071E-6 Pa s

$d = r/r^*$ with r^* = 317.763 kg/m^3

$$t = T^* / T \qquad \text{with } T^* = 647.226 \text{ K}$$

Ideal gas part:

$$\Psi_0(t) = \left[t^{0.5} \sum_{i=0}^{3} n_i^0 t^i \right]^{-1}$$

Real fluid part:

$$\Psi_1(d, t) = \exp\left[d \sum_{i=1}^{19} n_i (d-1)^{I_i} (t-1)^{J_i} \right]$$

Table 1: Coefficients of the ideal gas part

i	n_i
0	0.100 000 E+01
1	0.978 197
2	0.579 829
3	-0.202 354

Table 2: Coefficients and exponents of the real fluid part

i	I_i	J_i	n_i
1	0	0	0.513 204 7
2	0	1	0.320 565 6
3	0	4	-0.778 256 7
4	0	5	0.188 544 7
5	1	0	0.215 177 8
6	1	1	0.731 788 3
7	1	2	0.124 104 4 E+01
8	1	3	0.147 678 3 E+01
9	2	0	-0.281 810 7
10	2	1	-0.107 078 6 E+01
11	2	2	-0.126 318 4 E+01
12	3	0	0.177 806 4
13	3	1	0.460 504 0
14	3	2	0.234 037 9
15	3	3	-0.492 417 9
16	4	0	-0.417 661 0 E-01
17	4	3	0.160 043 5
18	5	1	-0.157 838 6 E-01
19	6	3	-0.362 948 1 E-02

2. Thermal Conductivity

Range of validity:

273.15 K ≤ T ≤ 398.15 K and p ≤ 400 MPa
398.15 K < T ≤ 523.15 K and p ≤ 200 MPa
523.15 K < T ≤ 673.15 K and p ≤ 150 MPa
673.15 K < T ≤ 1073.15 K and p ≤ 100 MPa

Reduced thermal conductivity: $\Lambda(d,t) = \Lambda_0(t)\Lambda_1(d,t) + \Lambda_2(d,t)$

where

where	$\Lambda = l / l^*$	with h^* = 0.4945 W/(m K)
	$d = r / r^*$	with r^* = 317.763 kg/m^3
	$t = T^* / T$	with T^* = 647.226 K

Ideal gas part:

$$\Lambda_0(t) = \left[t^{0.5} \sum_{i=0}^{3} n_i^0 t^i \right]^{-1}$$

First real fluid part:

$$\Lambda_1(d,t) = \exp\left[d \sum_{i=0}^{4} \sum_{j=0}^{5} n_{ij} (t-1)^i (d-1)^j \right]$$

Second real fluid part:

$$\Lambda_2(d,t) = \frac{0.0013848}{\Psi(d,t)} (td)^{-2} \left(\frac{\partial p}{\partial (t^{-1})} \right)_d^2 \left[d \left(\frac{\partial d}{\partial p} \right)_t \right]^{0.4678} d^{0.5} \exp\left[-18.66 (t^{-1} - 1)^2 - (d-1)^4 \right]$$

where $p = p / p^*$ with p^* = 22.115 MPa

Ψ according to above equations for the dynamic viscosity

Partial derivatives $\left(\frac{\partial p}{\partial (t^{-1})} \right)_d$ and $\left(\frac{\partial d}{\partial p} \right)_t$ from the corresponding equations of IAPWS-IF97 (see Appendix)

Table 3: Coefficients of the ideal gas part

i	n_i
0	0.100 000 0 E+01
1	0.697 826 7 E+01
2	0.259 909 6 E+01
3	-0.998 254 0

Table 4: Coefficients n_{ij} of the first real fluid part

i ® j ¯	0	1	2	3	4
0	0.132 930 46 E+01	0.170 183 63 E+01	0.522 461 58 E+01	0.871 276 75 E+01	-0.185 259 99 E+01
1	-0.404 524 37	-0.221 568 45 E+01	-0.101 241 11 E+02	-0.950 006 11 E+01	0.934 046 90
2	0.244 094 90	0.165 110 57 E+01	0.498 746 87 E+01	0.437 866 06 E+01	0.
3	0.186 607 51 E-01	-0.767 360 02	-0.272 976 94	-0.917 837 82	0.
4	-0.129 610 68	0.372 833 44	-0.430 833 93	0.	0.
5	0.448 099 53 E-01	-0.112 031 60	0.133 338 49	0.	0.

3. Surface tension between liquid and vapor phase

Range of validity: from the triple point to the critical point

Surface tension:

$$\frac{s}{1\ \mathrm{mN\ m^{-1}}} = 235.8(1-q)^{1.256}[1-0.625(1-q)]$$

where $q = T/T^*$ with $T^* = T_c = 647.096$ K

References

1. William T. Parry *et al.*, ASME International Steam Tables for Industrial Use, American Society of Mechanical Engineers 2000.

2. W. Wagner, A. Kruse, Properties of Water and Steam, Springer-Verlag, Berlin 1998.

Appendix: Partial derivatives $\left(\frac{\partial p}{\partial(t^{-1})}\right)_d$ and $\left(\frac{\partial d}{\partial p}\right)_t$

For region boundaries see http://www.cheresources.com/iapwsif97.shtml

Region 1:

$$\left(\frac{\partial p}{\partial(t^{-1})}\right)_d = \frac{\tilde{T}^*}{\tilde{p}^*}\frac{p^*(g_{pt}T^* - g_p T)}{T^2 g_{pp}}$$

$$\left(\frac{\partial d}{\partial p}\right)_t = -\frac{\tilde{p}^*}{\tilde{r}^* RT}\frac{g_{pp}}{g_p^2}$$

$\tilde{T}^* = 647.226$ K, $\tilde{p}^* = 22.115$ MPa, $\tilde{r}^* = 317.763$ kg/m^3

$T^* = 1386$ K, $p^* = 16.53$ MPa

For the partial derivatives g_π and $g_{\pi\pi}$ in region 1 see http://www.cheresources.com/iapwsif97.shtml

Region 2:

$$\left(\frac{\partial p}{\partial(t^{-1})}\right)_d = \frac{\tilde{T}^*}{\tilde{p}^*}\frac{p^*\left((g_{pt}^0 + g_{pt}^r)T^* - (g_p^0 + g_p^r)T\right)}{T^2(g_{pp}^0 + g_{pp}^r)}$$

$$\left(\frac{\partial d}{\partial p}\right)_t = -\frac{\tilde{p}^*}{\tilde{r}^* RT}\frac{(g_{pp}^0 + g_{pp}^r)}{(g_p^0 + g_p^r)^2}$$

$\tilde{T}* = 647.226$ K, $\tilde{p}* = 22.115$ MPa, $\tilde{r}* = 317.763$ kg/m^3

$T* = 540$ K, $p* = 1$ MPa

For the partial derivatives g_p^0, g_p^r, g_{pp}^0 and g_{pp}^r in region 2 see http://www.cheresources.com/iapwsif97.shtml

Region 3:

$$\left(\frac{\partial p}{\partial\left(t^{-1}\right)}\right)_d = \frac{\tilde{T}*}{\tilde{p}*}\frac{Rr^2}{r*}\left(f_d - \frac{T*}{T}f_{dt}\right)$$

$$\left(\frac{\partial d}{\partial p}\right)_t = \frac{\tilde{p}*}{\tilde{r}*}\frac{r*}{rRT\left(2f_d + \frac{r}{r*}f_{dd}\right)}$$

$\tilde{T}* = 647.226$ K, $\tilde{p}* = 22.115$ MPa, $\tilde{r}* = 317.763$ kg/m^3

$T* = 647.096$ K, $r* = 322$ kg/m^3

For the partial derivatives f_δ, $f_{\delta\delta}$, and $f_{\delta\tau}$ in region 3 see http://www.cheresources.com/iapwsif97.shtml