THERMODYNAMIC AND THERMOPHYSICAL PROPERTIES OF HUMID AIR BY USING IAPWS FORMULATIONS

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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 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 equation of states developed by The international Association for the Properties of Water and Steam (IAPWS) will be used to establish computer programs in java language to calculate properties of humid air. In order to calculate water properties IAPWS-95 is used, properties are compared with the previously developed IAPWS-97 computer codes to ensure accuracy of calculations. Dry air properties and mixing interaction properties of dry air and water is calculated by using EOS defined as IAPWS G8-10. Basic thermodynamic and heat-mass transfer equations are used to define properties such as dew point temperature, adyabatic 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 Peng-Robinson Cubic EOS (with critical property mixing rules) Humid air equations. A Graphical user interphase is also developed. All the program code are liste as free access in www.turhancoban.com adress. As subprograms properties of water and steam and properties of dry air can also be calculated by using this set of programs. All the codes are developed in java programming language.

Key Words: Thermodynamic properties of humid air, Thermodynamic properties of water and steam, thermodynamic properties of dry air, thermophysical properties of humid air

2. FORMULATIONS OF THE EQUATION OF STATES

Equation of state formulations of humid air will be considered three basic parts. The first part is for water properties, the second part is for the dry air properties and the third part is for the mixed interactions of dry air and water(air-water cross virial part). The equation of state is represented here in terms of the specific Helmholtz free energy of humid air, f^{AV}, expressed as a function of dry-air mass fraction A (kg dry air/kg total), temperature T (degree K) and humid-air mass density ρ(kg/m^3).[1]

$f^{AV}(A,T,\rho) = (1-A)f^V(T,\rho^V) + Af^A(T,\rho^A) + f^{mix}(A,T,\rho)$ 2.1

In this equation $\rho^A = A\rho$ 2.2 and $\rho^V = (1-A)\rho$ 2.3

The water-vapor part is given by IAPWS-95 Helmholtz free energy for water and steam[2]. This equation has the following form:

$$\frac{f^V(T,\rho^V)}{RT} = \phi^V(\delta,\tau) = \phi^{V0}(\delta,\tau) + \phi^{Vr}(\delta,\tau) \quad 2.4$$

Where $\delta = \rho^V/\rho_c^V$ and $\tau = T_c^V/T$ for steam and water T_c^V=647.096 K, ρ_c^V=322 kg/m^3 and R=0.46151805 kJ/(kgK). The equation for the ideal gas part of the Helmholtz free energy $\phi^{V0}(\delta,\tau)$ can be obtained by using the following equation:

$$\phi^{V0}(\delta,\tau) = \ln(\delta) + n_1^0 + n_2^0\tau + n_3^0\ln(\tau)\sum_{i=4}^{8} n_i^0 ln\left[1 - e^{-(\gamma_i^o)^2}\right] \quad 2.5$$

Table 2.1 Coefficients of Equation 2.5

i	n_i^0	γ_i^o	i	n_i^0	γ_i^o
1	-8.32044648201	-	5	0.97315	3.53734222
2	6.6832105268	-	6	1.27950	7.7473708
3	3.00632	-	7	0.966956	9.24437796
4	0.012436	1.28728967	8	0.24873	27.5075105

The equation for the residual part of the Helmholtz free energy $\phi^{Vr}(\delta,\tau)$ can be obtained by using the following equation:

$$\phi^{Vr}(\delta,\tau) = \sum_{i=1}^{7} n_i\delta^{d_i}\tau^{t_i} + \sum_{i=8}^{51} n_i\delta^{d_i}\tau^{t_i}\,e^{-\delta^{c_i}} + \sum_{i=52}^{54} n_i\delta^{d_i}\tau^{t_i}\,e^{-\alpha_i(\delta-\epsilon_i)^2-\beta_i(\tau-\gamma_i)^2} + \sum_{i=55}^{56} n_i\,\Delta^{b_i}\Psi \quad 2.6$$

With $\Delta = \theta^2 + B_i[(\delta-1)^2]^{a_i}$ 2.7

$$\theta = (1-\tau) + A_i[(\delta-1)^2]^{1/(2\beta_i)} \quad 2.8$$

$$\Psi = e^{-C_i(\delta-1)^2 - D_i(\tau-1)^2} \quad 2.9$$

Table 2.2 Coefficients of Equation 2.6

i	a_i	b_i	B_i	c_i	d_i	t_i	n_i	α_i	β_i	γ_i	ε_i	C_i	D_i	A_i
1	0	0	0	0	1	-0.5	1.25335479355230E-02	0	0	0	0	0	0	0
2	0	0	0	0	1	0.875	7.89576347228280E+00	0	0	0	0	0	0	0
3	0	0	0	0	1	1	-8.78032033035610E+00	0	0	0	0	0	0	0
4	0	0	0	0	2	0.5	3.18025093454180E-01	0	0	0	0	0	0	0
5	0	0	0	0	2	0.75	-2.61455338593580E-01	0	0	0	0	0	0	0
6	0	0	0	0	3	0.375	-7.81997516879810E-03	0	0	0	0	0	0	0
7	0	0	0	0	4	1	8.80894931021340E-03	0	0	0	0	0	0	0
8	0	0	0	1	1	4	-6.68565723079650E-01	0	0	0	0	0	0	0
9	0	0	0	1	1	6	2.04338109509650E-01	0	0	0	0	0	0	0
10	0	0	0	1	1	12	-6.62126050396870E-05	0	0	0	0	0	0	0
11	0	0	0	1	2	1	-1.92327211560020E-01	0	0	0	0	0	0	0
12	0	0	0	1	2	5	-2.57090430034380E-01	0	0	0	0	0	0	0
13	0	0	0	1	3	4	1.60748684862510E-01	0	0	0	0	0	0	0
14	0	0	0	1	4	2	-4.00928289258070E-02	0	0	0	0	0	0	0
15	0	0	0	1	4	13	3.93434226032540E-07	0	0	0	0	0	0	0
16	0	0	0	1	5	9	-7.59413770881440E-06	0	0	0	0	0	0	0
17	0	0	0	1	7	3	5.62509793518880E-04	0	0	0	0	0	0	0
18	0	0	0	1	9	4	-1.56086522571350E-05	0	0	0	0	0	0	0
19	0	0	0	1	10	11	1.15379964229510E-09	0	0	0	0	0	0	0
20	0	0	0	1	11	4	3.65821651442040E-07	0	0	0	0	0	0	0
21	0	0	0	1	13	13	-1.32511800746680E-12	0	0	0	0	0	0	0
22	0	0	0	1	15	1	-6.26395869124540E-10	0	0	0	0	0	0	0
23	0	0	0	2	1	7	-1.07936009089320E-01	0	0	0	0	0	0	0
24	0	0	0	2	2	1	1.76114910087520E-02	0	0	0	0	0	0	0
25	0	0	0	2	2	9	2.21322951675460E-01	0	0	0	0	0	0	0

26	0	0	0	2	2	10	-4.02476697635280E-01	0	0	0	0	0	0	0
27	0	0	0	2	3	10	5.80833999857590E-01	0	0	0	0	0	0	0
28	0	0	0	2	4	3	4.99691469908060E-03	0	0	0	0	0	0	0
29	0	0	0	2	4	7	-3.13587007125490E-02	0	0	0	0	0	0	0
30	0	0	0	2	4	10	-7.43159297103410E-01	0	0	0	0	0	0	0
31	0	0	0	2	5	10	4.78073299154800E-01	0	0	0	0	0	0	0
32	0	0	0	2	6	6	2.05279408959480E-02	0	0	0	0	0	0	0
33	0	0	0	2	6	10	-1.36364351103430E-01	0	0	0	0	0	0	0
34	0	0	0	2	7	10	1.41806344006170E-02	0	0	0	0	0	0	0
35	0	0	0	2	9	1	8.33265048807130E-03	0	0	0	0	0	0	0
36	0	0	0	2	9	2	-2.90523360095850E-02	0	0	0	0	0	0	0
37	0	0	0	2	9	3	3.86150855742060E-02	0	0	0	0	0	0	0
38	0	0	0	2	9	4	-2.03934865137040E-02	0	0	0	0	0	0	0
39	0	0	0	2	9	8	-1.65540500637340E-03	0	0	0	0	0	0	0
40	0	0	0	2	10	6	1.99555719795410E-03	0	0	0	0	0	0	0
41	0	0	0	2	10	9	1.58703083241570E-04	0	0	0	0	0	0	0
42	0	0	0	2	12	8	-1.63885683425300E-05	0	0	0	0	0	0	0
43	0	0	0	3	3	16	4.36136157238110E-02	0	0	0	0	0	0	0
44	0	0	0	3	4	22	3.49940054637650E-02	0	0	0	0	0	0	0
45	0	0	0	3	4	23	-7.67881978446210E-02	0	0	0	0	0	0	0
46	0	0	0	3	5	23	2.24462773320060E-02	0	0	0	0	0	0	0
47	0	0	0	4	14	10	-6.26897104146850E-05	0	0	0	0	0	0	0
48	0	0	0	6	3	50	-5.57111185656450E-10	0	0	0	0	0	0	0
49	0	0	0	6	6	44	-1.99057183544080E-01	0	0	0	0	0	0	0
50	0	0	0	6	6	46	3.17774973307380E-01	0	0	0	0	0	0	0
51	0	0	0	6	6	50	-1.18411824259810E-01	0	0	0	0	0	0	0
52	0	0	0	0	3	0	-3.13062603234350E+01	20	150	1.2	1	0	0	0
53	0	0	0	0	3	1	3.15461402377810E+01	20	150	1.2	1	0	0	0
54	0	0	0	0	3	4	-2.52131543416950E+03	20	250	1.3	1	0	0	0
55	3.5	0.9	0.2	0	0	0	-1.48746408567240E-01	0	0.3	0	0	28	700	0.32
56	3.5	1	0.2	0	0	0	3.18061108784440E-01	0	0.3	0	0	32	800	0.32

All thermodynamic values for water-steam can be derived from equation 2.4

Pressure (kPa): $\frac{P(\delta,\tau)}{\rho RT} = 1 + \delta \frac{\partial \phi^{Vr}(\delta,\tau)}{\partial \delta}$ 2.10

Entropy (kJ/(kgK)) : $\frac{s(\delta,\tau)}{R} = \tau \frac{\partial[\phi^{V0}(\delta,\tau)+\phi^{Vr}(\delta,\tau)]}{\partial \tau} - [\phi^{V0}(\delta,\tau) + \phi^{Vr}(\delta,\tau)]$ 2.11

Enthalpy (kJ/kg) : $\frac{h(\delta,\tau)}{RT} = 1 + \tau \frac{\partial[\phi^{V0}(\delta,\tau)+\phi^{Vr}(\delta,\tau)]}{\partial \tau} + \delta \frac{\partial \phi^{Vr}(\delta,\tau)}{\partial \delta}$ 2.12

Isochoric specific heat C_p(kJ/(kgK)) :

$$\frac{C_p(\delta,\tau)}{R} = -\tau^2[\phi^{V0}(\delta,\tau) + \phi^{Vr}(\delta,\tau)] + \frac{\left(1+\delta\frac{\partial\phi^{Vr}(\delta,\tau)}{\partial\delta} - \delta\frac{\partial^2\phi^{Vr}(\delta,\tau)}{\partial\delta\partial\tau}\right)^2}{1+2\delta\frac{\partial\phi^{Vr}(\delta,\tau)}{\partial\delta} + \delta^2\frac{\partial^2\phi^{Vr}(\delta,\tau)}{\partial\delta\partial\delta}} \quad 2.13$$

For saturation region following equations are given:

$\frac{P_\sigma(\delta',\tau)}{\rho' RT} = 1 + \delta' \frac{\partial \phi^{Vr}(\delta',\tau)}{\partial \delta}$ 2.14

$\frac{P_\sigma(\delta",\tau)}{\rho" RT} = 1 + \delta" \frac{\partial \phi^{Vr}(\delta",\tau)}{\partial \delta}$ 2.15

$\frac{P_\sigma(\delta',\tau)}{RT}\left(\frac{1}{\rho"} - \frac{1}{\rho'}\right) - ln\left(\frac{\rho'}{\rho"}\right)$ 2.16

Where ρ' is saturated liquid density and $\rho"$ is saturated vapor density.

Auxiliary equations for P_σ, ρ' , $\rho"$, h' , $h"$, , s' , $s"$ is also given in IAPWS-95 as:

$$\left(\frac{P_\sigma}{P_c}\right) = exp\left(\frac{T_c}{T}\left(a_1\vartheta + a_2\vartheta^{1.5} + a_3\vartheta^3 + a_4\vartheta^{3.5} + a_5\vartheta^4 + a_6\vartheta^{7.5}\right)\right) \quad 2.17$$

$$\left(\frac{dP_\sigma}{dT}\right) = -\frac{P_\sigma}{T}\left(ln\left(\frac{P_\sigma}{P_c}\right) + a_1\vartheta + 1.5a_2\vartheta^{0.5} + 3a_3\vartheta^2 + 3.5a_4\vartheta^{2.5} + 4a_5\vartheta^3 + 7.5a_6\vartheta^{6.5}\right) \quad 2.18$$

$$\left(\frac{\rho'}{\rho_c}\right) = \left(1 + b_1\vartheta^{1/3} + b_2\vartheta^{2/3} + b_3\vartheta^{5/3} + b_4\vartheta^{16/35} + b_5\vartheta^{43/3} + b_6\vartheta^{110/3}\right) \quad 2.19$$

$$ln\left(\frac{\rho"}{\rho_c}\right) = exp\left(c_1\vartheta^{2/6} + c_2\vartheta^{4/6} + c_3\vartheta^{8/6} + c_4\vartheta^{18/6} + c_5\vartheta^{37/6} + c_6\vartheta^{71/6}\right) \quad 2.20$$

$$\left(\frac{\alpha}{\alpha_0}\right) = \left(d_0 + d_1\theta^{-19} + d_2\theta + d_3\theta^{4.5} + d_4\theta^5 + d_5\theta^{54.5}\right) \quad 2.21$$

$$\left(\frac{\varphi}{\varphi_0}\right) = \left(e_0 + \frac{19}{20}d_1\theta^{-20} + d_2 ln\theta + \frac{9}{7}d_3\theta^{3.5} + \frac{5}{4}d_4\theta^4 + \frac{109}{107}d_5\theta^{53.5}\right) \quad 2.22$$

$$h' = \left(\frac{\alpha}{\alpha_0}\right) + \frac{T}{\rho\prime}\left(\frac{dP_\sigma}{dT}\right) \quad 2.23$$

$$h" = \left(\frac{\alpha}{\alpha_0}\right) + \frac{T}{\rho"}\left(\frac{dP_\sigma}{dT}\right) \quad 2.24$$

$$s' = \varphi + \frac{1}{\rho\prime}\left(\frac{dP_\sigma}{dT}\right) \quad 2.25$$

$$s" = \varphi + \frac{1}{\rho"}\left(\frac{dP_\sigma}{dT}\right) \quad 2.26$$

Where $\vartheta = \left(1 - \frac{T}{T_c}\right)$ and $\theta = \frac{T}{T_c}$ Coefficient of the Auxiliary equations are as follows:

Table 2.3 Coefficients of Auxiliary Equations 2.17-2.20

i	a	b	c
1	-7.85951783	1.99274064	-2.0315024
2	1.84408259	1.09965342	-2.68302940
3	-11.7866497	-0.510839303	-5.38626492
4	22.6807411	-1.75493479	-17.2991605
5	-15.9618719	-45.5170352	-44.7586581
6	1.80122502	-6.74694450e5	-63.9201063

Table 2.4 Coefficients of Auxiliary Equations 2.21-2.22

i	d	e
0	-1135.905627715	2319.5246
1	-5.65134998e-8	
2	2690.66631	
3	127.287297	
4	-135.003439	

Equation of State (the specific Helmholtz energy) for dry air:

$$f^A(T, \rho^A) = \frac{R^L T}{M_A}\alpha^A(\delta, \tau) = \frac{R^L T}{M_A}\left[\alpha^{A0}(\delta, \tau) + \alpha^{Ar}(\delta, \tau)\right] \qquad 2.27$$

Where R_L=8.31451 J/(molK) molar gas constant, M_A=0.02896546 kg/mol Molar mass of dry air. $\alpha^{A0}(\delta, \tau)$ is ideal gas part of the reduced specific Helmholtz energy and $\alpha^{Ar}(\delta, \tau)$ is the residual part of the reduced specific Helmholtz energy.

$$\alpha^{A0}(\delta,\tau) = \ln(\delta) + \sum_{i=1}^{5} n_i^0 \tau^{i-4} + n_6^0 \tau^{1.5} + n_7^0 \ln(\tau) + n_8^0 \ln[1 - \exp(-n_{11}^0 \tau)] +$$

$$n_9^0 \ln[1 - \exp(-n_{12}^0 \tau)] + n_{10}^0 \ln[2/3 - \exp(-n_{13}^0 \tau)] \qquad 2.28$$

$$\alpha^{Ar}(\delta,\tau) = \sum_{k=1}^{10} n_k \delta^{i_k} \tau^{j_k} + \sum_{k=11}^{19} n_k \delta^{i_k} \tau^{j_k} \exp(-n_k \delta^{t_k}) \qquad 2.29$$

Where $\tau = \frac{T_A^*}{T}$ $\quad T_A^* = 132.6312\ K \quad \delta = \frac{\rho^A}{\rho_A^*} \quad \rho_A^* = 10447.7\ mol/m^3$

Table 2.5 Coefficients of Equation 2.28

i	n_i^0
1	6.05719400E-08
2	-2.10274769E-05
3	-1.58860716E-04
4	9.74502517E+00
5	1.00986147E+01
6	-1.95363420E-04
7	2.49088803E+00
8	7.91309509E-01
9	2.12236768E-01
10	-1.97938904E-01
11	2.53636500E+01
12	1.69074100E+01
13	8.73127900E+01

Table 2.6 Coefficients of Equation 2.29

i	i_k	j_k	l_k	n_k
1	1	0	0	1.181607472290E-01
2	1	0.33	0	7.131163920790E-01
3	1	1.01	0	-1.618241920670E+00
4	2	0	0	7.141401789710E-02
5	3	0	0	-8.654213966460E-02
6	3	0.15	0	1.342111767040E-01
7	4	0	0	1.126267042180E-02
8	4	0.2	0	-4.205332288420E-02
9	4	0.35	0	3.490084319820E-02
10	6	1.35	0	1.649571831860E-04
11	1	1.6	1	-1.013650379120E-01
12	3	0.8	1	-1.738136909700E-01
13	5	0.95	1	-4.721031837310E-02
14	6	1.25	1	-1.225235542530E-02
15	1	3.6	3	-1.466296097130E-01
16	3	6	2	-3.160558798210E-02
17	11	3.25	2	2.335948061420E-04
18	1	3.5	3	1.482878919780E-02
19	3	15	3	-9.387828846670E-03

All thermodynamic values for dry air can be derived from equation 2.27

Pressure (kPa): $P(T,ro) = \rho^2 \frac{\partial f^A(T,\rho^A)}{\partial \rho}$ $\quad$ 2.30

Entropy (kJ/(kgK)) : $s(T,ro) = -\frac{\partial f^A(T,\rho^A)}{\partial T}$ $\quad$ 2.31

Enthalpy (kJ/kg) : $h(T,ro) = f^A(T,\rho^A) - T\frac{\partial f^A(T,\rho^A)}{\partial T} + \rho \frac{\partial f^A(T,\rho^A)}{\partial \rho}$ $\quad$ 2.32

Isochoric specific heat C_p(kJ/(kgK)) :

$$C_p(T,ro) = -T\frac{\partial^2 f^A(T,\rho^A)}{\partial T\partial T} + \frac{T\rho\left[\frac{\partial^2 f^A(T,\rho^A)}{\partial T\partial\rho}\right]^2}{\left(2\frac{\partial f^A(T,\rho^A)}{\partial\rho}+\rho\frac{\partial^2 f^A(T,\rho^A)}{\partial\rho\partial\rho}\right)} \quad 2.33$$

Equation of state for water-dry air interaction:

$$f^{mix}(A,T,\rho) = \frac{2A(1-A)\rho RT}{M_A M_W}\left\{B^{AW}(T) + \frac{3}{4}\rho\left[\frac{A}{M_A}C^{AAW}(T) + \frac{(1-A)}{M_W}C^{AWW}(T)\right]\right\} \quad 2.34$$

$$B^{AW}(T) = b^*\sum_{i=1}^{3} c_i\bar{T}^{d_i} \quad 2.35$$

$$C^{AAW}(T) = c^*\sum_{i=0}^{4} a_i\bar{T}^{-i} \quad 2.36$$

$$C^{AWW}(T) = -c^* exp\left[\sum_{i=0}^{4} b_i\bar{T}^{-i}\right] \quad 2.37$$

Where $\bar{T} = \frac{T}{100}$ Coefficients of the equation is given in Table 2.7

Table 2.7 Coefficients of Equation 2.35-2.37

i	a_i	b_i	c_i	d_i
0	4.827370E-04	-1.072888E+01	0.000000E+00	0.000000E+00
1	1.056780E-03	3.478020E+01	6.656870E+01	-2.370000E-01
2	-6.563940E-03	-3.833830E+01	-2.388340E+02	-1.048000E+00
3	2.944420E-02	3.340600E+01	-1.767550E+02	-3.183000E+00
4	-3.193170E-02	0.000000E+00	0.000000E+00	0.000000E+00

It should be note that this eqaution is also function of dry-air mass fraction A(kg dry air/kg total). This property closely related with specific humidity (humidity ratio) (kg water/kg dry air)

Now we can look at termodynamic properties of humid air as combined equation.

Pressure (kPa): $P(A,T,ro) = \rho^2\frac{\partial f^{AV}(A,T,\rho)}{\partial\rho}$ 2.38

Entropy (kJ/(kgK)) : $s(T,ro) = -\frac{\partial f^{AV}(A,T,\rho)}{\partial T}$ 2.39

Enthalpy (kJ/kg) : $h(T,ro) = f^{AV}(A,T,\rho) - T\frac{\partial f^{AV}(A,T,\rho)}{\partial T} + \rho\frac{\partial f^{AV}(A,T,\rho)}{\partial\rho}$ 2.40

Isochoric specific heat C_p(kJ/(kgK)) :

$$C_p(T,ro) = -T\frac{\partial^2 f^{AV}(A,T,\rho)}{\partial T\partial T} + \frac{T\rho\left[\frac{\partial^2 f^{AV}(A,T,\rho)}{\partial T\partial\rho}\right]^2}{\left(2\frac{\partial f^{AV}(A,T,\rho)}{\partial\rho}+\rho\frac{f^{AV}(A,T,\rho)}{\partial\rho\partial\rho}\right)} \quad 2.41$$

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:

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

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

Mole fraction of water: $1 - x_A$ 3.3

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

Partial pressure of water: $P^W = (1 - x_A)P$ 3.5

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

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

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

Dew point temperature (saturation temperature at partial pressure of water) $T_\sigma(P^W) = T_\sigma\big((1 - x_A)P\big)$ 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,

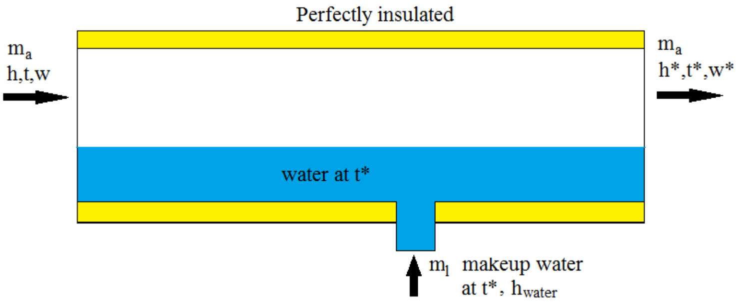


Figure 2.1 Adiabatic saturation temperature

So $m_a h(A, T, P) + m_l h^*_{water}(T^*, P) = m_a h(A^*, T^*, P)$ 3.10

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

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

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

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

Solution of these equations will require root finding methods.

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

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

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

$\eta(T_r, \rho_r) = H\left[\eta_0(T_r) + \Delta\eta(\rho_r)\right]$ 3.16

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

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

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

Where $\rho_r = \rho/\rho^*$ $T_r = T/T^*$ 3.20

Coefficients of the equations are given in Table 3.1

Coefficients of equations 3.14-3.19

T^* = 132.5 K	ρ^* = 314.3 kg/m3	Λ = 25.9778 ($10^{-3} W/(mK)$)	H=6.1609 (10^{-6} Pas)	
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 equavalent 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:

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

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

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

$\psi_0(\theta) = \theta^{0.5}\left[\sum_{i=1}^{4} n_i^0\, \theta^{1-i}\right]^{-1}$ 3.22 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

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

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

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

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

$$\Lambda_1(\delta)=n_1+n_2\delta+n_3exp[n_4(\delta+n_5)^2] \qquad 3.26$$

Table 3.5 Coefficients of equation 3.26

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

$$\Lambda_2(\delta,\theta)=(n_1\theta^{-10}+n_2)\delta^{1.8}exp[n_2(1-\delta^{2.8})]+n_4A\delta^{B}exp\left[\left(\frac{B}{1+B}\right)(1-\delta^{1+B})\right]+ n_5exp[n_6\theta^{1.5}+n_7\delta^{-5}] \qquad 3.27$$

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

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

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:

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

$$\phi_{AV}=\frac{\left[1+(\eta_A/\eta_V)^{1/2}(M_V/M_A)^{1/4}\right]}{\{8[1+(M_A/M_V)]\}^{1/2}} \qquad 3.28a$$

$$\phi_{VA}=\phi_{AV}\eta_V/\eta_A(M_A/M_V) \qquad 3.28b$$

For thermal conductivity, similar equations will be used.

$$\mathrm{k}_{mix} = \frac{x_A \mathrm{k}_A}{x_A + \mathrm{k}_A \phi_{AV}} + \frac{(1-x_A)\mathrm{k}_V}{(1-x_A) + \mathrm{k}_V \phi_{VA}} \quad 3.29 \quad \text{where}$$

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

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

4. COMPUTER DEVELOPMENTAND 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

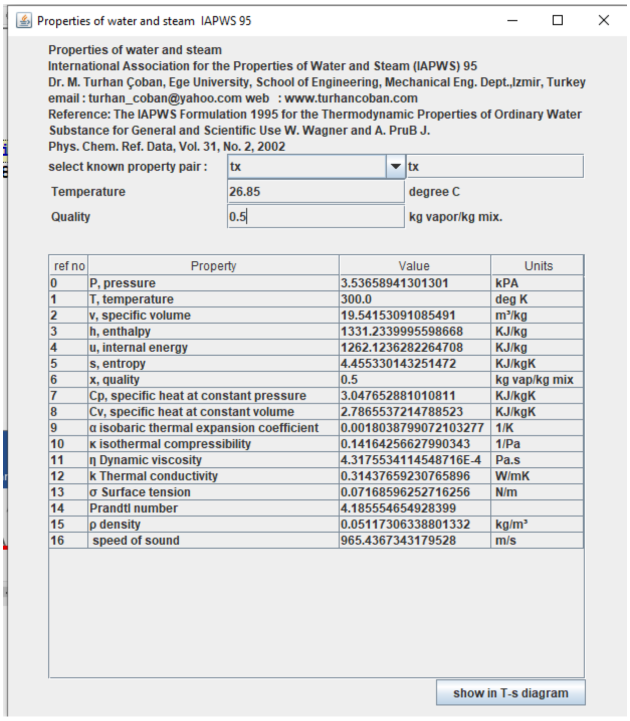
Table 4.1 Program lists

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 Kretzschamar 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
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 kPa	T degree K	v m^3/kg	h kJ/kg	u kJ/kg	s kJ/(kgK)	x kg vap/kg
steam	3.535746	300	19.55028	1331.584	1262.459	4.455994	0.5
steamIAPWS_IF97	3.536589	300	19.54153	1331.234	1262.124	4.45533	0.5
steam_IAPWS95	3.536718	300	19.54013	1331.21	1262.102	4.455244	0.5
steam	101.325	300	0.001003	112.7105	112.6089	0.393245	-1.1E-09
steamIAPWS_IF97	101.325	300	0.001003	112.665	112.5634	0.393097	-1
steam_IAPWS95	101.325	300	0.001003	112.6549	112.5532	0.393062	-2
steam	101.325	400	1.801666	2730.178	2547.624	7.495023	2.467381
steamIAPWS_IF97	101.325	400	1.802056	2730.272	2547.679	7.496078	2
steam_IAPWS95	101.325	400	1.801984	2730.301	2547.715	7.496202	2



Properties of water and steam
International Association for the Properties of Water and Steam (IAPWS) 95
Dr. M. Turhan Çoban, Ege University, School of Engineering, Mechanical Eng. Dept.,Izmir, Turkey
email : turhan_coban@yahoo.com web : www.turhancoban.com
Reference: 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

select known property pair : tx tx
Temperature 26.85 degree C
Quality 0.5 kg vapor/kg mix.

ref no	Property	Value	Units
0	P, pressure	3.53658941301301	kPA
1	T, temperature	300.0	deg K
2	v, specific volume	19.54153091085491	m³/kg
3	h, enthalpy	1331.2339995598668	KJ/kg
4	u, internal energy	1262.1236282264708	KJ/kg
5	s, entropy	4.455330143251472	KJ/kgK
6	x, quality	0.5	kg vap/kg mix
7	Cp, specific heat at constant pressure	3.047652881010811	KJ/kgK
8	Cv, specific heat at constant volume	2.7865537214788523	KJ/kgK
9	α isobaric thermal expansion coefficient	0.0018038799072103277	1/K
10	κ isothermal compressibility	0.14164256627990343	1/Pa
11	η Dynamic viscosity	4.3175534114548716E-4	Pa.s
12	k Thermal conductivity	0.31437659230765896	W/mK
13	σ Surface tension	0.07168596252716256	N/m
14	Prandtl number	4.185554654928399	
15	ρ density	0.05117306338801332	kg/m³
16	speed of sound	965.4367343179528	m/s

Figure 4.1 steam_IAPWS95 Graphic user interface

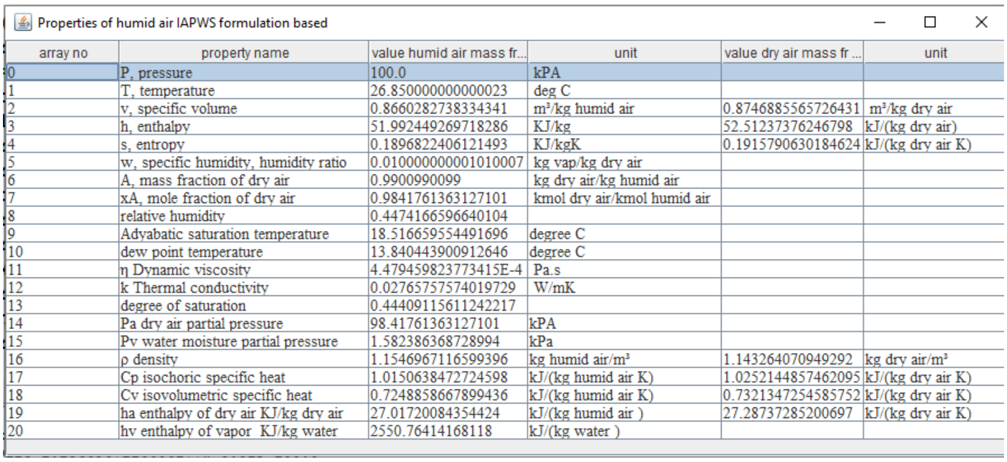
By using equations given above a class called air_IAPWS95 is developed. The result of this class is compared with Peng-Robinson EOS results as a mixing of the gases inside air and as a single gas with pseudocritical properties plus ideal gas equation of state. Results are given in table 4.3. It should 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 4 dry air models

dry air model	P kPa	T deg. K	ro kg/m^3	h kJ/kg	s kJ/kgK
air_IAPWS	100	300	1.1616	27.01362	0.098109

air_PR	100	300	1.16016	26.96343	0.097905
air_PR1	100	300	1.161866	27.03294	0.098201
air_PG	100	300	1.161241	27.01008	0.098098
air_IAPWS	300	300	3.486892	26.56149	-0.21858
air_PR	300	300	3.47403	26.96343	-0.21692
air_PR1	300	300	3.489305	27.07844	-0.21746
air_PG	300	300	3.483724	27.01008	-0.21726
air_IAPWS	500	300	5.814851	26.1112	-0.36654
air_PR	500	300	5.779339	26.96343	-0.36302
air_PR1	500	300	5.82155	27.12359	-0.36439
air_PG	500	300	5.806207	27.01008	-0.36389
air_IAPWS	1000	300	11.64547	24.99335	-0.56882
air_PR	1000	300	11.50547	26.96343	-0.56066
air_PR1	1000	300	11.67209	27.23498	-0.56407
air_PG	1000	300	11.61241	27.01008	-0.56286
air_IAPWS	100	350	0.995337	77.39375	0.253426
air_PR	100	350	0.994555	77.28153	0.252992
air_PR1	100	350	0.995496	77.44464	0.25363
air_PG	100	350	0.99535	77.39021	0.253415
air_IAPWS	200	350	1.990642	77.2332	0.053996
air_PR	200	350	1.987528	77.28153	0.054252
air_PR1	200	350	1.99128	77.49885	0.054621
air_PG	200	350	1.9907	77.39021	0.054448
air_IAPWS	300	350	2.985903	77.07313	-0.06285
air_PR	300	350	2.978923	77.28153	-0.06191
air_PR1	300	350	2.987341	77.55283	-0.06181
air_PG	300	350	2.986049	77.39021	-0.06194
air_IAPWS	500	350	4.976245	76.7544	-0.21041
air_PR	500	350	4.956994	77.28153	-0.20808
air_PR1	500	350	4.980244	77.66013	-0.20852
air_PG	500	350	4.976749	77.39021	-0.20857
air_IAPWS	1000	350	9.950525	75.96566	-0.41166
air_PR	1000	350	9.874817	77.28154	-0.40592
air_PR1	1000	350	9.966496	77.92432	-0.40766
air_PG	1000	350	9.953498	77.39021	-0.40754
air_IAPWS	100	450	0.773947	178.8411	0.508316
air_PR	100	450	0.77368	178.6447	0.507616
air_PR1	100	450	0.77402	178.9301	0.508614
air_PG	100	450	0.774161	178.8375	0.508305
air_IAPWS	300	450	2.320546	178.6841	0.192452
air_PR	300	450	2.318168	178.6447	0.192614
air_PR1	300	450	2.321214	179.1141	0.193362
air_PG	300	450	2.322483	178.8375	0.192949
air_IAPWS	500	450	3.865387	178.5285	0.045314
air_PR	500	450	3.858841	178.6447	0.046337
air_PR1	500	450	3.867254	179.2964	0.046836
air_PG	500	450	3.870805	178.8375	0.046317
air_IAPWS	1000	450	7.719584	178.1459	-0.15491
air_PR	1000	450	7.693924	178.6447	-0.15175
air_PR1	1000	450	7.727111	179.7449	-0.15186
air_PG	1000	450	7.741609	178.8375	-0.15265

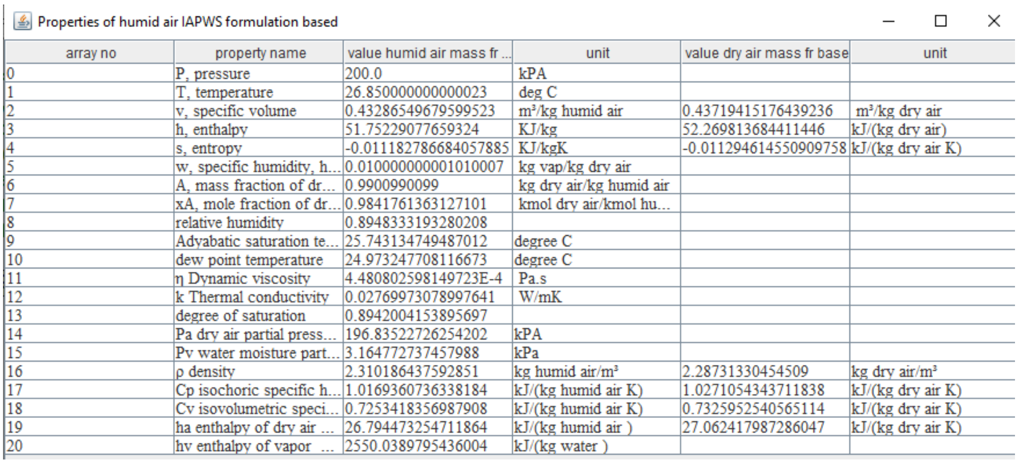
Properties of steam and dry air combined according to equations given above sections. The program is called **humid_air_IAPWS.**



Properties of humid air IAPWS formulation based

array no	property name	value humid air mass fr...	unit	value dry air mass fr ...	unit
0	P, pressure	100.0	kPA		
1	T, temperature	26.85000000000023	deg C		
2	v, specific volume	0.8660282738334341	m³/kg humid air	0.8746885565726431	m³/kg dry air
3	h, enthalpy	51.992449269718286	KJ/kg	52.51237376246798	kJ/(kg dry air)
4	s, entropy	0.1896822406121493	KJ/kgK	0.1915790630184624	kJ/(kg dry air K)
5	w, specific humidity, humidity ratio	0.010000000001010007	kg vap/kg dry air		
6	A, mass fraction of dry air	0.9900990099	kg dry air/kg humid air		
7	xA, mole fraction of dry air	0.9841761363127101	kmol dry air/kmol humid air		
8	relative humidity	0.4474166596640104			
9	Adyabatic saturation temperature	18.516659554491696	degree C		
10	dew point temperature	13.840443900912646	degree C		
11	η Dynamic viscosity	4.479459823773415E-4	Pa.s		
12	k Thermal conductivity	0.02765757574019729	W/mK		
13	degree of saturation	0.44409115611242217			
14	Pa dry air partial pressure	98.41761363127101	kPA		
15	Pv water moisture partial pressure	1.582386368728994	kPa		
16	ρ density	1.1546967116599396	kg humid air/m³	1.143264070949292	kg dry air/m³
17	Cp isochoric specific heat	1.0150638472724598	kJ/(kg humid air K)	1.0252144857462095	kJ/(kg dry air K)
18	Cv isovolumetric specific heat	0.7248858667899436	kJ/(kg humid air K)	0.7321347254585752	kJ/(kg dry air K)
19	ha enthalpy of dry air KJ/kg dry air	27.01720084354424	kJ/(kg humid air)	27.28737285200697	kJ/(kg dry air K)
20	hv enthalpy of vapor KJ/kg water	2550.76414168118	kJ/(kg water)		

Figure 4.2 humid_air_IAPWS Graphic output for P=100 kPa and T=300 K

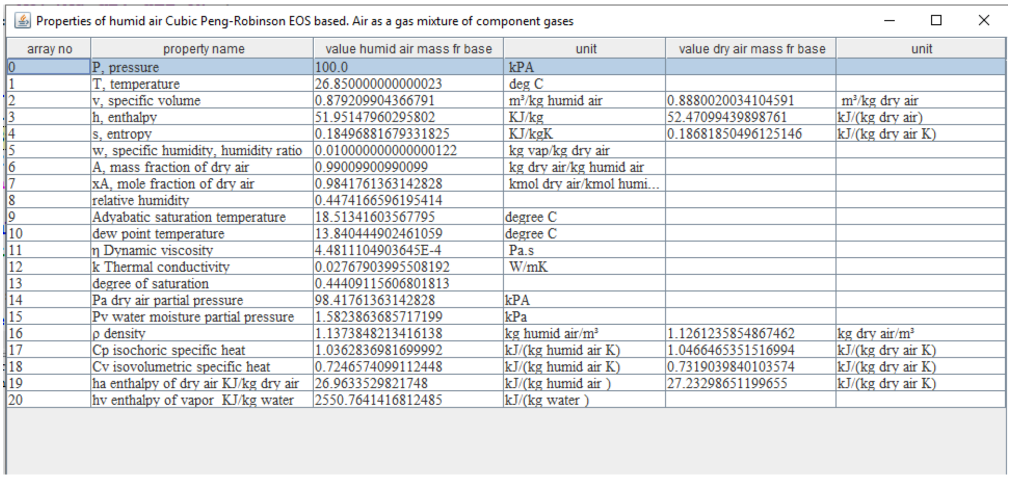


Properties of humid air IAPWS formulation based

array no	property name	value humid air mass fr ...	unit	value dry air mass fr base	unit
0	P, pressure	200.0	kPA		
1	T, temperature	26.85000000000023	deg C		
2	v, specific volume	0.43286549679599523	m^3/kg humid air	0.43719415176439236	m^3/kg dry air
3	h, enthalpy	51.75229077659324	KJ/kg	52.269813684411446	kJ/(kg dry air)
4	s, entropy	-0.011182786684057885	KJ/kgK	-0.011294614550909758	kJ/(kg dry air K)
5	w, specific humidity, h...	0.010000000001010007	kg vap/kg dry air		
6	A, mass fraction of dr...	0.9900990099	kg dry air/kg humid air		
7	xA, mole fraction of dr...	0.9841761363127101	kmol dry air/kmol hu...		
8	relative humidity	0.8948333193280208			
9	Adyabatic saturation te...	25.743134749487012	degree C		
10	dew point temperature	24.973247708116673	degree C		
11	η Dynamic viscosity	4.480802598149723E-4	Pa.s		
12	k Thermal conductivity	0.02769973078997641	W/mK		
13	degree of saturation	0.8942004153895697			
14	Pa dry air partial press...	196.83522726254202	kPA		
15	Pv water moisture part...	3.164772737457988	kPa		
16	ρ density	2.310186437592851	kg humid air/m^3	2.28731330454509	kg dry air/m^3
17	Cp isochoric specific h...	1.0169360736338184	kJ/(kg humid air K)	1.0271054343711838	kJ/(kg dry air K)
18	Cv isovolumetric speci...	0.7253418356987908	kJ/(kg humid air K)	0.7325952540565114	kJ/(kg dry air K)
19	ha enthalpy of dry air ...	26.794473254711864	kJ/(kg humid air)	27.062417987286047	kJ/(kg dry air K)
20	hv enthalpy of vapor ...	2550.0389795436004	kJ/(kg water)		

Figure 4.3 humid_air_IAPWS Graphic output for P=200 kPa and T=300 K

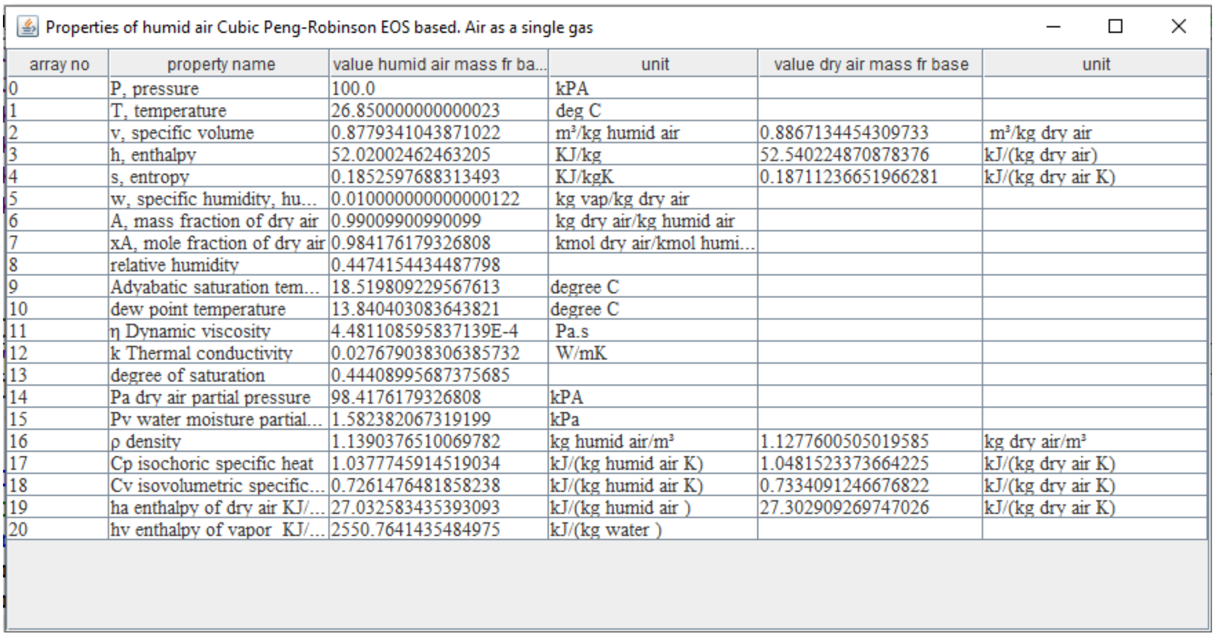
Seperately classes humid_air_PR, humid_air_PR1 and humid_air_PG is developed. The details of this classes will not be given here, but the results will be given for the same state, to compare the results.



Properties of humid air Cubic Peng-Robinson EOS based. Air as a gas mixture of component gases

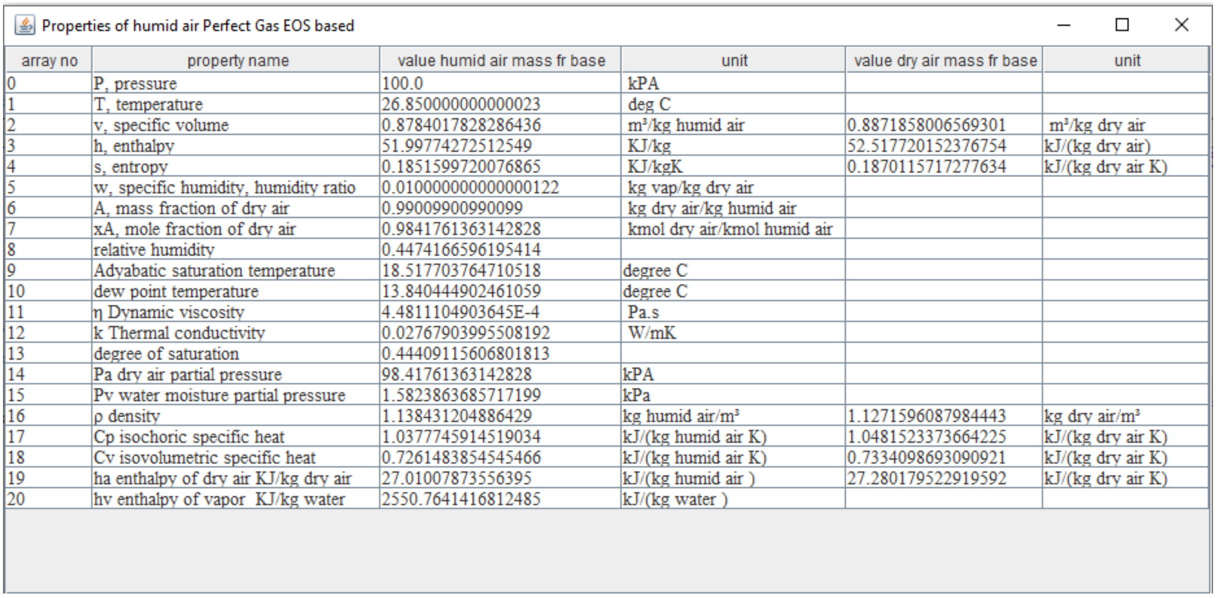
array no	property name	value humid air mass fr base	unit	value dry air mass fr base	unit
0	P, pressure	100.0	kPA		
1	T, temperature	26.85000000000023	deg C		
2	v, specific volume	0.879209904366791	m^3/kg humid air	0.8880020034104591	m^3/kg dry air
3	h, enthalpy	51.95147960295802	KJ/kg	52.47099439898761	kJ/(kg dry air)
4	s, entropy	0.18496881679331825	KJ/kgK	0.18681850496125146	kJ/(kg dry air K)
5	w, specific humidity, humidity ratio	0.010000000000000122	kg vap/kg dry air		
6	A, mass fraction of dry air	0.99009900990099	kg dry air/kg humid air		
7	xA, mole fraction of dry air	0.9841761363142828	kmol dry air/kmol humi...		
8	relative humidity	0.4474166596195414			
9	Adyabatic saturation temperature	18.51341603567795	degree C		
10	dew point temperature	13.840444902461059	degree C		
11	η Dynamic viscosity	4.4811104903645E-4	Pa.s		
12	k Thermal conductivity	0.02767903995508192	W/mK		
13	degree of saturation	0.44409115606801813			
14	Pa dry air partial pressure	98.41761363142828	kPA		
15	Pv water moisture partial pressure	1.5823863685717199	kPa		
16	ρ density	1.1373848213416138	kg humid air/m^3	1.1261235854867462	kg dry air/m^3
17	Cp isochoric specific heat	1.0362836981699992	kJ/(kg humid air K)	1.0466465351516994	kJ/(kg dry air K)
18	Cv isovolumetric specific heat	0.7246574099112448	kJ/(kg humid air K)	0.7319039840103574	kJ/(kg dry air K)
19	ha enthalpy of dry air KJ/kg dry air	26.9633529821748	kJ/(kg humid air)	27.23298651199655	kJ/(kg dry air K)
20	hv enthalpy of vapor KJ/kg water	2550.7641416812485	kJ/(kg water)		

Figure 4.4 humid_air_PR 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 ba...	unit	value dry air mass fr base	unit
0	P, pressure	100.0	kPA		
1	T, temperature	26.850000000000023	deg C		
2	v, specific volume	0.8779341043871022	m^3/kg humid air	0.8867134454309733	m^3/kg dry air
3	h, enthalpy	52.02002462463205	KJ/kg	52.540224870878376	kJ/(kg dry air)
4	s, entropy	0.1852597688313493	KJ/kgK	0.18711236651966281	kJ/(kg dry air K)
5	w, specific humidity, hu...	0.010000000000000122	kg vap/kg dry air		
6	A, mass fraction of dry air	0.99009900990099	kg dry air/kg humid air		
7	xA, mole fraction of dry air	0.984176179326808	kmol dry air/kmol humi...		
8	relative humidity	0.4474154434487798			
9	Adyabatic saturation tem...	18.519809229567613	degree C		
10	dew point temperature	13.840403083643821	degree C		
11	η Dynamic viscosity	4.481108595837139E-4	Pa.s		
12	k Thermal conductivity	0.027679038306385732	W/mK		
13	degree of saturation	0.44408995687375685			
14	Pa dry air partial pressure	98.4176179326808	kPA		
15	Pv water moisture partial...	1.582382067319199	kPa		
16	ρ density	1.1390376510069782	kg humid air/m^3	1.1277600505019585	kg dry air/m^3
17	Cp isochoric specific heat	1.0377745914519034	kJ/(kg humid air K)	1.0481523373664225	kJ/(kg dry air K)
18	Cv isovolumetric specific...	0.7261476481858238	kJ/(kg humid air K)	0.7334091246676822	kJ/(kg dry air K)
19	ha enthalpy of dry air KJ/...	27.032583435393093	kJ/(kg humid air)	27.302909269747026	kJ/(kg dry air K)
20	hv enthalpy of vapor KJ/...	2550.7641435484975	kJ/(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	26.850000000000023	deg C		
2	v, specific volume	0.8784017828286436	m^3/kg humid air	0.8871858006569301	m^3/kg dry air
3	h, enthalpy	51.99774272512549	KJ/kg	52.517720152376754	kJ/(kg dry air)
4	s, entropy	0.1851599720076865	KJ/kgK	0.1870115717277634	kJ/(kg dry air K)
5	w, specific humidity, humidity ratio	0.010000000000000122	kg vap/kg dry air		
6	A, mass fraction of dry air	0.99009900990099	kg dry air/kg humid air		
7	xA, mole fraction of dry air	0.9841761363142828	kmol dry air/kmol humid air		
8	relative humidity	0.4474166596195414			
9	Adyabatic saturation temperature	18.517703764710518	degree C		
10	dew point temperature	13.840444902461059	degree C		
11	η Dynamic viscosity	4.4811104903645E-4	Pa.s		
12	k Thermal conductivity	0.02767903995508192	W/mK		
13	degree of saturation	0.44409115606801813			
14	Pa dry air partial pressure	98.41761363142828	kPA		
15	Pv water moisture partial pressure	1.5823863685717199	kPa		
16	ρ density	1.138431204886429	kg humid air/m^3	1.1271596087984443	kg dry air/m^3
17	Cp isochoric specific heat	1.0377745914519034	kJ/(kg humid air K)	1.0481523373664225	kJ/(kg dry air K)
18	Cv isovolumetric specific heat	0.7261483854545466	kJ/(kg humid air K)	0.7334098693090921	kJ/(kg dry air K)
19	ha enthalpy of dry air KJ/kg dry air	27.01007873556395	kJ/(kg humid air)	27.280179522919592	kJ/(kg dry air K)
20	hv enthalpy of vapor KJ/kg water	2550.7641416812485	kJ/(kg water)		

Figure 4.6 humid_air_PG Graphic output for P=100 kPa and T=300 K

5. CONCLUSIONS

In air conditioning processes in order to predict thermodynamic and thermopysical properties of humid air (a mixture of dry air and water vapor) usually perfect gas equation of state is utilised, But some processes such as drying of humid air in a compressed air tank, adding water to the compressor of gas turbine power plant to improve overall efficiency will require better approaches. In thermophysical property predictions, most used approach ist o assume such properties as only function of temperature. In reality properties such as viscosity and thermal coductivity heavily depends on pressure as well as temperature. Furthermore such properties are quite a nonlinear function of pressure so that a linear interpolation type of correction of properties will not be correct. In this study, a computer model of thermodynamic and thermopysical properties of humid by using air equation states developed by The international Association for the Properties of Water and Steam and for dry air viscosity and thermal conductivitys 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 using cubic Peng-Robinson formulations 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 fort he researchers wish to develop their own version of computer codes in their desired programming language.

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