

THERMODYNAMIC AND THERMOPHYSICAL PROPERTIES OF HUMID AIR BY USING SCHREIBER AND PITZER EOS (DRY AIR) AND IAPWS 97 (STEAM)

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1 Abstract: In humid air thermodynamic property calculations, it is usually ideal gas EOS is used. The basic reason for this is simplicity of using ideal gas EOS. For most air condition applications it might be sufficient, but when applications with higher pressure zones and very low temperatures are considered error level will increased. An equation of state with better accuracy of thermodynamic properties will be required for extreme cases. In this study Scheireber-Pitzer equation of state for dry air and IAPWS97 equation for water vapor will be used to establish computer programs in java language to calculate properties of humid air. Scheiber-Pitzer equation of state is a general real gas EoS form that utilized Pitzer's acentricity factor and a modified Benedict Webb-Rubin EoS. It is basically quadratic curve fitting equation to reference fluids by using Pitzer's acentricity factor as a variable. A rich list of curve fitting reference fluids, including hydrocarbons and other gases, are used to obtain curve fitting coefficients. Mixing of air and water is carried out by using real gas mixing equations. Water properties such as saturation vapor pressure, saturation liquid and vapor densities are taken by utilizing IAPWS95 water and steam EOS. Basic thermodynamic and heat-mass transfer equations are used to define properties such as dew point temperature, adiabatic saturation temperature and wet bulb temperature. In order to calculate thermophysical properties such as viscosity, thermal conductivity etc. combination of cubic surface splines and Wilke, Reichenberg... methods are used. Results of developed equations are compared with Ideal gas and IAPWS-97 EOS & IAPWS G8-10 Humid air EOS and Peng-robinson EoS of humid air. A Graphical user interphase is also developed. All the program codes are listed as free access in www.turhancoban.com adress. As subprograms Properties of dry air and pure gas and gas mixtures can also be calculated by using set of Scheireber-Pitzer EoS programs. All the codes are developed in java programming language.

Keywords: Thermodynamic properties of humid air, Scheireber-Pitzer EoS, IAPWS97 EoS, thermodynamic properties of dry air, thermophysial properties of humid air

2 Formulation of Equation of State

We will consider Scheiber-Pitzer equation of states for pure gases[19]. Details of the Scheiber-Pitzer EoS is given below.

$$\begin{aligned} Z &= \frac{P}{\rho_{RT}} = 1 + B(T_r, \rho_r)\rho_r + C(T_r, \rho_r)\rho_r^2 + \\ &D(T_r, \rho_r)\rho_r^3 + E(T_r, \rho_r)\rho_r^5 + F(T_r, \rho_r)\rho_r^7 + \\ &G(T_r, \rho_r)\rho_r^8 + H(T_r, \rho_r)\rho_r^{10} + I(T_r, \rho_r)\rho_r^{12} \quad (2.1) \\ B(T_r, \rho_r) &= c_1 + \frac{c_2}{T_r} + \frac{c_3}{T_r^2} + \frac{c_4}{T_r^6} \quad (2.2) \\ C(T_r, \rho_r) &= c_5 + \frac{c_6}{T_r} + \frac{c_7}{T_r^3} + \frac{c_8}{T_r^4} \exp(-\rho_r^2) = C_1(T_r) + \\ C_2(T_r) \exp(-\rho_r^2) &\quad (2.3) \\ D(T_r, \rho_r) &= c_9 + \frac{c_{10}}{T_r} + \frac{c_{11}}{T_r^2} \quad (2.4) \end{aligned}$$

$$E(T_r, \rho_r) = \frac{c_{12}}{T_r} + \frac{c_{13}}{T_r^3} \quad (2.5)$$

$$F(T_r, \rho_r) = \frac{c_{14}}{T_r^2} + \frac{c_{15}}{T_r^3} \quad (2.6)$$

$$G(T_r, \rho_r) = \frac{c_{16}}{T_r^3} + \left(\frac{c_{17}}{T_r^3} + \frac{c_{18}}{T_r^4} \right) \exp(-\rho_r^2) = G_1(T_r) +$$

$$G_2(T_r) \exp(-\rho_r^2) \quad (2.7)$$

$$H(T_r, \rho_r) = \left(\frac{c_{19}}{T_r^3} + \frac{c_{20}}{T_r^4} \right) \exp(-\rho_r^2) =$$

$$H_2(T_r) \exp(-\rho_r^2) \quad (2.8)$$

$$I(T_r, \rho_r) = \left(\frac{c_{21}}{T_r^3} + \frac{c_{22}}{T_r^4} \right) \exp(-\rho_r^2) = I_2(T_r) \exp(-\rho_r^2) \quad (2.9)$$

$$c_i = C_{i,0} + C_{i,1}\omega + C_{i,2}\omega^2 \quad (2.10)$$

Where ω in Scheiber-Pitzer equation of states coefficient is called **Pitzer's acentric factor**. This factor is calculated as

$$\omega = -\log_{10} P_{\text{saturated vapor}}(\text{at } T_r = 0.7) - 1$$

(2.11)

Table 2.1 C[i][j] Coefficients of Scheiber-Pitzer EoS

	j=1	j=2	j=3
C1,j	0.442259	0.72565	0
C2,j	-0.98097	0.218714	0
C3,j	-0.611142	-1.24976	0
C4,j	-0.00515624	-0.189187	0
C5,j	0.1513654	2.306706	-10.41174
C6,j	-0.04382625	4.696068	15.14146
C7,j	1.102699	3.129384	-9.521409
C8,j	-0.6361056	0.3266766	2.904622
C9,j	0.008759626	-3.204099	8.002338
C10,j	0.3412103	8.872169	-14.40386
C11,j	-0.8842722	-6.687471	11.76854
C12,j	0.1375109	0.2432806	-0.5515101
C13,j	-0.1443457	1.286932	-2.180988
C14,j	-0.00596955	0.04541961	0
C15,j	0.02450537	-0.4158241	0.7914067
C16,j	-0.00419959	0.0910596	-0.1786378
C17,j	0.000466548	-1.262028	-2.826772
C18,j	-0.01945101	0.781222	4.190046
C19,j	0.04083643	1.398844	0
C20,j	-0.03546917	-1.456041	0
C21,j	-	0.2104505	0
C22,j	0.005896265	0.2191255	0

Derivatives of the equations:

$$\frac{\partial B(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[-\frac{c_2}{T_r^2} - 2 \frac{c_3}{T_r^3} - 6 \frac{c_4}{T_r^7} \right] \quad (2.12)$$

$$\frac{\partial C(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[-\frac{c_5}{T_r^2} - 3 \frac{c_7}{T_r^4} - 4 \frac{c_8}{T_r^5} \exp(-\rho_r^2) \right] \quad (2.13)$$

$$\frac{\partial D(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[-\frac{c_{10}}{T_r^2} - 3 \frac{c_{11}}{T_r^4} \right] \quad (2.14)$$

$$\frac{\partial E(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[-\frac{c_{12}}{T_r^2} - 3 \frac{c_{13}}{T_r^4} \right] \quad (2.15)$$

$$\frac{\partial F(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[-2 \frac{c_{14}}{T_r^3} - 3 \frac{c_{13}}{T_r^4} \right] \quad (2.16)$$

$$\frac{\partial G(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[-3 \frac{c_{16}}{T_r^4} + \left(-3 \frac{c_{17}}{T_r^4} - 4 \frac{c_{18}}{T_r^5} \right) \exp(-\rho_r^2) \right] \quad (2.17)$$

$$\frac{\partial H(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[\left(-3 \frac{c_{19}}{T_r^4} - 4 \frac{c_{18}}{T_r^5} \right) \exp(-\rho_r^2) \right] \quad (2.18)$$

$$\frac{\partial I(T_r, \rho_r)}{\partial T} = \frac{1}{T_c} \left[\left(-3 \frac{c_{21}}{T_r^4} - 4 \frac{c_{22}}{T_r^5} \right) \exp(-\rho_r^2) \right] \quad (2.19)$$

Helmholtz energy equation will be used to predict other thermodynamic properties

$$dA = -SdT - Pdv \quad (2.20)$$

$$\left. \frac{\partial A}{\partial v} \right|_T = -P \quad (2.21)$$

$$dA = -Pdv = \frac{P}{\rho^2} d\rho \quad (2.22)$$

$$A - A_0 = \int_{\rho_0}^{\rho} \frac{P}{\rho^2} d\rho = \int_0^{\rho} \frac{P}{\rho^2} d\rho + \int_{\rho_0}^0 \frac{P}{\rho^2} d\rho = \int_0^{\rho} \frac{P}{\rho^2} d\rho + \int_{\rho_0}^0 \frac{\rho RT}{\rho^2} d\rho \quad (2.23)$$

The second term (limits between low density ρ_0 and density 0) can be defined as an ideal state case where $P = \rho RT$. Now we can add and subtract ideal gas density term of the equation

$$A - A_0 = \int_{\rho_0}^{\rho} \frac{P}{\rho^2} d\rho = \int_0^{\rho} \frac{P}{\rho^2} d\rho + \int_{\rho_0}^0 \frac{\rho RT}{\rho^2} d\rho + \int_0^{\rho} \frac{\rho RT}{\rho^2} d\rho - \int_0^0 \frac{\rho RT}{\rho^2} d\rho \quad (2.24)$$

Considering for real EoS $P = Z\rho RT$ equation becomes

$$A - A_0 = \int_{\rho_0}^{\rho} \frac{P}{\rho^2} d\rho = \int_0^{\rho} \frac{P}{\rho^2} d\rho + \int_{\rho_0}^0 \frac{\rho RT}{\rho^2} d\rho + \int_0^{\rho} \frac{\rho RT}{\rho^2} d\rho - \int_0^0 \frac{\rho RT}{\rho^2} d\rho$$

$$A - A_0 = \int_0^{\rho} \frac{Z\rho RT - \rho RT}{\rho^2} d\rho + \int_{\rho_0}^{\rho} \frac{\rho RT}{\rho^2} d\rho$$

$$A - A_0 = \int_0^{\rho} \frac{RT(Z-1)}{\rho} d\rho + \int_{\rho_0}^{\rho} \frac{\rho RT}{\rho^2} d\rho$$

$$A - A_0 = \int_0^{\rho_r} \frac{RT}{\rho_r} [B(T_r, \rho_r)\rho_r + C(T_r, \rho_r)\rho_r^2 + D(T_r, \rho_r)\rho_r^3 + E(T_r, \rho_r)\rho_r^5 + F(T_r, \rho_r)\rho_r^7 + G(T_r, \rho_r)\rho_r^8 + H(T_r, \rho_r)\rho_r^{10} + I(T_r, \rho_r)\rho_r^{12}] d\rho_r + \int_{\rho_{r0}}^{\rho_r} \frac{RT}{\rho_r} d\rho_r \quad (2.25)$$

$$A - A_0 = RT \int_0^{\rho_r} [B(T_r, \rho_r) + C(T_r, \rho_r)\rho_r + D(T_r, \rho_r)\rho_r^2 + E(T_r, \rho_r)\rho_r^4 + F(T_r, \rho_r)\rho_r^6 + G(T_r, \rho_r)\rho_r^7 + H(T_r, \rho_r)\rho_r^9 + I(T_r, \rho_r)\rho_r^{11}] d\rho_r + RT \ln \frac{\rho_r}{\rho_{r0}} \quad (2.26)$$

Some of the terms in this integration includes terms of exponential and power multiplications. This integrations are carried out as follows:

$$K(m, \rho_r) = \int_0^{\rho_r} \rho_r^m \exp(-\rho_r^2) d\rho_r = \int_0^{\rho_r} \sum_{n=0}^{\infty} (-1)^n \frac{\rho_r^{2n+m}}{n!} d\rho_r = \sum_{n=0}^{\infty} (-1)^n \frac{\rho_r^{2n+m+1}}{(2n+m+1)n!} \quad (2.27)$$

Handling these terms such as above Taylor series are much easier than taken numerical integration, then Helmholtz departure function becomes:

$$A - A_0 = RT \left(B\rho_r + C_1 \frac{\rho_r^2}{2} + C_2 K(1, \rho_r) + D \frac{\rho_r^3}{3} + E \frac{\rho_r^5}{5} + F \frac{\rho_r^7}{7} + G_1 \frac{\rho_r^8}{8} + G_2 K(8, \rho_r) + H_2 K(10, \rho_r) + I_2 K(12, \rho_r) \right) + RT \ln \left(\frac{\rho_r}{\rho_{r0}} \right) \quad (2.28)$$

Entropy departure function:

$$S - S_0 = - \left. \frac{\partial(A - A_0)}{\partial T} \right|_{\rho}$$

$$S - S_0 = R \left(B\rho_r + C_1 \frac{\rho_r^2}{2} + C_2 K(1, \rho_r) + D \frac{\rho_r^3}{3} + E \frac{\rho_r^5}{5} + F \frac{\rho_r^8}{8} + G_1 \frac{\rho_r^9}{9} + G_2 K(8, \rho_r) + H_2 K(10, \rho_r) + I_2 K(12, \rho_r) \right) + RT \left(\frac{dB}{dT} \rho_r + \frac{dC_1}{dT} \frac{\rho_r^2}{2} + \frac{dC_2}{dT} K(1, \rho_r) + \frac{dD}{dT} \frac{\rho_r^3}{3} + \frac{dE}{dT} \frac{\rho_r^5}{5} + \frac{dF}{dT} \frac{\rho_r^8}{8} + \frac{dG_1}{dT} \frac{\rho_r^9}{9} + \frac{dG_2}{dT} K(8, \rho_r) + \frac{dH_2}{dT} K(10, \rho_r) + \frac{dI_2}{dT} K(12, \rho_r) \right) + R \ln \left(\frac{\rho_r}{\rho_{r0}} \right) \quad (2.29)$$

Enthalpy departure function:

$$H - H_0 = (A - A_0) + T(S - S_0) + RT(Z - 1) \quad (2.30)$$

Internal energy departure function:

$$U - U_0 = (A - A_0) + T(S - S_0) \quad (2.31)$$

Gibbs energy departure function:

$$G - G_0 = (A - A_0) + RT(Z - 1) \quad (2.32)$$

The fugacity-pressure ratio:

$$\ln \frac{f}{P} = \frac{(A - A_0)}{RT} + \ln \frac{v}{v_0} + (Z - 1) - \ln(Z) \quad 2.33$$

Data is also needed to solve $C_p(T)$ value. In order to establish that, NIST tables given at the address <https://janaf.nist.gov/> is used. The following partial continuous formulation is taken. the following partial difference curve fitting formula is used

$$C_{pi}(T) = A_i + B_i 10^{-3} T + \frac{C_i 10^5}{T^2} + D_i 10^{-6} T^2 \quad (2.34)$$

$T_{Li} \leq T \leq T_{Hi}$

As an example case of Partial continuous curve fitting of Cp values Data for Nitrogen is given below.

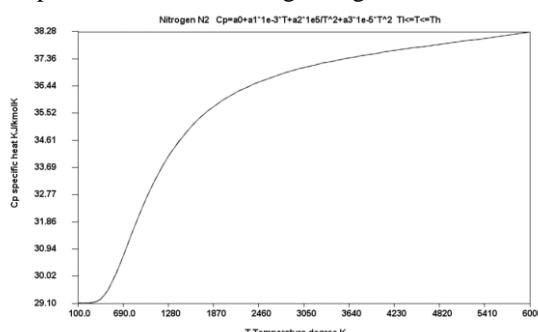


Figure 2.1 Cp of Nitrogen kJ/(kmolK)

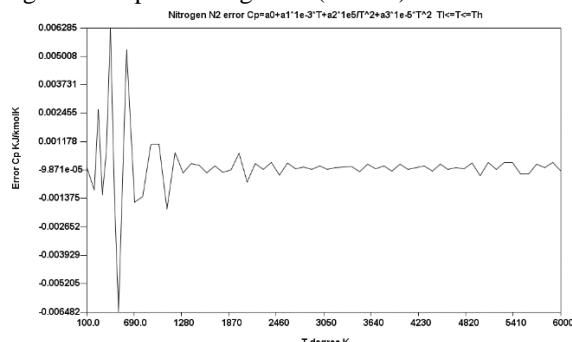


Figure 2.2 Error of Cp in Nitrogen kJ/(kmol K)

Table 2.2 Cp (kJ/kmol K) partial continuous curve fitting equations for N₂ Nitrogen

i	A _i	B _i	C _i	D _i	T _{Li} K	T _{Hi} K
0	29.408631	-2.251447	-0.012473	4.520889	100	350
1	27.646169	0.882356	0.770074	4.764423	350	700
2	21.601706	14.878414	3.812808	-4.165467	700	1200
3	29.830766	5.421561	-15.043096	-1.089614	1200	1700
4	35.476742	0.973583	-42.547627	-0.097466	1700	2200
5	34.928203	1.319404	-38.184192	-0.159911	2200	2700
6	36.262526	0.581500	-50.898362	-0.045731	2700	3200
7	35.657341	0.766169	-34.665936	-0.059817	3200	3700
8	36.418045	0.432596	-44.184706	-0.020152	3700	4200
9	38.077688	-0.152960	-80.311808	0.036794	4200	4700
10	37.760284	-0.049949	-73.101156	0.027769	4700	5200
11	39.973855	-0.854555	-77.575938	0.101253	5200	6000

For some gases only data is available is in polynomial curve fitting format, for this cases polynomial form is assumed.

$$C_{pi}(T) = \sum_{i=0}^n A_i T^i \quad (2.35)$$

Mixing of the gases: Pseudocritical property approach will be used. According to this concept a pseudocritical properties of the gas mixtures are calculated and then gas mixture can be evaluated similar to a single gas equation. Mixing rules for a Schreiber-Pitzer mix is given as follows:

$$N = \sum_i N_i \quad (2.36)$$

Where N_i is mole number of each substance in the mixture.

$$y_i = \frac{N_i}{N} \quad (2.37)$$

Where y_i is mole percentages of each substance.

$$T_c = \frac{1}{v_c^{1/4}} \sum_i \sum_j y_i y_j v_{cij}^{1/4} T_{cij} \quad (3.38)$$

Where T_c is pseudo-critical temperature of mixture. Due to characteristic of mixture there is no one critical temperature but critical temperature of each species in the mixture, therefore this value does not have a physical significance and only for calculation purposes.

$$v_c = \sum_i \sum_j y_i y_j v_{cij} \quad (2.39)$$

Where v_c is pseudocritical specific volume

$$\omega = \sum_i y_i \omega_i \quad (3.36)$$

Where ω is Pitzer's acentric factor of the mixture

$$T_{cij} = (T_{ci} T_{cj})^{1/2} k'_{ij} \quad (2.40)$$

$$k'_{ij} =$$

$$\frac{8(v_{ci} v_{cj})^{1/2}}{(v_{ci}^{1/3} + v_{cj}^{1/3})^3} \quad (2.41)$$

k'_{ij} is binary interaction coefficients. Due to difference of molecules in the mixture and intermolecular forces effecting because of the difference. This equation will give only approximation. The exact value can only be obtain by experimental measurements of mixture of two gases.

$$v_{cij} = \frac{1}{8} (v_{ci}^{1/3} + v_{cj}^{1/3})^3 \quad (2.42)$$

$$Z_c = (0.2905 - 0.085\omega) \quad (2.43)$$

Where Z_c is pseudo-critical compressibility factor. As it is seen from the equation, it is given only as a function of Pitzer's acentric factor.

$$P_c = Z_c R T_c / v_c \quad (2.44)$$

Where Z_c is pseudo-critical pressure.

Thermodynamic properties of dry air is calculated by using gas mixture and assuming dry air as a gas mixture as:

gas	Formula	Mole %
Nitrogen	N ₂	78.12
Oxygen	O ₂	20.96
Argon	Ar	0.92

For the steam calculations class steamIAPWS_IF97 is used. Details of these equation of state is as follows: International Association for the Properties of Water and Steam(IAPWS) is developed a new set of equation of states for industrial use. This new set of equations are developed in 1997. Steam properties are given by 5 sets of equation of states, as shown in the Figure 2.11

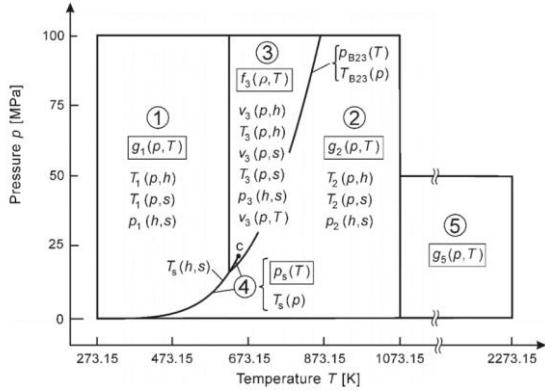


Figure 2.3 Zone definitions for different sub EOS for IAPWS-IF97

The first equation, which covers basically **liquid region** has the following gibbs free energy form:

$$\frac{g_1(P,T)}{RT} = \gamma(\pi, \tau) = \sum_{i=1}^{34} n_i (71 - \pi)^{I_i} (\tau - 1222)^{J_i} \quad (2.45)$$

Where $\pi = \frac{P}{P^*}$, $\tau = \frac{T^*}{T}$, $P^* = 16.62$ MPa and $T^* = 1386$ K, $R = 0.461526$ kJ/(kgK)

Table 2.3 coefficients of eqn. 2.45

i	I _i	J _i	n _i	i	I _i	J _i	n _i
1	0	-2	0.146329712	18	2	3	-4.41418E-06
2	0	-1	-0.845481872	19	2	17	-7.26950E-16
3	0	0	-3.756360367	20	3	-4	-3.16796E-05
4	0	1	3.385516917	21	3	0	-2.82708E-06
5	0	2	-0.957919634	22	3	6	-8.52051E-10
6	0	3	0.157720385	23	4	-5	-2.24253E-06
7	0	4	-0.016616417	24	4	-2	-6.51712E-07
8	0	5	0.000812146	25	4	10	-1.43417E-13
9	1	-9	0.000283191	26	5	-8	-4.05170E-07
10	1	-7	-0.000607063	27	8	-11	-1.27343E-09
11	1	-1	-0.018990068	28	8	-6	-1.74249E-10
12	1	0	-0.032529749	29	21	-29	-6.87621E-19
13	1	1	-0.021841717	30	23	-31	1.44783E-20
14	1	3	-5.28384E-05	31	29	-38	2.63358E-23
15	2	-3	-0.000471843	32	30	-39	-1.19476E-23
16	2	0	-0.000300018	33	31	-40	1.82281E-24
17	2	1	4.76614E-05	34	32	-41	-9.35371E-26

Thermodynamic relations can be calculated from these thermodynamic relations

$$\text{Specific volume: } v = \left(\frac{\partial g}{\partial P} \right)_T \quad (2.46)$$

$$\text{Specific enthalpy: } h = g - T \left(\frac{\partial g}{\partial T} \right)_P \quad (2.47)$$

$$\text{Specific internal energy: } u = g - T \left(\frac{\partial g}{\partial T} \right)_P - P \left(\frac{\partial g}{\partial P} \right)_T \quad (2.48)$$

$$\text{Specific entropy: } s = \left(\frac{\partial g}{\partial T} \right)_P \quad (2.49)$$

$$\text{Specific isobaric heat capacity: } C_p = \left(\frac{\partial h}{\partial T} \right)_P \quad (2.50)$$

$$\text{Specific isochoric heat capacity: } C_v = \left(\frac{\partial u}{\partial T} \right)_V \quad (2.51)$$

The second equation equation, which covers vapor region has the following gibbs free energy form:

$$\frac{g_2(P,T)}{RT} = \gamma(\pi, \tau) = \gamma^0(\pi, \tau) + \gamma^r(\pi, \tau) \quad (2.52)$$

Where $\pi = \frac{P}{P^*}$, $\tau = \frac{T^*}{T}$, $R = 0.461526$ kJ/(kgK),

$\gamma^0(\pi, \tau)$ is the ideal gas part of EOS, and $\gamma^r(\pi, \tau)$ is the real gas part of the EOS. Ideal gas part equation:

$$\gamma^0(\pi, \tau) = \ln(\pi) + \sum_{i=1}^9 n_i^0 \tau^{J_i} \quad (2.53)$$

Where $P^* = 1$ MPa and $T^* = 540$ K

Table 2.4 coefficients of eqn. 2.52

i	J _i	n _i ⁰	i	J _i	n _i ⁰
1	0	-9.6928E+00	6	-2	1.4241E+00
2	1	1.0087E+01	7	-1	-4.3840E+00
3	-5	-5.6088E-03	8	2	-2.8409E-01
4	-4	7.1453E-02	9	3	2.1268E-02
5	-3	-4.0710E-01			

dimensionless residual part of the basic equation $g_2(P,T)$ is as follows:

$$\gamma^r(\pi, \tau) = \sum_{i=1}^{43} n_i \pi^{I_i} (\tau - 0.5)^{J_i} \quad (2.53)$$

Where $P^* = 1$ MPa and $T^* = 540$ K

Table 2.5 coefficients of eqn. 2.53

i	I _i	J _i	n _i	i	I _i	J _i	n _i
1	1	0		7	0		-5.9060E-18
2	1	1	-1.78349E-02	24	7	11	-1.2622E-06
3	1	2	-4.59960E-02	25	7	25	-3.8947E-02
4	1	3	-5.75813E-02	26	8	8	1.1256E-11
5	1	6	-5.03253E-02	27	8	36	-8.2311E+00
6	2	1	-3.30326E-05	28	9	13	1.9810E-08
7	2	2	-1.89490E-04	29	10	4	1.0407E-19
8	2	4	-3.93928E-03	30	10	10	-1.0235E-13
9	2	7	-4.37973E-02	31	10	14	-1.0018E-09
10	2	36	-2.66745E-05	32	16	29	-8.0883E-11
11	3	0	2.04817E-08	33	16	50	1.0693E-01
12	3	1	4.38707E-07	34	18	57	-3.3662E-01
13	3	3	-3.22777E-05	35	20	20	8.9186E-25
14	3	6	-1.50339E-03	36	20	35	3.0629E-13
15	3	35	-4.06683E-02	37	20	48	-4.2002E-06
16	4	1	-7.88473E-10	38	21	21	-5.9056E-26
17	4	2	1.27907E-08	39	22	53	3.7827E-06
18	4	3	4.82254E-07	40	23	39	-1.2769E-15
19	5	7	2.29221E-06	41	24	26	7.3088E-29
20	6	3	-1.67148E-11	42	24	40	5.5415E-17
21	6	16	-2.11715E-03	43	24	58	-9.4370E-07
22	6	35	-2.38957E+01				

Region 3 equation is given as Helmholtz free energy form:

$$\frac{f_3(\rho, T)}{RT} = \phi(\delta, \tau) = n_1 \ln(\delta) + \sum_{i=2}^{40} n_i \delta^{I_i} \tau^{J_i} \quad (2.54)$$

Where $\delta = \frac{\rho}{\rho^*}$, $\tau = \frac{T^*}{T}$, $T^* = T_c = 647.096$ and $R = 0.461526 \text{ kJ/(kgK)}$

Table 2.6 coefficients of eqn. 2.54

i	I _i	J _i	n _i	i	I _i	J _i	n _i
1	0	0	1.0658E+00	21	3	4	-2.0190E+00
2	0	0	-1.5733E+01	22	3	16	-8.2148E-03
3	0	1	2.0944E+01	23	3	26	-4.7596E-01
4	0	2	-7.6868E+00	24	4	0	4.3984E-02
5	0	7	2.6186E+00	25	4	2	-4.4476E-01
6	0	10	-2.8081E+00	26	4	4	9.0572E-01
7	0	12	1.2053E+00	27	4	26	7.0522E-01
8	0	23	-8.4567E-03	28	5	1	1.0771E-01
9	1	2	-1.2654E+00	29	5	3	-3.2914E-01
10	1	6	-1.1524E+00	30	5	26	-5.0871E-01
11	1	15	8.8521E-01	31	6	0	-2.2175E-02
12	1	17	-6.4208E-01	32	6	2	9.4261E-02
13	2	0	3.8493E-01	33	6	26	1.6436E-01
14	2	2	-8.5215E-01	34	7	2	-1.3503E-02
15	2	6	4.8972E+00	35	8	26	-1.4834E-02
16	2	7	-3.0503E+00	36	9	2	5.7923E-04
17	2	22	3.9421E-02	37	9	26	3.2309E-03
18	2	26	1.2558E-01	38	10	0	8.0965E-05
19	3	0	-2.7999E-01	39	10	1	-1.6558E-04
20	3	2	1.3900E+00	40	11	26	-4.4924E-05

It should be noted that this set of equation is function of density and temperature, and basic equation is helmholts equation so, let us list definition of other thermodynamic properties

$$\text{Pressure: } P = \rho^2 \left(\frac{\partial f}{\partial \rho} \right)_T \quad (2.55)$$

$$\text{Specific enthalpy: } h = f - T \left(\frac{\partial f}{\partial T} \right)_p + \rho \left(\frac{\partial f}{\partial \rho} \right)_T \quad (2.56)$$

$$\text{Specific internal energy: } u = f - T \left(\frac{\partial f}{\partial T} \right)_p \quad (2.57)$$

$$\text{Specific entropy: } s = \left(\frac{\partial f}{\partial T} \right)_p \quad (2.58)$$

$$\text{Specific isobaric heat capacity: } C_p = \left(\frac{\partial h}{\partial T} \right)_p \quad (2.59)$$

$$\text{Specific isochoric heat capacity: } C_v = \left(\frac{\partial u}{\partial T} \right)_v \quad (2.60)$$

Region 4 of the equation defines saturation region. The basic equation is given as a polynomial Region 4 of the equation defines saturation region. The basic equation is given as a polynomial

$$\beta^2 \vartheta^2 + n_1 \beta^2 \vartheta + n_2 \beta^2 + n_3 \beta \vartheta^2 + n_4 \beta \vartheta + n_5 \beta + n_6 \vartheta^2 + n_7 \vartheta + n_8 = 0 \quad (2.61)$$

Where

$$\beta = \left(\frac{P_s}{P^*} \right)^{0.25} \quad (2.62)$$

$$\vartheta = \frac{T_s}{T^*} + \frac{n_9}{\left(\frac{T_s}{T^*} \right) - n_{10}} \quad (2.63)$$

From this equation both saturation pressure and saturation temperature equation can be derived.

$$\frac{P_s}{P^*} = \left[\frac{2C}{-B + (B^2 - 4AC)^{0.5}} \right]^4 \quad (2.64)$$

Where $P^* = 1 \text{ MPa}$

$$A = \vartheta^2 + n_1 \vartheta + n_2$$

$$B = n_3 \vartheta^2 + n_4 \vartheta + n_5$$

$$C = n_6 \vartheta^2 + n_7 \vartheta + n_8$$

Table 2.7 coefficients of eqn. 2.64

i	n _i	i	n _i
1	1.16705E+03	6	1.49151E+01
2	-7.24213E+05	7	-4.82327E+03
3	-1.70738E+01	8	4.05113E+05
4	1.20208E+04	9	-2.38556E-01
5	-3.23256E+06	10	6.50175E+02

It is also possible to drive saturation temperature equation from the basic polynomial as:

$$T_s = \frac{D - [(n_{10} + D)^2 - 4(n_9 + n_{10}D)]^{0.5}}{2} \quad (2.65)$$

Where $T^* = 1 \text{ K}$

$$D = \frac{2G}{-F - (F^2 - 4EG)^{0.5}}$$

$$E = \beta^2 + n_3 \beta + n_6$$

$$F = n_1 \beta^2 + n_4 \beta + n_7$$

$$G = n_2 \beta^2 + n_5 \beta + n_8$$

And the final region for steam is region 5, again given as gibbs free equation type EOS

$$\frac{g_5(P, T)}{RT} = \gamma(\pi, \tau) = \gamma^0(\pi, \tau) + \gamma^r(\pi, \tau) \quad (2.66)$$

Where $\pi = \frac{P}{P^*}$, $\tau = \frac{T^*}{T}$, $R = 0.461526 \text{ kJ/(kgK)}$, $\gamma^0(\pi, \tau)$ is the ideal gas part of EOS, and $\gamma^r(\pi, \tau)$ is the real gas difference of the EOS. Ideal gas part equation: $\gamma^0(\pi, \tau) = \ln(\pi) + \sum_{i=1}^9 n_i^0 \tau^{J_i}$ (2.6.24)

Where $P^* = 1 \text{ MPa}$ and $T^* = 1000 \text{ K}$

Table 2.8 coefficients of eqn. 2.66

i	J _i ⁰	n _i ⁰	i	J _i ⁰	n _i ⁰
1	0	-13.17998367	4	-2	0.36901535
2	1	6.854084163	5	-1	-3.116131821
3	-3	-0.024805149	6	2	-0.329616265

The real gas part of the equation

$$\gamma^r(\pi, \tau) = \sum_{i=1}^{43} n_i \pi^{I_i} \tau^{J_i} \quad (2.67)$$

Table 2.8 coefficients of eqn. 2.67

i	I _i	J _i	n _i	i	I _i	J _i	n _i
1	1	1	1.57364E-03	4	2	3	2.24400E-06
2	1	2	9.01538E-04	5	2	9	-4.11633E-06
3	1	3	-5.02701E-03	6	3	7	3.79195E-08

At reference [8] more detailed set of equations are given for this calculations, for example reverse equation sets are given so that instead of additional curve fitting to get the variables this additional sets can

be utilized A program in java (steamIAPWS_IF97) is prepared to use this set of EOS. A user interface is also prepared (steamTableIF97.java). The user interface input frame is given in the following figure.

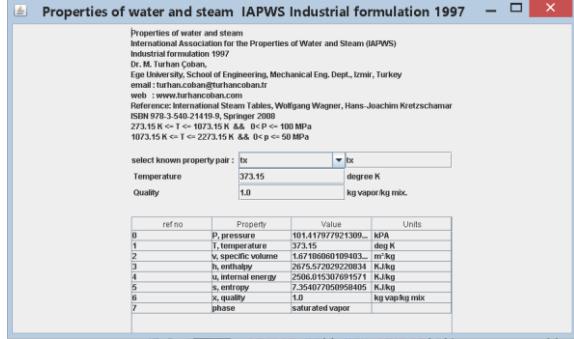


Figure 2.12 GUI for thermodynamic properties of steam

Equations for humid air:

$$h^{AV}(A, T, \rho) = (1 - A)h^V(T, \rho^V) + Ah^A(T, \rho^A) \quad (2.68)$$

$$s^{AV}(A, T, \rho) = (1 - A)s^V(T, \rho^V) + As^A(T, \rho^A) \quad (2.69)$$

3. Additional Formulations

As a gas mixture, usually utilised in air conditioning industry, definitions used in standart air conditioning industry should also be expressed. Some of these properties are:

$$\text{Humidity ratio } w = \left(\frac{1}{A}\right) - 1 \quad (3.1)$$

$$\text{Mole fraction of dry air } x_A = \frac{A(M_W/M_A)}{1-A[1-(M_W/M_A)]} \quad (3.2)$$

$$\text{Mole fraction of water: } 1 - x_A \quad (3.3)$$

$$\text{Mass fraction of dry air: } A = \frac{x_A}{1-(1-x_A)[1-(M_W/M_A)]} \quad (3.4)$$

$$\text{Partial pressure of water: } P^W = (1 - x_A)P \quad (3.5)$$

$$\text{Partial pressure of saturated water: } P^{Wsat} = (1 - x_A^{sat})P = P_\sigma(T) \quad (3.6)$$

$$\text{Relative humidity: } RH = \frac{P^W}{P^{Wsat}} = \frac{(1-x_A)}{(1-x_A^{sat})} \quad (3.7)$$

$$\text{Degree of saturation DOS} = \frac{m^W}{m^{Wsat}} = \frac{1-A}{1-A^{sat}} \quad (3.8)$$

$$\text{Dew point temperature (saturation temperature at partial pressure of water) } T_\sigma(P^W) = T_\sigma((1 - x_A)P) \quad (3.9)$$

Another concept used for wet air is adyabatic saturation temperature. If air flow through an infinite length channel filled with water at the bottom and all walls are insulated, it will absorb water and will be reached to adyabatic saturation point. The temparature of adyabatic saturation point is also called wet air

temperature, it is an idealised thermodynamic concept and can be calculated from the energy balance of the infinitely long channel. Basic energy equation:

Energy of the air entering the channel = enegy of the air leaving the channel + energy of evaporated water,

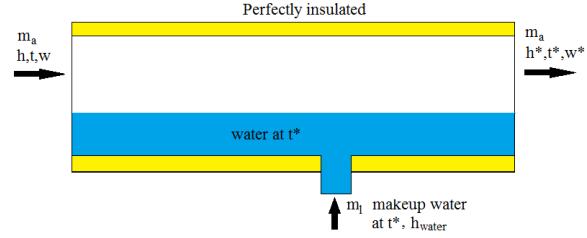


Figure 2.1 Adiabatic saturation temperature

$$\text{So } m_a h(A, T, P) + m_l h_{water}^*(T^*, P) = m_a h(A^*, T^*, P) \quad (3.10)$$

$$m_l = m_a (w^* - w) = m_a \left(\frac{1}{A^*} - \frac{1}{A} \right) \quad (3.11)$$

$$h(A, T, P) + \left(\frac{1}{A^*} - \frac{1}{A} \right) h_{water}^*(T^*, P) = h(A^*, T^*, P) \quad (3.12)$$

Since the exit is at saturation state relative humidity at exit is 1 so

$$RH = \frac{P^W}{P^{Wsat}} = \frac{(1-x_A)}{(1-x_A^{sat})} = 1.0 \quad (3.13)$$

Solution of these equations will require root finding methods.

In order to calculate thermophysical properties (thermal conductivity and viscosity) of dry air Kadoya et al[1] equations are used. This equations has the following form:

$$\eta_0(T_r) = A_0 T_r + A_1 T_r^{0.5} + A_2 + \frac{A_3}{T_r} + \frac{A_4}{T_r^2} + \frac{A_5}{T_r^3} + \frac{A_6}{T_r^4} \quad (3.14)$$

$$\Delta\eta(\rho_r) = \sum_{i=1}^4 B_i \rho_r^i \quad (3.15)$$

$$|\eta_0(T_r) + \Delta\eta(\rho_r)| = H[\eta_0(T_r) + \Delta\eta(\rho_r)] \quad (3.16)$$

$$k_0(T_r) = C_0 T_r + C_1 T_r^{0.5} + C_2 + \frac{C_3}{T_r} + \frac{C_4}{T_r^2} + \frac{C_5}{T_r^3} + \frac{C}{T_r^4} \quad (3.17)$$

$$\Delta k(\rho_r) = \sum_{i=1}^4 D_i \rho_r^i \quad (3.18)$$

$$k(T_r, \rho_r) = \Lambda[k_0(T_r) + \Delta k(\rho_r)] \quad (3.19)$$

Where

$$\rho_r = \frac{\rho}{\rho^*} \quad T_r = \frac{T}{T^*} \quad T^* = 132.5 \text{ K} \quad \rho^* = 314.3 \frac{\text{kg}}{\text{m}^3}$$

$$\Lambda = 25.9778 \left(\frac{10^{-3}W}{mK} \right) \quad H = 6.1609 (10 - 6 \text{ Pas}) \quad (3.20)$$

Coefficients of the equations are given in Table 3.1

Table 3.1 Coefficients of equations 3.14-3.19

i	A _i	B _i	C _i	D _i
0	0.128517	0.465601	0.239503	0.402287

1	2.60661	1.26469	0.00649768	0.356603
2	-1	-0.511425	1	-0.163159
3	-0.709661	0.2746	-1.92615	0.138059
4	0.662534		2.00383	-0.0201725
5	-0.197846		-1.07553	
6	0.00770147		0.229414	

In order to both check and error control purposes a surface cubic spline curve fitting equivalent formulation is also created. The data for curve fitting based on NIST data for thermal conductivity and viscosity for dry air. Viscosity and thermal conductivity values are taken from IAPWS Industrial Formulation 1997[15]. This equations are as follows:

Viscosity equations:

$$\eta(\rho, T) = \psi(\delta, \theta) = \eta^* [\psi_0(\theta) \psi_1(\delta, \theta)] \quad 3.21$$

$$\text{Where } \eta^* = 10^{-6} \text{ Pas} \quad \delta = \frac{\rho}{\rho^*} \quad \theta = T/T^*$$

$$\text{with } T^* = T_c = 647.096 \text{ K} \quad \rho^* = \rho_c = 322 \text{ kg/m}^3$$

$$\psi_0(\theta) = \theta^{0.5} [\sum_{i=1}^4 n_i^0 \theta^{1-i}]^{-1} \quad 3.22 \text{ Coefficients of equation given below:}$$

Table 3.2 Coefficients of equation 3.22

i	n_i^0
1	0.167752e-1
2	0.220462e-1
3	0.6366564e-2
4	-0.241605e-2

$$\psi_1(\delta, \theta) = \exp \left[\delta \sum_{i=1}^{21} n_i (\delta - 1)^{I_i} \left(\frac{1}{\theta} - 1 \right)^{J_i} \right] \quad 3.23$$

Table 3.3 Coefficients of equation 3.23

i	I _i	J _i	N _i	i	I _i	J _i	N _i
1	0	0	5.200940E-01	12	2	2	-7.724790E-01
2	0	1	8.508950E-02	13	2	3	-4.898370E-01
3	0	2	-1.083740E+00	14	2	4	-2.570400E-01
4	0	3	-2.895550E-01	15	3	0	1.619130E-01
5	1	0	2.225310E-01	16	3	1	2.573990E-01
6	1	1	9.991150E-01	17	4	0	-3.253720E-02
7	1	2	1.887970E+00	18	4	3	6.984520E-02
8	1	3	1.266130E+00	19	5	4	8.721020E-03
9	1	5	1.205730E-01	20	6	3	-4.356730E-03
10	2	0	-2.813780E-01	21	6	5	-5.932640E-04
11	2	1	-9.068510E-01				

Thermal conductivity equations

$$\frac{k(\rho, T)}{\kappa^*} = \Lambda(\delta, \theta) = \Lambda_0(\theta) + \Lambda_1(\delta) + \Lambda_2(\delta, \theta) \quad (3.24)$$

$$\Lambda_0(\theta) = \theta^{0.5} \sum_{i=1}^4 n_i^0 \theta^{i-1} \quad (3.25)$$

Table 3.4 Coefficients of equation 3.25

i	n_i^0
1	0.102811e-1
2	0.299621e-1
3	0.156146e-1
4	-0.422464e-2

$$\Lambda_1(\delta) = n_1 + n_2 \delta + n_3 \exp[n_4(\delta + n_5)^2] \quad 3.26$$

Table 3.5 Coefficients of equation 3.26

i	n_i
1	0.39707
2	0.400302
3	-0.171587e4
4	-0.239219e1

$$\Lambda_2(\delta, \theta) = (n_1 \theta^{-10} + n_2) \delta^{1.8} \exp[n_2(1 - \delta^{2.8})] + n_4 A \delta^B \exp \left[\left(\frac{B}{1+B} \right) (1 - \delta^{1+B}) \right] + n_5 \exp[n_6 \theta^{1.5} + n_7 \delta^{-5}] \quad (3.27)$$

$$A(\theta) = 2 + n_8 (\Delta \theta)^{-0.6} \quad (3.27a)$$

$$B(\theta) = \begin{cases} (\Delta \theta)^{-1} & \text{for } \theta \geq 1 \\ n_9 (\Delta \theta)^{-0.6} & \text{for } \theta < 1 \end{cases} \quad (3.27b) \text{ with } \Delta \theta = |\theta - 1| + n_{10}$$

Table 3.6 Coefficients of equation 3.27

i	n_i	i	n_i
1	7.013090E-02	6	-4.117170E+00
2	1.185200E-02	7	-6.179370E+00
3	6.428570E-01	8	8.229940E-02
4	1.699370E-03	9	1.009320E+01
5	-1.020000E+00	10	3.089760E-03

For mixing of dry air and water Wilke equation[6] will be used. This equation has the following form:

$$\eta_{mix} = \frac{x_A n_A}{x_A + n_A \phi_{AV}} + \frac{(1-x_A) n_V}{(1-x_A) + n_V \phi_{VA}} \quad (3.28) \text{ where}$$

$$\phi_{AV} = \frac{[1 + (n_A/n_V)^{1/2} (M_V/M_A)^{1/4}]}{\{8[1 + (M_A/M_V)]\}^{1/2}} \quad (3.28a)$$

$$\phi_{VA} = \phi_{AV} n_V / n_A (M_A/M_V) \quad (3.28b)$$

For thermal conductivity, similar equations will be used.

$$k_{mix} = \frac{x_A k_A}{x_A + k_A \phi_{AV}} + \frac{(1-x_A) k_V}{(1-x_A) + k_V \phi_{VA}} \quad (3.29) \text{ where}$$

$$\phi_{AV} = \frac{[1 + (k_A/k_V)^{1/2} (M_V/M_A)^{1/4}]}{\{8[1 + (M_A/M_V)]\}^{1/2}} \quad (3.29a)$$

$$\phi_{VA} = \phi_{AV} k_V / k_A (M_A/M_V) \quad (3.29b)$$

4. Computer development and error check

Several programs (classes) in java language to carry out this analysis. The list of program(class) names are given in Table 4.1

Table 4.1 Program lists

Class/interface name	Source
----------------------	--------

Interface if_x	Base interface general definition for function f(x)
Interface if_x	Base interface general definition for function f0(x0,x1,x2..) f1(x0,x1,x2,..) ...
steam	Water-steam EOS Keenan, Keys,Hill, Moore 1969
steamIAPWS_IF97	Water-steam EOS International Steam Tables, Wolfgang Wagner, Hans-Joachim Kretzschmar ISBN 978-3-540-21419-9
steam_IAPWS95	The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use W. Wagner and A. PruB J. Phys. Chem. Ref. Data, Vol. 31, No. 2, 2002
Gas_SP	Scheireiber-Pitzer EoS Pure gases
Gmix_SP	Scheireiber-Pitzer EoS Gas mixtures
air_SP	Scheireiber-Pitzer EoS for air
Humid_air_SP	Humid air EoS utilises Scheireiber-Pitzer EoS for dry air
air_IAPWS	Dry air EOS. Guideline on an Equation of State for Humid Air in Contact with Seawater and Ice, Consistent with the IAPWS Formulation 2008 for the Thermodynamic Properties of Seawater
air_PR	Dry air EOS. using Peng Robinson EOS for mixtures The properties of Gases & Liquids Robert C. Reid et al., Janaf Tables (NIST data https://janaf.nist.gov/)
air-PR1	Dry air EOS. using Peng Robinson EOS as a single gas. Pseudocritical properties are assumed for air. The properties of Gases & Liquids Robert C. Reid et al., Janaf Tables (NIST data https://janaf.nist.gov/)
Air_PG	Dry air EOS. using Perfect gas EOS as a single gas.
humid_air_IAPWS	Humid air EOS, Guideline on an Equation of State for Humid Air in Contact with Seawater and Ice, Consistent with the IAPWS Formulation 2008 for the Thermodynamic Properties of Seawater
humid_air_PR	Humid air EOS using peng Robinson EOS as mixtures fro dry air. The properties of Gases & Liquids Robert C. Reid et al., Janaf Tables (NIST data https://janaf.nist.gov/ , www.turhancoban.com)
humid_air_PR1	Humid air EOS using peng Robinson EOS as a single gas for dry air, The properties of Gases & Liquids Robert C. Reid et al., Janaf Tables (NIST data https://janaf.nist.gov/ , www.turhancoban.com)
humid_air_PG	Humid air EOS using Perfect gas EOS for air, The properties of Gases & Liquids Robert C. Reid et al., Janaf Tables (NIST data

	https://janaf.nist.gov/ , www.turhancoban.com
Gas	Pure ideal gas EOS including air and other gases www.turhancoban.com SCO1.jar
Plot	2D Plot program www.turhancoban.com SCO1.jar
GasTable	Graphic User Interface for class Gas
Wetair	Ideal Gas Humid air EOS utilises Gas class and steam class
psT	Graphic User Interface for class wetair
steamTable	Graphic User Interface for class steam
steamTableIF97	Graphic User Interface for class steamIAPWS_IF97
steamTableIAPWS95	Graphic User Interface for class steam_IAPWS95

In Table 4.2 different EOS results compared for 3 thermodynamic states. A Graphic user interface programs are also given for non-researchers to utilise these programs. For utilisation of researchers a small sample code is given to show calling of thermodynamic and thermophysical properties for a given state.

Table 4.2 Comparisons of 3 different EOS for water & Steam thermodynamic properties.

Class	P	T	v	h	u	s	x
steam	3.535 746	300	19.55 028	1331. 584	1262. 459	4.45599 4	0.5
steamIAPWS_IF97	3.536 589	300	19.54 153	1331. 234	1262. 124	4.45533	0.5
steam_IAPWS95	3.536 718	300	19.54 013	1331. 21	1262. 102	4.45524 4	0.5
steam	101.3 25	300	0.001 003	112.7 105	112.6 089	0.39324 5	-1.1E-09
steamIAPWS_IF97	101.3 25	300	0.001 003	112.6 65	112.5 634	0.39309 7	-1
steam_IAPWS95	101.3 25	300	0.001 003	112.6 549	112.5 532	0.39306 2	-2
steam	101.3 25	400	1.801 666	2730. 178	2547. 624	7.49502 3	2.467 381
steamIAPWS_IF97	101.3 25	400	1.802 056	2730. 272	2547. 679	7.49607 8	2
steam_IAPWS95	101.3 25	400	1.801 984	2730. 301	2547. 715	7.49620 2	2

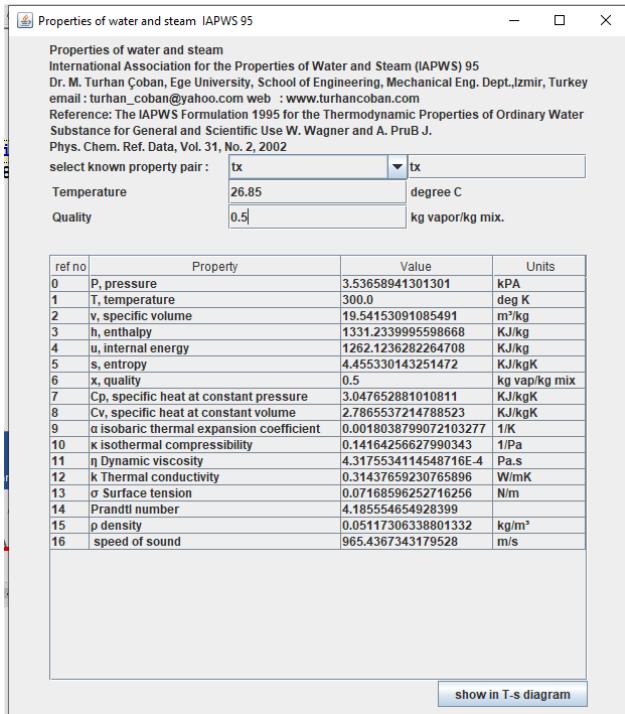


Figure 4.1 steam_IAPWS95 Graphic user interface

By using equations given above a class called air_IAPWS95 is developed. The result of this class is compared with Peng-Robinson EOS results as a mixing of the gases inside air and as a single gas with pseudocritical properties plus ideal gas equation of state. Results are given in table 4.3. It should be note that enthalpies of the perfect gas case (air_PG) is the same regardless of temperature.

Table 4.3 Air properties at different states for 5 dry air models

dry air model	P kPa	T deg. K	ro kg/m^3	h kJ/kg	s kJ/kgK
Schreiber Pitzer	100	300	0.8613451	27.020214	0.098237
Lee-Kesler	100	300	0.8606799	27.032945	0.098208
Peng-Robinson	100	300	0.8606847	27.03313	0.0982013
IAPWS	100	300	0.8608818	27.013616	0.098109
Perfect_Gas	100	300	0.8611474	27.010079	0.0980983
Schreiber-Pitzer	100	350	1.0049141	77.408758	0.2534885
Lee-Kesler	100	350	1.0045201	77.444638	0.2536303
Peng-Robinson	100	350	1.0045276	77.445073	0.2536314
IAPWS	100	350	1.0046844	77.393749	0.253426
Perfect Gas	100	350	1.0046719	77.390207	0.2534153
Schreiber_Pitzer	300	300	0.2871075	26.558151	-0.2183159
Lee-Kesler	300	300	0.2865871	26.941114	-0.2174628

Peng-Robinson	300	300	0.2865906	26.941568	-0.2174598
IAPWS	300	300	0.2867884	26.561485	-0.2185783
Perfect_	300	300	0.2870491	27.010079	-0.2172574
Schreiber-Pitzer	300	350	0.3349703	77.076111	-0.0628454
Lee-Kesler	300	350	0.3347429	77.4155	-0.0618087
Peng-Robinson	300	350	0.3347488	77.416709	-0.0618056
IAPWS	300	350	0.3349071	77.073131	-0.062854
Perfect Gas	300	350	0.3348906	77.390207	-0.0619404
Schreiber-Pitzer	500	300	0.17226	26.09895	-0.3661031
Lee-Kesler	500	300	0.171773	26.851465	-0.3643929
Peng-Robinson	500	300	0.1717763	26.852267	-0.3643897
IAPWS_EoS	500	300	0.1719734	26.111196	-0.3665391
Perfect Gas	500	300	0.1722295	27.010079	-0.3638894
Schreiber_Pitzer	500	350	0.2009815	76.745602	-0.2104141
Lee-Kesler	500	350	0.2007908	77.388008	-0.2085193
Peng_Robinson_EoS	500	350	0.2007964	77.390024	-0.2085136
IAPWS_EoS	500	350	0.2009547	76.7544	-0.2104072
Perfect_Gas_EoS	500	350	0.2009344	77.390207	-0.2085724
Schreiber_and_Pitzer_Eos	1000	300	0.0861244	24.963392	-0.5679122
Lee_Kesler_EoS	1000	300	0.0856721	26.637046	-0.5640777
Peng_Robinson_EoS	1000	300	0.0856755	26.638907	-0.5640692
IAPWS_EoS	1000	300	0.0858703	24.993351	-0.5688153
Perfect_Gas_EoS	1000	300	0.0861147	27.010079	-0.5628567
Schreiber_and_Pitzer_Eos	1000	350	0.1004899	75.92866	-0.4116798
Lee_Kesler_EoS	1000	350	0.1003338	77.326424	-0.4076628
Peng_Robinson_EoS	1000	350	0.1003393	77.330613	-0.4076497
IAPWS_EoS	1000	350	0.1004972	75.96566	-0.4116639

Perfect_Gas_EoS	1000	350	0.10046	77.3902	-	0.40753
S			72	07		97

Properties of steam and dry air combined according to equations given above sections. The program is called humid_air_SP

Properties of humid air Schreiber and Pitzer Eos based						
array no	property name	value humid air mass fr base	unit	value dry air mass fr.	unit	
0	P, pressure	100.0	kPa			
1	T, temperature	27.0	deg C			
2	v, specific volume	25.402341825970233	m ³ /kg humid air	25.656254244229...	m ³ /kg dry air	
3	h, enthalpy	804.4010246905976	KJ/kg	812.4450349376045	KJ/kg dry air	
4	s, entropy	3.047651475131444	KJ/kgK	3.0781279898554	KJ/kg dry air	
5	w, specific humidity, humidity ratio	0.01000000000000009	kg vapor/kg dry air			
6	A, mass fraction of dry air	0.990099909909901	kg dry air/kg humid air			
7	xA, mole fraction of dry air	0.984180003703808	kmol dry air/kmol humid air			
8	relative humidity	0.4433824953837536				
9	Adiabatic saturation temperature	26.32007690387733	degree C			
10	dew point temperature	13.83668476782572	degree C			
11	n Dynamic viscosity	4.4812745272595E-4	Pa.s			
12	k Thermal conductivity	0.0276895953567513	W/mK			
13	degree of saturation	0.44014714231...				
14	Pa dry air partial pressure	98.4180003703808	kPa			
15	Pv water moisture partial pressure	1.58139966294919193	hPa			
16	p density	0.039166604209519016	kg humid air/m ³	0.0398782551...	kg dry air/m ³	
17	Cp isochoric specific heat	28.8564299835202	J/K(kg humid air K)	29.1449428217554	J/K(kg dry air)	
18	Cv isovolumetric specific heat	20.596798613585	J/K(kg humid air K)	20.80276192599721	J/K(kg dry air)	
19	ha enthalpy of dry air KJ/kg dry air	786.9345711437845	KJ/kg humid air	794.03916855224	KJ/kg dry air	
20	hv enthalpy of vapor J/Kg water	2551.046379382008	J/K(kg water)			

Figure 4.1 humid_air_SP Graphic output for P=100 kPa and T=300 K

Properties of humid air Schreiber and Pitzer Eos based						
array no	property name	value humid air mass fr base	unit	value dry air mass fr base	unit	
0	P, pressure	200.0	kPa			
1	T, temperature	27.0	deg C			
2	v, specific volume	12.69643234387684	m ³ /kg humid air	12.823416847631561	m ³ /kg dry air	
3	h, enthalpy	795.86374092307	KJ/kg	805.842378402759	KJ/kg dry air	
4	s, entropy	3.0781279898554	KJ/kgK	3.0821307586032	KJ/kg dry air	
5	w, specific humidity, humidity ratio	0.01000000000000009	kg vapor/kg dry air			
6	A, mass fraction of dry air	0.990099909909901	kg dry air/kg humid air			
7	xA, mole fraction of dry air	0.984180003703808	kmol dry air/kmol humid air			
8	relative humidity	0.4433824953837536				
9	Adiabatic saturation temperature	26.32007690387733	degree C			
10	dew point temperature	14.98911193013117	degree C			
11	n Dynamic viscosity	4.482557823839E-4	Pa.s			
12	k Thermal conductivity	0.0277305060403924	W/mK			
13	degree of saturation	0.44014714231...				
14	Pa dry air partial pressure	194.8160003703808	kPa			
15	Pv water moisture partial pressure	3.16399032192383	hPa			
16	p density	0.078761592591793	kg humid air/m ³	0.07798233590017753	kg dry air/m ³	
17	Cp isochoric specific heat	28.8564299835202	J/K(kg humid air K)	29.1449428217554	J/K(kg dry air)	
18	Cv isovolumetric specific heat	20.596798613585	J/K(kg humid air K)	20.80276192599721	J/K(kg dry air)	
19	ha enthalpy of dry air KJ/kg dry air	780.391216575938	J/K(kg humid air)	788.1423178411789	J/K(kg dry air)	
20	hv enthalpy of vapor J/Kg water	2550.3212182693835	J/K(kg water)			

Figure 4.2 humid_air_SP Graphic output for Graphic output for P=200 kPa and T=300 K

Separately classes humid_air_IAPWS, and humid_air_PG and humid_air_PR1 is developed. The details of this classes will not be given here, but the results will be given for the same state, to compare the results.

Properties of humid air IAPWS formulation based						
array no	property name	value humid air mass fr base	unit	value dry air mass fr base	unit	
0	P, pressure	100.0	kPa			
1	T, temperature	27.0	deg C			
2	v, specific volume	25.402341825970233	m ³ /kg humid air	25.656254244229...	m ³ /kg dry air	
3	h, enthalpy	804.4010246905976	KJ/kg	812.4450349376045	KJ/kg dry air	
4	s, entropy	3.047651475131444	KJ/kgK	3.0781279898554	KJ/kg dry air	
5	w, specific humidity, humidity ratio	0.01000000000000009	kg vapor/kg dry air			
6	A, mass fraction of dry air	0.990099909909901	kg dry air/kg humid air			
7	xA, mole fraction of dry air	0.9841761361314283	kmol dry air/kmol humid air			
8	relative humidity	0.4434908764528124				
9	Adiabatic saturation temperature	26.32007690387733	degree C			
10	dew point temperature	13.84044190444836	degree C			
11	n Dynamic viscosity	4.4797692042079	Pa.s			
12	k Thermal conductivity	0.0276863608203	W/mK			
13	degree of saturation	0.44014714231...				
14	Pa dry air partial pressure	98.41761361314283	kPa			
15	Pv water moisture partial pressure	1.582383651716977	hPa			
16	p density	0.078761592591793	kg humid air/m ³	0.07798233590017753	kg dry air/m ³	
17	Cp isochoric specific heat	0.015088555201293	J/K(kg humid air K)	0.0252192410753307	J/K(kg dry air)	
18	Cv isovolumetric specific heat	0.02748023833253497	J/K(kg humid air K)	0.0321413071586031	J/K(kg dry air K)	
19	ha enthalpy of dry air KJ/kg dry air	27.168150462752937	J/K(kg humid air)	27.439831967380467	J/K(kg dry air K)	
20	hv enthalpy of vapor J/Kg water	2551.046212195935	J/K(kg water)			

Figure 4.5 humid_air_PG (Perfect Gas) Graphic output for P=100 kPa and T=300 K

Properties of humid air IAPWS formulation based						
array no	property name	value humid air mass fr base	unit	value dry air mass fr base	unit	
0	P, pressure	200.0	kPa			
1	T, temperature	26.850000000000002	deg C			
2	v, specific volume	0.4378654987595923	m ³ /kg humid air	0.4379145176439236	m ³ /kg dry air	
3	h, enthalpy	31.73229077659324	KJ/kg	32.269913684411446	KJ/kg dry air	
4	s, entropy	0.4378654987595923	KJ/kgK	0.4380864864907885	KJ/kg dry air	
5	w, specific humidity, humidity ratio	0.01000000000000009	kg vapor/kg dry air			
6	A, mass fraction of dry air	0.990099909909901	kg dry air/kg humid air			
7	xA, mole fraction of dry air	0.98417613613127101	kmol dry air/kmol humi...			
8	relative humidity	0.894833193280208				
9	Adiabatic saturation te...	25.743134749487012	degree C			
10	dew point temperature	24.973297470816673	degree C			
11	n Dynamic viscosity	4.48080259814973E-4	Pa.s			
12	k Thermal conductivity	0.0276997079897941	W/mK			
13	degree of saturation	0.894833193280208				
14	Pa dry air partial press...	28.852271652925432	kPa			
15	Pv water moisture part...	3.164773737457988	kPa			
16	o density	2.310186457592851	kg humid air/m ³	2.28731330454509	kg dry air/m ³	
17	Cp isochoric specific heat	0.116936706735183	J/K(kg humid air K)	0.127105434711838	J/K(kg dry air K)	
18	Cv isovolumetric specific heat	0.27354173254711854	J/K(kg humid air K)	0.325952540565114	J/K(kg dry air K)	
19	ha enthalpy of dry air KJ/kg dry air	26.994473254711854	J/K(kg humid air)	27.062417987286047	J/K(kg dry air K)	
20	hv enthalpy of vapor J/Kg water	2550.0389795436004	J/K(kg water)			

Figure 4.3 humid_air_IAPWS Graphic output for P=100 kPa and T=300 K

Properties of humid air Cubic Peng-Robinson EOS based. Air as a single gas						
array no	property name	value humid air mass fr base	unit	value dry air mass fr base	unit	
0	P, pressure	100.0	kPa			
1	T, temperature	26.850000000000002	deg C			
2	v, specific volume	0.4378654987595923	m ³ /kg humid air	0.4379145176439236	m ³ /kg dry air	
3	h, enthalpy	31.73229077659324	KJ/kg	32.269913684411446	KJ/kg dry air	
4	s, entropy	0.4378654987595923	KJ/kgK	0.4380864864907885	KJ/kg dry air	
5	w, specific humidity, humidity ratio	0.01000000000000009	kg vapor/kg dry air			
6	A, mass fraction of dry air	0.990099909909901	kg dry air/kg humid air			
7	xA, mole fraction of dry air	0.98417613613127101	kmol dry air/kmol humid air			
8	relative humidity	0.894833193280208				
9	Adiabatic saturation temperat...	18.138097610096782	degree C			
10	dew point temperature	13.8044490246109	degree C			
11	n Dynamic viscosity	4.48110893837139E-4	Pa.s			
12	k Thermal conductivity	0.0276997079897941	W/mK			
13	degree of saturation	0.894833193280208				
14	Pa dry air partial pressure	98.41761361314283	kPa			
15	Pv water moisture partial pressure	1.583238651716977	hPa			
16	o density	1.138431204886479	kg humid air/m ³	1.1271596087984443	kg dry air/m ³	
17	Cp isochoric specific heat	0.1037745914519034	J/K(kg humid air K)	0.104815233735642	J/K(kg dry air K)	
18	Cv isovolumetric specific heat	0.27064838545466	J/K(kg humid air K)	0.334098693090921	J/K(kg dry air K)	
19	ha enthalpy of dry air KJ/kg dry air	27.0100783556395	J/K(kg humid air)	27.28011572919592	J/K(kg dry air K)	
20	hv enthalpy of vapor J/Kg water	2550.7641461832485	J/K(kg water)			

Figure 4.5 humid_air_PR1 Graphic output for P=100 kPa and T=300 K

Properties of humid air Perfect Gas EOS based						
array no	property name	value humid air mass fr base	unit	value dry air mass fr base	unit	
0	P, pressure	100.0	kPa			
1	T, temperature	26.850000000000002	deg C			
2	v, specific volume	0.4378654987595923	m ³ /kg humid air	0.4379145176439236	m ³ /kg dry air	
3	h, enthalpy	31.73229077659324	KJ/kg	32.269913684411446	KJ/kg dry air	
4	s, entropy	0.4378654987595923	KJ/kgK	0.4380864864907885	KJ/kg dry air	

linear interpolation type of correction of properties will not be correct. In this study, a computer model of thermodynamic and thermophysical properties of humid by using Schreiber and Pitzer_equation of states used. For dry air viscosity and thermal conductivities equations based on experimental studies by Kadoya et al[1] and Lemmon et al[2] is used. Water viscositiy equations are taken from IAPWS Industrial Formulation 1997[4] and then these data combined by using Wilke equation[6]. Computer models for different set of real gas equation of State by IAPWS EOS, Peng-Robinson EoS and perfect gas formulations are also derived and results are compared. All computer codes developed in java programming language and program codes are given as free acess to researchers at internet adress www.turhancoban.com. All equations for property of water-steam, dry air and humid air is given with details and coefficients for the researchers wish to develop their own version of computer codes in their desired programming language.

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