

Basic Thermodynamics: Software Solutions – Part V


Dr. M. Thirumaleshwar



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Real and Ideal gases and Gas mixtures



Basic Thermodynamics: Software Solutions – Part V

1st edition

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ISBN 978-87-403-0705-4

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9 Real and ideal gases and gas mixtures

Learning objectives:

1. 'Ideal gas', 'Perfect gas', 'Semi-perfect gases' and 'Real gas' are defined.
2. Various equations of state for Ideal as well as real gases are presented.
3. Next, 'compressibility factor' and 'principle of corresponding states' are discussed.
4. Topics of Internal energy, Enthalpy and Specific heats for Ideal gases are reviewed.
5. Next, properties of mixtures of ideal gases are dealt with.
6. Dalton's Law, Gibbs-Dalton Law, Avogadro's Law etc are stated. Procedures to calculate sp. heats, apparent Molecular weight, Gas constant, internal energy, enthalpy etc of a mixture of ideal gases is explained.
7. Above topics are illustrated by solving several problems.

9.1 Introduction:

In this chapter, we shall study the concept of 'Ideal gas', 'Perfect gas' and 'Real gases'. We shall deal with property diagrams and various equations of state. We shall also explain about the principle of corresponding states and the generalized compressibility chart in connection with the real gases. Calculation of specific heats at constant volume and constant pressure for gases will be enumerated next.

9.2 Ideal, Perfect and Real Gases:

For an *Ideal gas*:

- Molecule is treated as a 'point mass'
- It is assumed that gas molecules occupy negligible volume
- No molecular attraction
- Molecular collisions are elastic
- Follows the law: $P.v = R.T$, where P = pressure (Pa), v = sp. volume (m^3/kg), T = temperature (K), and R = gas constant for that particular gas ($\text{J}/\text{kg.K}$)
- Specific heats are functions of temperature

For a *Perfect gas*:

- All the assumptions are the same, except that the specific heats are constants and do not vary with temperature

In reality, there is no ideal or perfect gas. H_2 , O_2 , N_2 , He etc behave nearly as perfect gases and are known as '*semi perfect gases*'.

For a *Realgas*:

- Molecular volumes and intermolecular attraction will be considered.
- Several equations of state have been proposed

9.3 Ideal Gas Laws and Property diagrams for an Ideal (or perfect) gas [1, 2]:

9.3.1 Boyle's Law:

It states: "Volume of a given mass of perfect gas varies inversely as the absolute pressure when the absolute pressure is constant". i.e.

$$P \cdot V = \text{const} \quad \text{for const. } T \dots \dots \dots (4.1)$$



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9.3.2 Charles' Law:

"If any gas is heated at constant pressure, its volume changes directly as its absolute temperature". i.e.

$$\frac{V}{T} = \text{const} \quad \text{when } P \text{ is const} \dots\dots\dots(4.2a)$$

$$\text{i.e.} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \dots\dots\dots(4.2b)$$

9.3.3 P-V-T surface for Ideal gas:

Each point on the P-V-T surface represents an equilibrium point.

Note that P-V, P-T and T-V diagrams are the projections of this surface on the respective coordinates:

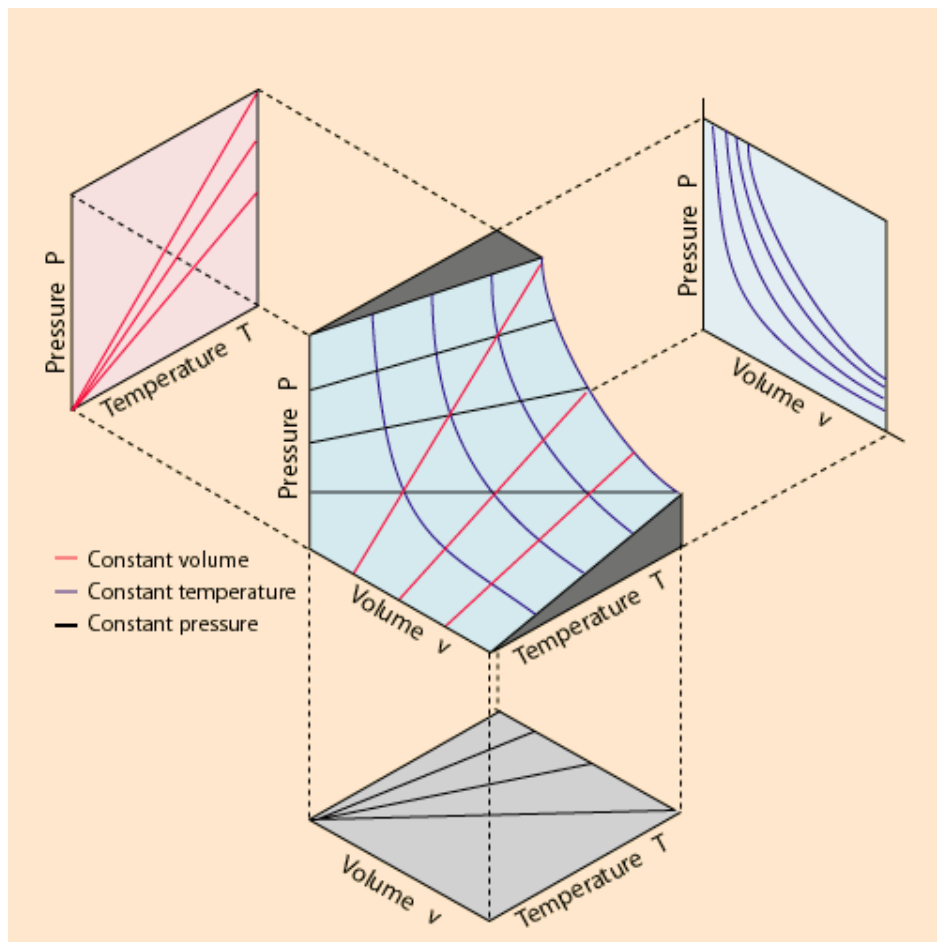


Fig. 9.1 P-V-T surface for an Ideal gas [13]

9.4 Ideal gas equation of state:

An equation of state gives a relation among the three measurable quantities P, V and T. Ideal gas equation of state is written in the following ways:

$$P \cdot v = R \cdot T \quad \dots\dots(4.3a)$$

$$P \cdot V = m \cdot R \cdot T \quad \dots\dots(4.3b)$$

$$P = \rho \cdot R \cdot T \quad \dots\dots(4.3c)$$

where:

P = pressure (kPa), V = volume (m³), m = mass (kg), v = specific volume (m³/kg),

T = absolute temperature (K), ρ = density (kg/m³),

R = particular gas constant (kJ/kg.K) = R_u/M , where

R_u = Universal gas constant = 8.314 (kJ/kmol.K), M = Molar mass for the gas,

$$= 8.314 \text{ (kPa.m}^3\text{/kmol.K)}$$

$$= 0.08314 \text{ (bar.m}^3\text{/kmol.K)}$$

$$= 1.986 \text{ (Btu/lbmol.R)}$$

$$= 10.73 \text{ (psia.ft}^3\text{/lbmol.R)}$$

$$= 1545 \text{ ft.lbf/lbmol.R)}$$

Other forms of Ideal gas equation are:

$$P \cdot V = N \cdot R_u \cdot T \quad \dots\dots(4.4a)$$

$$P \cdot \bar{v} = R_u \cdot T \quad \dots\dots(4.4b)$$

where N = no. of moles, \bar{v} = molar sp. volume

Note that:

$$m = M \cdot N \quad \text{kg} \dots\dots\dots(4.5)$$

Values of gas constant R for a few gases is given below:

	Gas Constant, R (kJ/kg-K)
Air	0.2870
Ammonia	0.4882
Carbon Dioxide	0.1889
Helium	2.0771
Hydrogen	4.1243
Nitrogen	0.2968
Oxygen	0.2598
R-12	0.06876
R-134a	0.08149

Table 9.1 Values of gas constant R for a few gases

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9.5 Deviation from Ideal gas behavior – Compressibility factor:

While the Ideal gas equation is very simple to use, it must be noted that it is mostly applicable for gases at low densities, i.e. at low pressures and high temperatures. Gases deviate considerably from ideal gas behavior at regions near the critical point and saturation lines. This is shown below:

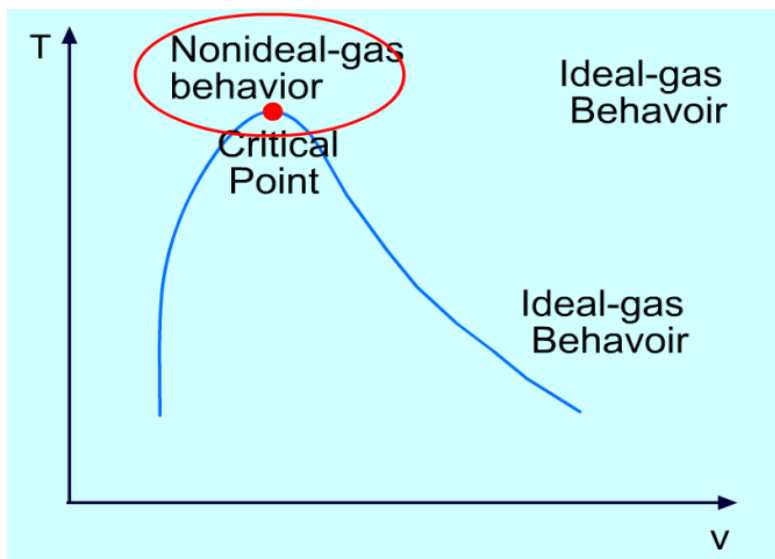


Fig. 9.2 Deviation from Ideal gas law [7]

Departure from Ideal gas behavior against pressure for some gases is illustrated below:

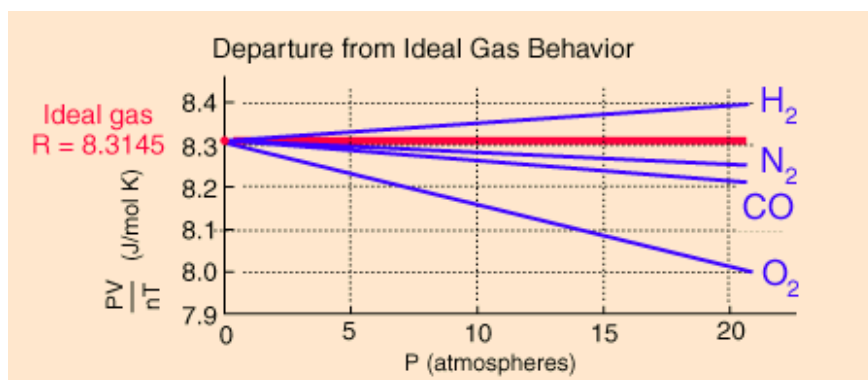


Fig. 9.3 Deviation from Ideal gas law for some gases [9]

For the specific case of Water/Steam, following graph illustrates the regions where Ideal gas law can be applied without much error. Note that around the critical point, the error is unacceptably high i.e. about 330%.

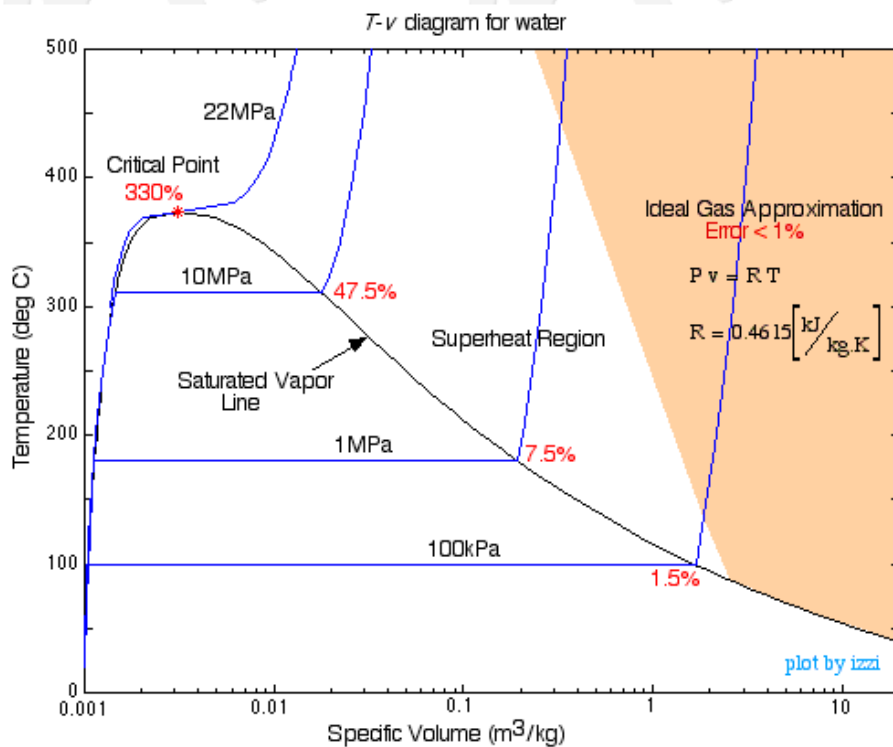


Fig. 9.4 Region where Ideal gas law is applicable for Water/Steam [8]

To account for the deviation from Ideal gas law, we introduce a correction factor, Z , called ‘**compressibility factor**’, as follows:

$$Z = \frac{P \cdot V}{R \cdot T} \quad \dots\dots(4.6)$$

or, $P \cdot V = Z \cdot R \cdot T \quad \dots\dots(4.7)$

Also, $Z = \frac{v_{\text{actual}}}{v_{\text{ideal}}} \quad \dots\dots(4.8)$

where $v_{\text{ideal}} = \frac{R \cdot T}{P}$

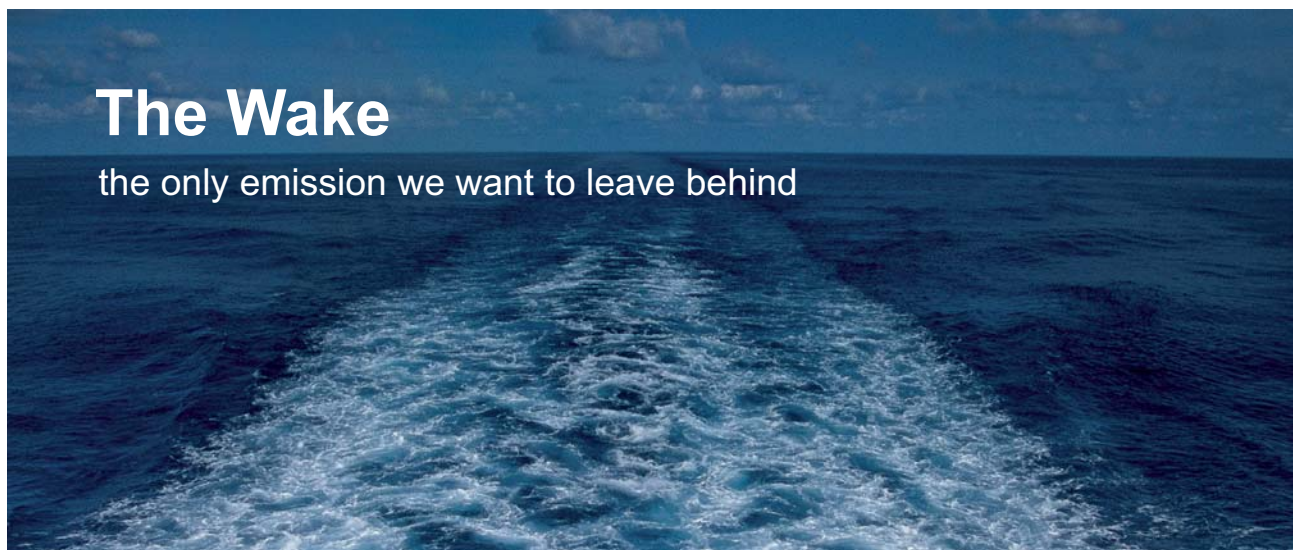
Note that $Z = 1$ for Ideal gas.

Different gases behave differently with variation of pressure and temperature, but their behavior is observed to be identical when the pressures and temperatures are 'normalized' with respect to the critical pressures and temperatures of respective gases. So, we define:

$$P_R = \frac{P}{P_{cr}} \quad \dots\dots(4.9a), \text{ and}$$

$$T_R = \frac{T}{T_{cr}} \quad \dots\dots(4.9b)$$

Where P_R is called 'Reduced pressure' and T_R is called 'Reduced temperature'.




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Values of 'critical parameters' for a few substances are given below:

Gas	Chemical Formula	Pressure P_c bar	Temperature T_c K	Specific Volume $\bar{v}_c \text{ m}^3 / \text{kg-mole}$
Air	---	37.7	132.8	0.083
Ammonia	NH ₃	112.8	405.8	0.073
Argon	A	44.7	151.0	0.075
Carbon dioxide	CO ₂	73.8	304.2	0.094
Carbon monoxide	CO	35.0	133.0	0.093
Freon-12	CCl ₂ F ₂	40.3	385.0	0.215
Helium	He	2.3	5.2	0.058
Hydrogen	H ₂	13.0	33.2	0.065
Nitrogen	N ₂	33.9	126.1	0.090
Oxygen	O ₂	50.6	154.5	0.075
Sulphur dioxide	SO ₂	78.8	430.5	0.0123
Steam	H ₂ O	220.9	647.3	0.056

And following table gives a more detailed information from TEST [15]:

Material Properties Useful for the Real Gas Model					
Substance	Formula	Molar Mass	Critical-Point Properties		
		\bar{M} kg/kmol	Temperature	Pressure	Volume
			T_{cr} K	P_{cr} MPa	v_{cr} m ³ /kmol
Air	--	28.97	132.5	3.77	0.0883
Ammonia	NH ₃	17.03	405.5	11.28	0.0724
Argon	Ar	39.948	151	4.86	0.0749
Benzene	C ₆ H ₆	78.115	562	4.92	0.2603
Bromine	Br ₂	159.808	584	10.34	0.1355
n-Butane	C ₄ H ₁₀	58.124	425.2	3.8	0.2547
Carbon Dioxide	CO ₂	44.01	304.2	7.39	0.0943
Carbon Monoxide	CO	28.011	133	3.5	0.093
Carbon Tetrachloride	CCl ₄	153.82	556.4	4.56	0.2759
Chlorine	Cl ₂	70.906	417	7.71	0.1242
Chloroform	CHCl ₃	119.38	536.6	5.47	0.2403
Dichlorodifluoromethane (R-12)	CCl ₂ F ₂	120.91	384.7	4.01	0.2179
Dichlorofluoromethane (R-21)	CHCl ₂ F	102.92	451.7	5.17	0.1973
Ethane	C ₂ H ₆	30.07	305.5	4.48	0.148
Ethyl-Alcohol	C ₂ H ₅ OH	46.07	516	6.38	0.1673
Ethylene	C ₂ H ₄	28.054	282.4	5.12	0.1242
Helium	He	4.003	5.3	0.23	0.0578
n-Hexane	C ₆ H ₁₄	86.179	507.9	3.03	0.3677
Hydrogen (normal)	H ₂	2.016	33.3	1.3	0.0649
Krypton	Kr	83.8	209.4	5.5	0.0924
Methane	CH ₄	16.043	191.1	4.64	0.0993
Methyl alcohol	CH ₃ OH	32.042	513.2	7.95	0.118

Methyl chloride	CH ₃ Cl	50.488	416.3	6.68	0.143
Neon	Ne	20.183	44.5	2.73	0.0417
Nitrogen	N ₂	28.013	126.2	3.39	0.0899
Nitrous oxide	N ₂ O	44.013	309.7	7.27	0.0961
Oxygen	O ₂	31.999	154.8	5.08	0.078
Propane	C ₃ H ₈	44.097	370	4.26	0.1998
Propylene	C ₃ H ₆	42.081	365	4.62	0.181
Sulfur dioxide	SO ₂	64.063	430.7	7.88	0.1217
Tetrafluoroethane (R-134a)	CF ₃ CH ₂ F	102.03	374.3	4.067	0.1847
Trichlorofluoromethane (R-11)	CCl ₃ F	137.37	471.2	4.38	0.2478
Water	H ₂ O	18.015	647.3	22.09	0.0568
Xenon	Xe	131.3	289.8	5.88	0.1186

Table 9.2

If values of Z determined from experiments for various gases are plotted against P_R and T_R , following plot is obtained:

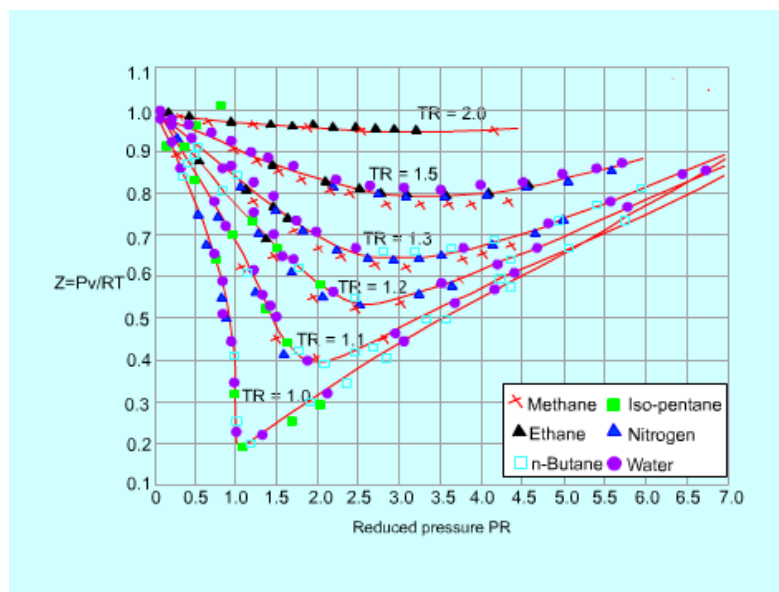


Fig. 9.5 Z values for various gases [7]

It is noted that 'Z factor is approximately the same for all gases at the same reduced pressure and temperature'. This is known as the *principle of corresponding states*.

In problem solving, generally, we use the Lee-Kesler compressibility chart, based on ideal fluid assumption:

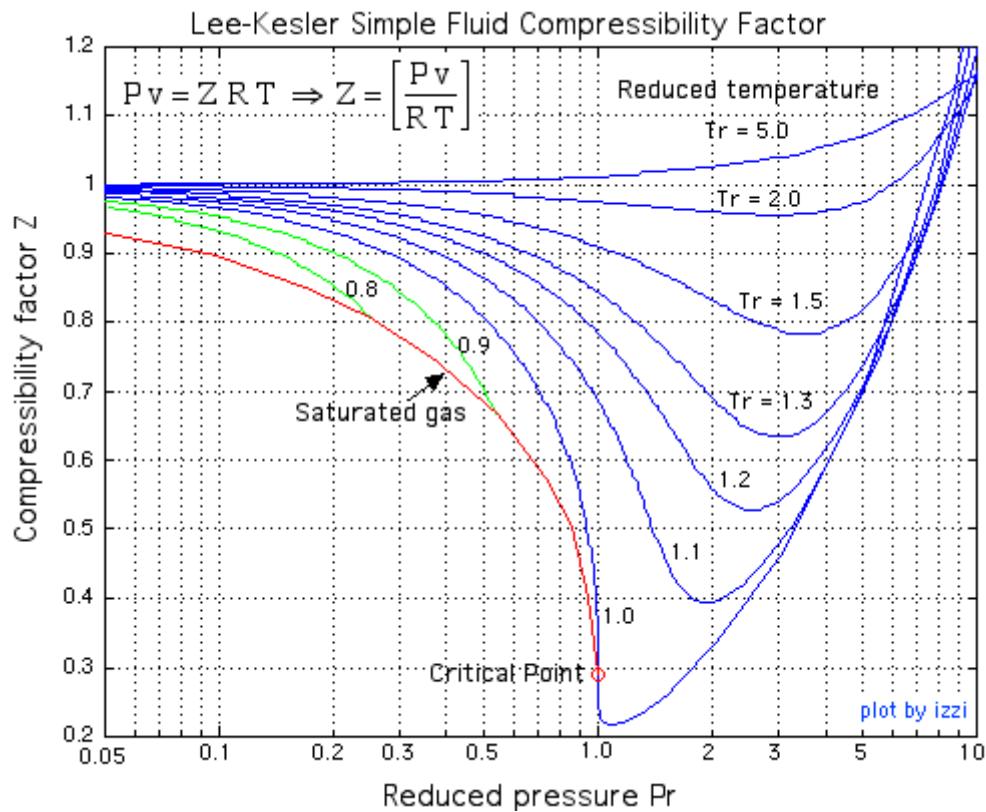


Fig. 9.6 Lee-Kesler compressibility chart [8]

We note the following from the generalized compressibility chart:

- (i) At very low pressures, i.e. at $P_R \ll 1$, gases behave like an ideal gas irrespective of temperature
- (ii) At high temperatures, i.e. at $T_R > 2$, ideal gas behavior can be assumed irrespective of pressure, except at very high pressures of $P_R \gg 1$
- (iii) Deviation from ideal gas behavior is most pronounced in the region near the critical point.

9.6 Equations of state for 'Real gases':

Several equations of state have been proposed in an attempt to predict P-V-T behavior of substances over a wider range of pressures and temperatures. We shall present a few of them below:

9.6.1 Van der Waal's equation of state:

This is one of the earliest attempts (1873) to increase the range of applicability of ideal gas equation by inserting factors to take into account the intermolecular attractions and the finite volume occupied by the molecules in a real gas. It is of the following form:

$$\left(P + \frac{a}{v^2}\right) \cdot (v - b) = R \cdot T \quad \text{.....(4.10)}$$

Here, the term (a/v^2) accounts for the intermolecular attraction and the term b accounts for the volume occupied by the molecules. The constants a and b are given *in terms of critical properties* as follows:

$$a = \frac{27 \cdot R^2 \cdot T_{cr}}{64 \cdot P_{cr}} \quad \text{and} \quad b = \frac{R \cdot T_{cr}}{8 \cdot P_{cr}} \quad \text{.....(4.11)}$$

To express Van der Waals equation in terms of mole basis, replace v by \bar{v} and R by R_u in the above equations.

a and b can thus be calculated from the critical properties of a given gas.

Values of a and b for some common fluids are given below [17]

TABLE A-24 Constants for the van der Waals, Redlich–Kwong, and Benedict–Webb–Rubin Equations of State

1. van der Waals and Redlich–Kwong: Constants for pressure in bar, specific volume in m^3/kmol , and temperature in K

Substance	van der Waals		Redlich–Kwong	
	$\text{bar} \left(\frac{\text{m}^3}{\text{kmol}} \right)^2$	$\frac{\text{m}^3}{\text{kmol}}$	$\text{bar} \left(\frac{\text{m}^3}{\text{kmol}} \right)^2 \text{K}^{1/2}$	$\frac{\text{m}^3}{\text{kmol}}$
Air	1.368	0.0367	15.989	0.02541
Butane (C_4H_{10})	13.86	0.1162	289.55	0.08060
Carbon dioxide (CO_2)	3.647	0.0428	64.43	0.02963
Carbon monoxide (CO)	1.474	0.0395	17.22	0.02737
Methane (CH_4)	2.293	0.0428	32.11	0.02965
Nitrogen (N_2)	1.366	0.0386	15.53	0.02677
Oxygen (O_2)	1.369	0.0317	17.22	0.02197
Propane (C_3H_8)	9.349	0.0901	182.23	0.06242
Refrigerant 12	10.49	0.0971	208.59	0.06731
Sulfur dioxide (SO_2)	6.883	0.0569	144.80	0.03945
Water (H_2O)	5.531	0.0305	142.59	0.02111

Source: Calculated from critical data.

Van der Waal's constants for a few gases and liquids are given below:

	a (L ² bar/mol ²)	b (L/mol)
Acetic acid	17.82	0.1068
Acetic anhydride	20.16	0.1263
Acetone	14.09	0.0994
Acetonitrile	17.81	0.1168
Acetylene	4.448	0.05136
Ammonia	4.225	0.03707
Argon	1.363	0.03219
Benzene	18.24	0.1154
Bromobenzene	28.94	0.1539
Butane	14.66	0.1226
Carbon dioxide	3.640	0.04267
Carbon disulfide	11.77	0.07685
Carbon monoxide	1.505	0.03985
Carbon tetrachloride	19.7483	0.1281
Chlorine	6.579	0.05622
Chlorobenzene	25.77	0.1453
Chloroethane	11.05	0.08651
Chloromethane	7.570	0.06483
Cyanogen	7.769	0.06901
Cyclohexane	23.11	0.1424



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Diethyl sulfide	19.00	0.1214
Dimethyl ether	8.180	0.07246
Dimethyl sulfide	13.04	0.09213
Ethane	5.562	0.0638
Ethanethiol	11.39	0.08098
Ethanol	12.18	0.08407
Ethyl acetate	20.72	0.1412
Ethylamine	10.74	0.08409
Fluorobenzene	20.19	0.1286
Fluoromethane	4.692	0.05264
Freon	10.78	0.0998
Germanium tetrachloride	22.90	0.1485
Helium	0.03457	0.0237
Hexane	24.71	0.1735
Hydrogen	0.2476	0.02661
Hydrogen bromide	4.510	0.04431
Hydrogen chloride	3.716	0.04081
Hydrogen selenide	5.338	0.04637
Hydrogen sulfide	4.490	0.04287
Iodobenzene	33.52	0.1656
Krypton	2.349	0.03978
Mercury	8.200	0.01696
Methane	2.283	0.04278
Methanol	9.649	0.06702
Neon	0.2135	0.01709
Nitric oxide	1.358	0.02789
Nitrogen	1.408	0.03913
Nitrogen dioxide	5.354	0.04424
Nitrous oxide	3.832	0.04415
Oxygen	1.378	0.03183
Pentane	19.26	0.146
Phosphine	4.692	0.05156
Propane	8.779	0.08445
Silane	4.377	0.05786
Silicon tetrafluoride	4.251	0.05571
Sulfur dioxide	6.803	0.05636
Tin tetrachloride	27.27	0.1642
Toluene	24.38	0.1463
Water	5.536	0.03049
Xenon	4.250	0.05105

Table 9.3 Van der Waals constants for a few gases and volatile liquids [10]

Source: Weast. R.C. (Ed.), *Handbook of Chemistry and Physics (53rd Edn.)*, Cleveland: Chemical Rubber Co., 1972.

Units:

$$1 \text{ J}\cdot\text{m}^3/\text{mol}^2 = 1 \text{ m}^6\cdot\text{Pa}/\text{mol}^2 = 10 \text{ L}^2\cdot\text{bar}/\text{mol}^2$$

$$1 \text{ L}^2\text{atm}/\text{mol}^2 = 101\,325 \text{ J}\cdot\text{m}^3/\text{kmol}^2 = 101\,325 \text{ Pa}\cdot\text{m}^6/\text{kmol}^2$$

$$1 \text{ dm}^3/\text{mol} = 1 \text{ L}/\text{mol} = 1 \text{ m}^3/\text{kmol} \text{ (where kmol is kilomoles = 1000 moles)}$$

In terms of ‘reduced pressure, volume and temp:

If we define:

$$P_r = \frac{P}{P_c} \quad \dots\text{reduced pressure}$$

$$v_r = \frac{v}{v_c} \quad \dots\text{reduced sp. volume}$$

$$T_r = \frac{T}{T_c} \quad \dots\text{reduced temperature}$$

Then, Van der Waal's eqn. can be written as:

$$\left(P_r + \frac{3}{2v_r}\right)\left(v_r - \frac{1}{3}\right) = \frac{8}{3}T_r$$

Note that this eqn. does not contain gas const. R or the constants a and b.

Though Van der Waals equation represents an early attempt to improve the range of ideal gas equation, its range is still very limited.

9.6.2 Beattie – Bridgeman equation of state:

This equation, proposed in 1928, takes the following form:

$$P = \frac{R_u T}{\bar{v}^2} \left(1 - \frac{c}{\bar{v} T^3}\right) (\bar{v} + B) - \frac{A}{\bar{v}^2} \quad \text{where}$$

$$A = A_0 \left(1 - \frac{a}{\bar{v}}\right) \quad B = B_0 \left(1 - \frac{b}{\bar{v}}\right) \quad \dots\dots\dots(4.12)$$

This equation is reasonably *accurate for densities up to less than about 2.5 times the density at the critical point.*

Values of constants in Beattie-Bridgeman equation for a few substances are given below:

Gas	A_0	a	B_0	b	c
Air	131.8441	0.01931	0.04611	-0.001101	43400
Argon, Ar	30.7802	0.02328	0.03931	0.0	59900
Carbon dioxide, CO ₂	507.2836	0.07132	0.10476	0.07235	660000
Helium, He	2.1886	0.05984	0.01400	0.0	40
Hydrogen, H ₂	20.0117	-0.00506	0.02096	-0.04359	504
Nitrogen, N ₂	136.2315	0.02617	0.05046	-0.00691	42000
Oxygen, O ₂	151.0857	0.02562	0.04624	0.004208	48000

Table 9.4 Values of constants in Beattie-Bridgeman equation [7]

While using the above Table, note that P is in kPa, \bar{v} is in m³/kmol, T is in K and R_u is equal to 8.314 (kPa·m³)/(kmol·K).

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9.6.3 Benedict–Webb–Rubin (BWR) equation of state (1940):

In this equation number of constants is raised to 8. BWR equation is of following form:

$$P = \frac{R_u T}{\bar{v}} + \left(B_0 R_u T - A_0 - \frac{C_0}{T^2} \right) \frac{1}{\bar{v}^2} + \frac{b R_u T - a}{\bar{v}^3} + \frac{a \alpha}{\bar{v}^6} + \frac{c}{\bar{v}^3 T^2} \left(1 + \frac{\gamma}{\bar{v}^2} \right) e^{-\gamma/\bar{v}^2} \quad \text{.....(4.13)}$$

Constants in eqn. (4.13) are given in the following Table:

Gas	a	A ₀	b	B ₀	c×10 ⁻⁴	C ₀ ×10 ⁻⁵	α×10 ⁵	γ
n-Butane, C ₄ H ₁₀	190.68	1021.6	0.039998	0.12436	3205	1006	110.1	0.0340
Carbon dioxide, CO ₂	13.86	277.30	0.007210	0.04991	151.1	140.4	8.470	0.0054
Carbon monoxide, CO	3.71	135.87	0.002632	0.05454	10.54	8.673	13.50	0.0060
Methane, CH ₄	5.00	187.91	0.003380	0.04260	25.78	22.86	12.44	0.0060
Nitrogen, N ₂	2.54	106.73	0.002328	0.04074	7.379	8.164	12.72	0.0053

Table 9.5 Values of constants in BWR equation [7]

Here, note that P is in kPa, \bar{v} is in m³/kmol, T is in K and R_u is 8.314 (kPa·m³)/(kmol·K).

BWR equation is accurate at densities up to 2.5 times the density at the critical point.

In 1962, Strohbridge improved this equation further by raising the number of constants to 16. It is therefore, more suitable for computer analysis.

9.6.4 Redlich – Kwong equation of state [5]:

$$P = \frac{RT}{V_m - b} - \frac{a}{\sqrt{T} V_m (V_m + b)} \quad \text{.....(4.14)}$$

where

$$a = \frac{0.42748 R^2 T_c^{2.5}}{p_c} \quad \text{.....(4.15)}$$

$$b = \frac{0.08662 R T_c}{p_c} \quad \text{.....(4.16)}$$

Here, R is the Universal gas constant = 8.314472 J/mol.K. V_m is the molar volume, i.e. volume of 1 mole of liquid or gas; P_c is the pressure at the critical point; V_c is the molar volume at the critical point. R-K equation performs poorly for liquid phase. It is suitable for gas phase calculation when $P_r < (T_r/2)$.

9.6.5 Peng-Robinson equation of state (1976) [5]:

This equation is most widely used in chemical engineering thermodynamics. It gives better prediction of liquid states as compared to other equations of state. This equation of state requires three inputs per compound: T_c , P_c and the acentric factor ω . This equation has the following form:

$$P = \frac{RT}{V_m - b} - \frac{a\alpha}{V_m^2 + 2bV_m - b^2} \quad \dots(4.17)$$

where

$$a = \frac{0.45724 R^2 T_c^2}{p_c} \quad \dots(4.18)$$

$$b = \frac{0.07780 R T_c}{p_c} \quad \dots(4.19)$$

$$\alpha = \left(1 + \left(0.37464 + 1.54226\omega - 0.26992\omega^2\right) \left(1 - T_r^{0.5}\right)\right)^2 \quad \dots(4.20)$$

and,

$$T_r = \frac{T}{T_c} \quad \dots(4.21)$$

Also, Universal gas constant $R = 8.314472$ J/mol.K. V_m is the molar volume, i.e. volume of 1 mole of liquid or gas; P_c is the pressure at the critical point; V_c is the molar volume at the critical point.

The Peng-Robinson equation is *particularly useful* for all calculations of all fluid properties in *Natural gas processes*. Further, this equation has reasonable accuracy near the critical point; therefore, it is suitable to calculate the compressibility factors and liquid density.

9.6.6 Virial equation of state [5]:

All the above equations of state depend on measured properties of fluids. But, the virial equation of state is derived directly from statistical mechanics. It is of following form:

$$\frac{P V_m}{RT} = 1 + \frac{B}{V_m} + \frac{C}{V_m^2} + \frac{D}{V_m^3} + \dots \quad \text{.....(4.22)}$$

And,

$$B = -V_c \quad \text{.....(4.23)}$$

$$C = \frac{V_c^2}{3} \quad \text{.....(4.24)}$$

Here, R is the Universal gas constant = 8.314472 J/mol.K. V_m is the molar volume, i.e. volume of 1 mole of liquid or gas; P_c is the pressure at the critical point; V_c is the molar volume at the critical point. Accuracy can be increased by increasing the number of terms in eqn. (4.22).

9.7 Internal energy (u) and enthalpy (h) of an Ideal gas:

Joule's Law: "Specific internal energy of a gas is a function of temp only and is independent of both pressure and volume"

i.e. $u = f(T)$ only.

And, for enthalpy:

$$h = u + P \cdot v = u + R \cdot T$$

i.e. $h = f(T)$ only.

9.8 Specific heats of Ideal gases:

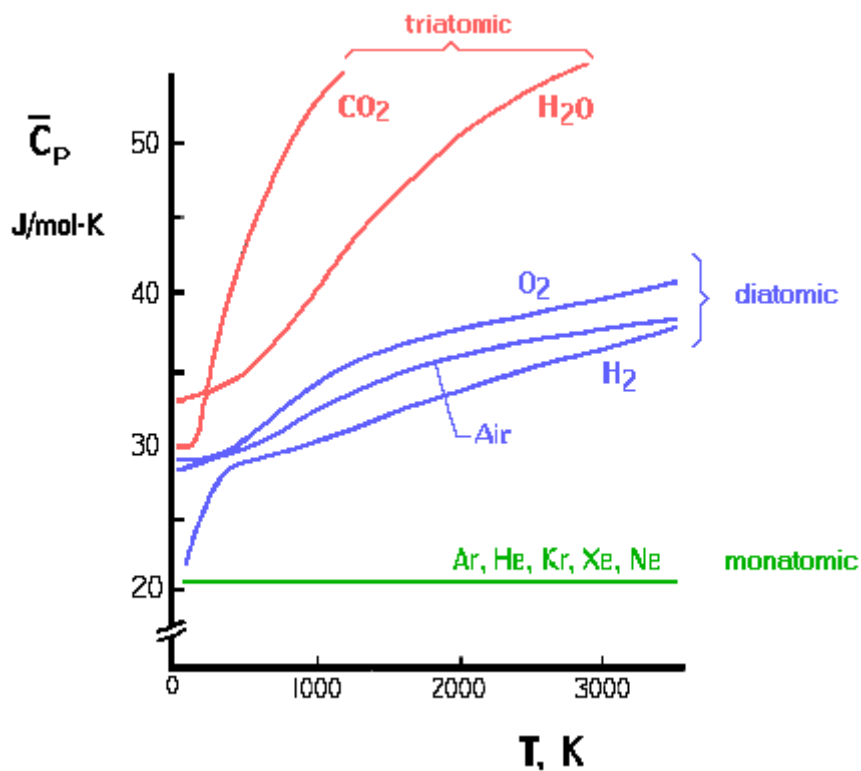
For an Ideal gas:

$$c_v = \frac{du}{dT} \quad \text{..sp.heat at const. vol....for any process}$$

$$c_p = \frac{dh}{dT} \quad \text{..sp.heat at const. pressure..}$$

$$c_p - c_v = R \quad \text{...where R is Gas constant.}$$

Isobaric sp. heats for several gases [16]:



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Sp. heats of Ideal gas are functions of temp only.

Ideal gas sp. heats of some common gases are presented below in a Table, easy to use [17]:

Table T-10 Ideal Gas Specific Heats of Some Common Gases (kJ/kg · K)

Temp. K	c_p	c_v	c_p	c_v	c_p	c_v	c_p	c_v	c_p	c_v	c_p	c_v	Temp. K
	Air		Nitrogen, N ₂		Oxygen, O ₂		Carbon Dioxide, CO ₂		Carbon Monoxide, CO		Hydrogen, H ₂		
250	1.003	0.716	1.039	0.742	0.913	0.653	0.791	0.602	1.039	0.743	14.051	9.927	250
300	1.005	0.718	1.039	0.743	0.918	0.658	0.846	0.657	1.040	0.744	14.307	10.183	300
350	1.008	0.721	1.041	0.744	0.928	0.668	0.895	0.706	1.043	0.746	14.427	10.302	350
400	1.013	0.726	1.044	0.747	0.941	0.681	0.939	0.750	1.047	0.751	14.476	10.352	400
450	1.020	0.733	1.049	0.752	0.956	0.696	0.978	0.790	1.054	0.757	14.501	10.377	450
500	1.029	0.742	1.056	0.759	0.972	0.712	1.014	0.825	1.063	0.767	14.513	10.389	500
550	1.040	0.753	1.065	0.768	0.988	0.728	1.046	0.857	1.075	0.778	14.530	10.405	550
600	1.051	0.764	1.075	0.778	1.003	0.743	1.075	0.886	1.087	0.790	14.546	10.422	600
650	1.063	0.776	1.086	0.789	1.017	0.758	1.102	0.913	1.100	0.803	14.571	10.447	650
700	1.075	0.788	1.098	0.801	1.031	0.771	1.126	0.937	1.113	0.816	14.604	10.480	700
750	1.087	0.800	1.110	0.813	1.043	0.783	1.148	0.959	1.126	0.829	14.645	10.521	750
800	1.099	0.812	1.121	0.825	1.054	0.794	1.169	0.980	1.139	0.842	14.695	10.570	800
900	1.121	0.834	1.145	0.849	1.074	0.814	1.204	1.015	1.163	0.866	14.822	10.698	900
1000	1.142	0.855	1.167	0.870	1.090	0.830	1.234	1.045	1.185	0.888	14.983	10.859	1000

Source: Tables T-10 are adapted from K. Wark, *Thermodynamics*, 4th ed., McGraw-Hill, New York, 1983, as based on "Tables of Thermal Properties of Gases," NBS Circular 564, 1955.

Generally, variation of sp. heats for different ideal gases are expressed as *third order polynomials in T*, and are available in Thermodynamics Text books / handbooks.

As an example:

$$c_{p_bar} = a + b * T + c * T^2 + d * T^3$$

where T is in Kelvin, c_{p_bar} in kJ/kmol.K

And a, b, c and d for some gases are [1]:

Substance	a	b	c	d
Air	28.11	0.1967E-2	0.4802E-5	-1.966E-9
N2	28.9	-0.1571E-2	0.8081E-5	-2.873E-9
O2	25.48	1.520E-2	-0.7155E-5	1.312E-9
CO2	22.26	5.981E-2	-3.501E-5	7.469E-9
CO	28.16	0.1675E-2	0.5372E-5	-2.222E-9
H2	29.11	-0.1916E-2	0.4003E-5	-0.8704E-9
Water vapor	32.24	0.1923E-2	1.055E-5	-3.595E-9
Ammonia (NH3)	27.568	2.5630E-2	0.99072E-5	-6.6909E-9
Methane (CH4)	19.89	5.024E-2	1.269E-5	-11.01E-9

9.9 Some Processes with Ideal gases: (See Chapter 4)

9.9.1 Work:

Work = Force x distance, N.m (= 1 Joule)

Work is a 'path function' i.e. an inexact differential.

9.9.2 pdV- work or displacement work:

$$dW = p \cdot dV$$

$$W_{12} = \int_{V_1}^{V_2} p \, dV \quad \dots \text{Integration performed on a quasi-static path}$$

9.9.3 pdV- work in various quasi-static processes:

(a). Constant pressure (isobaric) process:

$$W_{12} = p \cdot (V_2 - V_1)$$

(b). Constant volume (isochoric) process:

$$W_{12} = 0$$

(c). For a process in which $pV = \text{const} \dots$ Isothermal process:

$$W_{12} = p_1 \cdot V_1 \cdot \ln\left(\frac{p_1}{p_2}\right)$$

(d). For a process in which $pV^\gamma = \text{const} \dots$ reversible adiabatic or isentropic process:

$$W_{12} = \frac{p_1 \cdot V_1 - p_2 \cdot V_2}{\gamma - 1} = \frac{R \cdot (T_1 - T_2)}{\gamma - 1} = \frac{p_1 \cdot V_1}{n - 1} \left[1 - \left(\frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

Also, for a perfect gas:

$$p \cdot v = R \cdot T$$

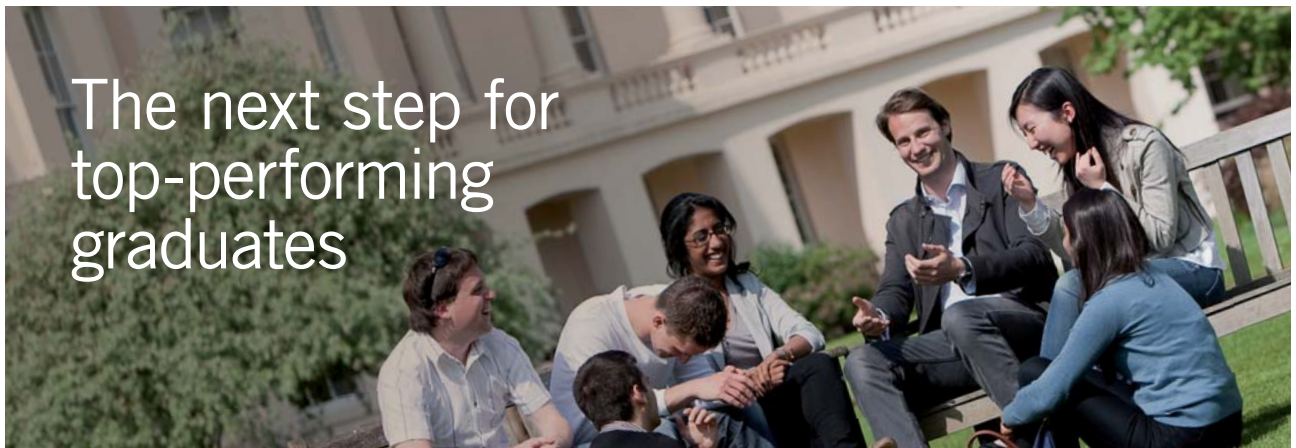
And for isentropic process, $pv^\gamma = \text{const.}$, we have:

$$T \cdot v^{\gamma-1} = \text{constant}$$

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2} \right)^\gamma$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2} \right)^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{\gamma-1}{\gamma}}$$



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(e). For a process in which $pV^n = \text{const.}$polytropic process:

$$W_{12} = \frac{p_1 \cdot V_1 - p_2 \cdot V_2}{n - 1} = \frac{p_1 \cdot V_1}{n - 1} \left[1 - \left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}} \right]$$

$$\text{i.e. } W_{12} = \frac{R \cdot (T_1 - T_2)}{n - 1}$$

Also: for a polytropic process:

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2} \right)^n$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2} \right)^{n-1}$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}}$$

For a perfect gas:

$$p \cdot v = R \cdot T \quad du = c_v \cdot dT$$

$$\gamma = \frac{c_p}{c_v} \quad c_p - c_v = R$$

$$\text{i.e. } c_v = \frac{R}{\gamma - 1}$$

Then, heat transfer during a polytropic process (for a perfect gas):

$$Q = (u_2 - u_1) + W = c_v \cdot (T_2 - T_1) + R \cdot (T_1 - T_2)$$

Simplifying, we get:

$$Q_{\text{poly}} = \frac{\gamma - n}{\gamma - 1} \cdot \frac{R \cdot (T_1 - T_2)}{n - 1}$$

$$\text{i.e. } Q_{\text{poly}} = \frac{\gamma - n}{\gamma - 1} \cdot W_{\text{poly}}$$

Polytropic sp. heat:

$$\text{Polytr. sp. heat: } c_n = c_v \cdot \frac{\gamma - n}{1 - n}$$

9.10 Properties of Mixtures of Ideal gases [18]:

9.10.1 Dalton's Law:

The pressure of a mixture of gases is equal to the sum of the partial pressures of the constituents.

The partial pressure of each constituent is that pressure which the gas would exert if it occupied alone that volume occupied by the mixture at the same temperature.

Considering a mixture of two Ideal gases A and B:

$$m = m_A + m_B \quad \text{and,}$$

$$p = p_A + p_B \quad \text{...by Dalton's Law}$$

For a mixture of i no. of ideal gases:

$$m = m_A + m_B + m_C + \dots + m_i$$

$$p = p_A + p_B + p_C + \dots + p_i$$

Or,

$$m = \sum m_i$$

and,

$$p = \sum p_i$$

9.10.2 Gibbs-Dalton Law:

The internal energy, enthalpy and entropy of a gaseous mixture are respectively equal to the sums of the internal energies, enthalpies and entropies of the constituents.

Each constituent has that internal energy, enthalpy and entropy which it could have if it occupied alone that volume occupied by the mixture at the temperature of the mixture.

i.e. we have:

$$m \cdot u = m_A \cdot u_A + m_B \cdot u_B + \dots$$

$$m \cdot h = m_A \cdot h_A + m_B \cdot h_B + \dots$$

$$m \cdot s = m_A \cdot s_A + m_B \cdot s_B + \dots$$

Or,

$$m \cdot u = \sum m_i \cdot u_i$$

$$m \cdot h = \sum m_i \cdot h_i$$

$$m \cdot s = \sum m_i \cdot s_i$$



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9.10.3 Volumetric analysis of a gas mixture:

Consider a volume V of a gaseous mixture at a temp T consisting of three constituents A, B and C. Let each of the constituents be compressed to the total pressure p of the mixture and let the temp remain constant. The partial volumes occupied by the constituents will then be V_A , V_B and V_C .

And, we get:

$$V_A = \frac{p_A}{p} \cdot V \quad \dots \text{etc.}$$

In general:

$$V_i = \frac{p_i}{p} \cdot V$$

$$\text{i.e. } \sum V_i = \sum (p_i \cdot V) / p = (V / p) \cdot \sum p_i$$

$$\text{But, } p = \sum p_i$$

$$\text{Therefore: } \sum V_i = V$$

Thus, **“volume of a mixture of gases is equal to the sum of the volumes of the individual constituents when each exists alone at the pressure and temp of mixture.”** ... This is known as **Amagat’s Law**.

Remember:

$$n = m / M \text{ where}$$

n is the no. of moles, m = mass of gas, and M = molecular weight of gas

Avogadro’s Law: “number of moles of any gas is proportional to the volume of the gas at a given pressure and temperature”.

So, total number of moles in a vessel containing a mixture of gases must equal the sum of the moles of the individual constituents.

i.e.

$$n = n_A + n_B + n_C + \dots$$

$$\text{i.e. } n = \sum n_i$$

9.10.4 Apparent Molecular weight and Gas constant:

If a gas mixture, with total number of moles n , occupies a total volume of V , at a temperature T , then:

$$p \cdot V = R_u \cdot T \cdot \sum n_i$$

i.e. $p \cdot V = n \cdot R_u \cdot T$ where R_u is the Universal gas const.

Apparent mol. weight is defined as: $M = m / n$

where, m = the mass of the mixture, and n = no. of moles in the mixture

Apparent Gas constant for the mixture is defined as $R = R_u / M$

It can be assumed that the mixture of perfect gases behaves like a perfect gas and obeys the perfect gas laws.

Apparent gas constant of mixture in terms of individual gas constants:

$$R = \sum (m_i / m) \cdot R_i$$

where (m_i / m) = mass fraction of constituent i

Also note that:

$$\frac{p_i}{p} = \frac{n_i}{n} = \frac{V_i}{V}$$

i.e. Molar analysis is identical with the volumetric analysis, and both are equal to the ratio of partial pressure to the total pressure.

Also:

$$M = \sum (n_i / n) \cdot M_i$$

And,

$$M = 1 / \sum (m_i / M_i)$$

where m_i is the mass fraction of species i , M_i is its mol. wt.

9.10.5 Sp. heats of a Gas mixture:

$$c_v = \sum (m_i / m) \cdot c_{vi}, \text{ and}$$

$$c_p = \sum (m_i / m) \cdot c_{pi}$$

$$R = c_p - c_v = \sum (m_i / m) \cdot R_i \dots \text{ gives for the mixture}$$

For the mixture, we can also write:

$$\gamma = c_p / c_v$$

$$c_p = \gamma \cdot R / (\gamma - 1)$$

$$c_v = R / (\gamma - 1)$$

Molar sp. heats:

$$C_p = M \cdot c_p$$

$$C_v = M \cdot c_v$$



$$C_p - C_v = M \cdot R = R_u \dots \text{the Universal Gas const.}$$

Also,

$$U = n \cdot C_v \cdot T \text{ and,}$$

$$H = n \cdot C_p \cdot T$$

And,

$$C_v = \sum (n_i / n) \cdot C_{vi}$$

$$C_p = \sum (n_i / n) \cdot C_{pi}$$

9.10.6 Mixing of two Ideal gases at same P and T [Ref: 2]:

Let a mass m_A of ideal gas A at a given P and T be mixed with m_B of ideal gas B at the same P and T, such that the final ideal gas mixture is also at P and T. Then, entropy change for the process is:

$$\Delta S_{\text{mix}} = -m_A \cdot R_A \cdot \ln(y_A) - m_B \cdot R_B \cdot \ln(y_B)$$

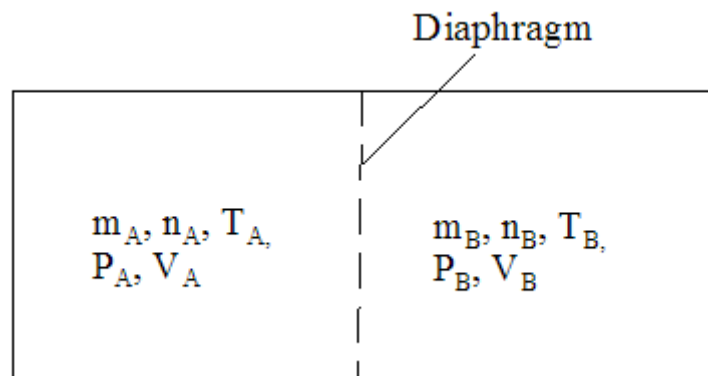
i.e.
$$\Delta S_{\text{mix}} = -n_A \cdot R_u \cdot \ln(y_A) - n_B \cdot R_u \cdot \ln(y_B)$$

Note that increase in entropy depends only on the no. of moles of component gases and is *independent* of the composition of the gas.

9.10.7 Adiabatic mixing of two Ideal gases: [Ref: 18]:

Two cases are considered:

1. Two compartments, separated by a membrane contain two ideal gases A and B, one in each compartment.



Now, the membrane is removed and the gases mix:

$m = m_A + m_B,$ $V = V_A + V_B,$ $n = n_A + n_B$ P, T	<p>Mixture of Gases A and B</p>
--	-------------------------------------

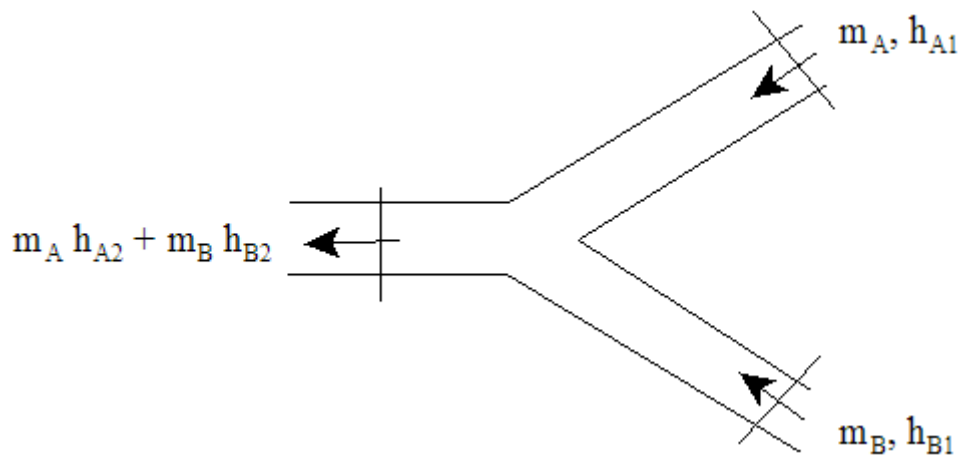
The process is equivalent to free expansion of each gas. So, **equating the total internal energies before and after mixing**, we get:

$$U_1 = n_A \cdot C_{vA} \cdot T_A + n_B \cdot C_{vB} \cdot T_B$$

$$U_2 = (n_A \cdot C_{vA} + n_B \cdot C_{vB}) \cdot T$$

and,
$$T = \frac{n_A \cdot C_{vA} \cdot T_A + n_B \cdot C_{vB} \cdot T_B}{n_A \cdot C_{vA} + n_B \cdot C_{vB}}$$

2. If two streams of fluid meet to form a common stream in **steady flow**, we apply **steady flow energy eqn** to the mixing section. Neglecting the changes in P.E. and K.E. we get:



$$m_A \cdot h_{A1} + m_B \cdot h_{B1} + Q = m_A \cdot h_{A2} + m_B \cdot h_{B2} + W$$

For adiabatic flow, $Q = 0$, Also $W = 0$. Then, we get:

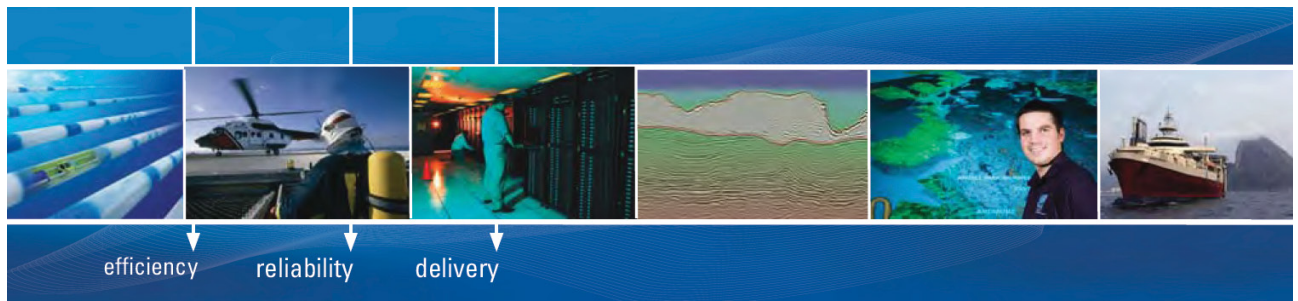
$$m_A \cdot h_{A1} + m_B \cdot h_{B1} = m_A \cdot h_{A2} + m_B \cdot h_{B2}$$

Now, $h = c_p \cdot T$. Therefore:

$$m_A \cdot c_{pA} \cdot T_A + m_B \cdot c_{pB} \cdot T_B = m_A \cdot c_{pA} \cdot T + m_B \cdot c_{pB} \cdot T$$

$$\text{and, } T = \frac{m_A \cdot c_{pA} \cdot T_A + m_B \cdot c_{pB} \cdot T_B}{m_A \cdot c_{pA} + m_B \cdot c_{pB}}$$

T is the temp after mixing.



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In terms of moles of gases:

$$T = \frac{n_A \cdot C_{pA} \cdot T_A + n_B \cdot C_{pB} \cdot T_B}{n_A \cdot C_{pA} + n_B \cdot C_{pB}}$$

where $C_p = M \cdot c_p$ and,

$$M = \frac{m}{n} \quad \text{and} \quad n \cdot C_p = m \cdot c_p$$

=====

9.11 Problems solved with Mathcad:

Prob. 9.1 Sp. vol. of CO₂ at 120 C is 1.2 m³/kg. Determine the pressure exerted by CO₂ (i) by Ideal gas eqn. (ii) by Van der Waals eqn. [VTU – Jan. 2004]

Mathcad Solution:

Data:

$$\begin{aligned} R_u &:= 8314.4 \quad \text{J/kg.mole.K} & m &:= 1 \quad \text{kg} & T &:= 120 + 273 \quad \text{K} \\ V &:= 1.2 \quad \text{m}^3 & M &:= 44 \quad \text{Mol. wt of CO}_2 \end{aligned}$$

Calculations:

(i) By Ideal gas eqn.:

$$R := \frac{R_u}{M} \quad \text{i.e.} \quad R = 188.964 \quad \text{J.kg.K}$$

$$\text{Therefore:} \quad p := \frac{m \cdot R \cdot T}{V} \quad \text{Pa}$$

$$\text{i.e.} \quad p = 6.189 \times 10^4 \quad \text{Pa.... Ans.}$$

(ii) By Van der Waals eqn.:

We have the Van der Waal's constants for CO₂:

$$a = 3.647 \text{ bar} \cdot (\text{m}^3/\text{kmol})^2 = 364700 \text{ Pa} \cdot (\text{m}^3/\text{kmol})^2$$

$$b = 0.0428 \text{ m}^3/\text{mol}$$

i.e. For CO₂:

$$a := 364700 \text{ Pa} \cdot (\text{m}^3/\text{kmol})^2 \quad b := 0.0428 \text{ m}^3/\text{mol}$$

$$\bar{v} := \frac{V}{\left(\frac{m}{M}\right)} \quad \bar{v} = 52.8 \text{ m}^3/\text{kg} \cdot \text{mol}$$

i.e. For CO₂:

$$a := 364700 \text{ Pa} \cdot (\text{m}^3/\text{kmol})^2 \quad b := 0.0428 \text{ m}^3/\text{mol}$$

$$\bar{v} := \frac{V}{\left(\frac{m}{M}\right)} \quad \bar{v} = 52.8 \text{ m}^3/\text{kg} \cdot \text{mol}$$

$$p_{\text{VW}} := \frac{R_u \cdot T}{\bar{v} - b} - \frac{a}{\bar{v}^2} \quad \text{....Van der waal's eqn. for pressure}$$

i.e. $p_{\text{VW}} = 6.18 \times 10^4 \text{ Pa}$ Pressure as per Van der Waal's eqn.....Ans.

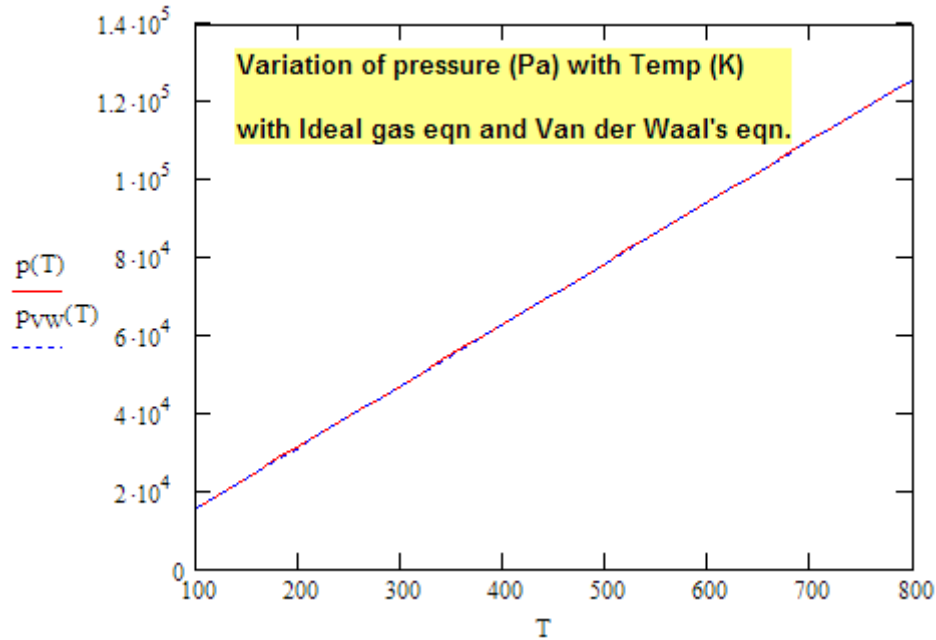
In addition:

Plot the variation of p with T as T varies from 100 K to 800 K, using Ideal gas eqn and Van der Waal's eqn:

$$p(T) := \frac{m \cdot R \cdot T}{V} \quad \text{....define p as a function of T}$$

$$p_{\text{VW}}(T) := \frac{R_u \cdot T}{\bar{v} - b} - \frac{a}{\bar{v}^2} \quad \text{....define pVW as a function of T}$$

$T := 100, 120 \dots 800$...define a range variable T



=====

Prob.9.2. Determine the pressure exerted by CO₂ in a container of 1.5 m³ capacity when it contains 6 kg at 27 C (i) by Ideal gas eqn. (ii) by Van der Waals eqn, (iii) by Beattie Bridgman eqn.

Mathcad Solution:

Data:

$$R_u := 8314.4 \quad \text{J/kg.mole.K} \quad m := 6 \quad \text{kg} \quad T := 300 \quad \text{K} \quad V := 1.5 \quad \text{m}^3$$

$$M := 44 \quad \text{Mol. wt of CO}_2$$

Calculations:

(i) By Ideal gas eqn.:

$$R := \frac{R_u}{M} \quad \text{i.e.} \quad R = 188.964 \quad \text{J/kg.K}$$

$$p := \frac{m \cdot R \cdot T}{V} \quad \text{Pa} \quad \text{i.e.} \quad p = 2.268 \times 10^5 \quad \text{Pa....Pressure by Ideal gas eqn.... Ans}$$

(ii) By Van der Waals eqn.:

For CO₂: $a := 364700 \text{ Pa} \cdot (\text{m}^3/\text{kmol})^2$ $b := 0.0428 \text{ m}^3/\text{kmol}$

$$\bar{v} := \frac{V}{\left(\frac{m}{M}\right)} \quad \bar{v} = 11 \quad \text{m}^3/\text{kg} \cdot \text{mol}$$

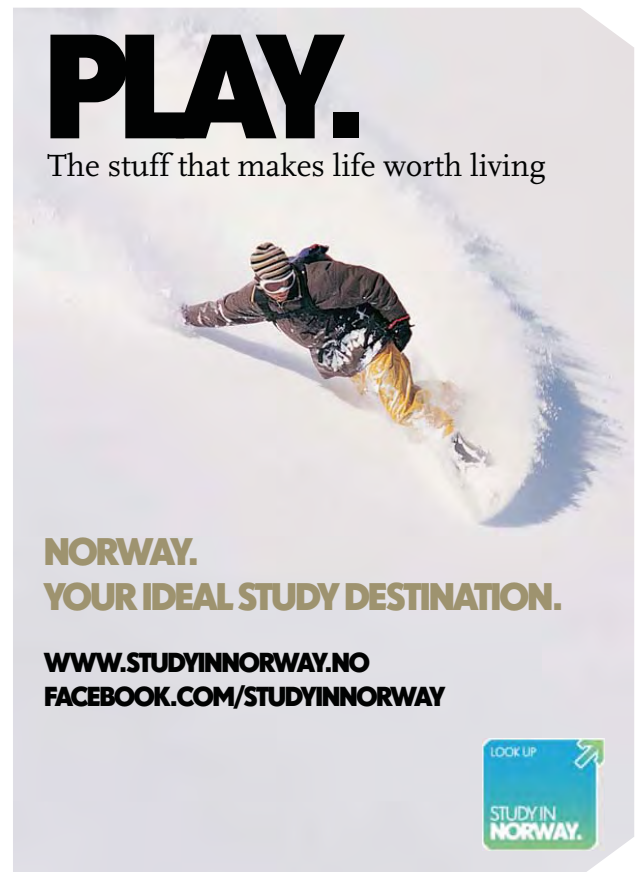
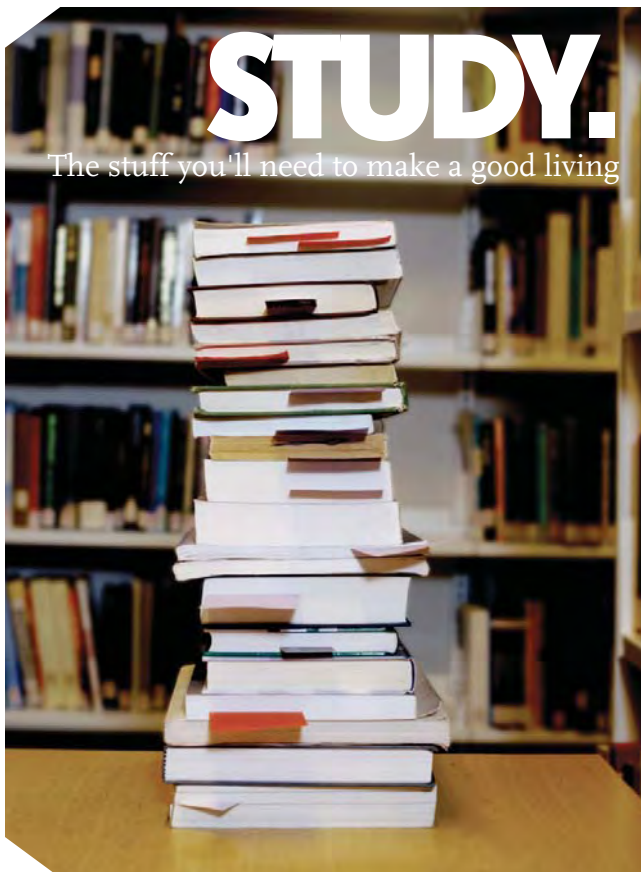
$$p_{\text{VW}} := \frac{R_u \cdot T}{\bar{v} - b} - \frac{a}{\bar{v}^2} \quad \dots \text{Van der Waals eqn.}$$

i.e. $p_{\text{VW}} = 2.246 \times 10^5 \text{ Pa}$ **Pa....Pressure by Van der Waal's eqn.... Ans**

(iii) By Beattie Bridgeman eqn.:

For CO₂ we have:

$$aa := 0.07132 \quad bb := 0.07235 \quad cc := 66 \cdot 10^{-4} \quad A_0 := 507.2836 \quad B_0 := 0.10476$$



$$A := A_0 \cdot \left(1 - \frac{aa}{vbar}\right) \quad A = 503.995$$

$$B := B_0 \cdot \left(1 - \frac{bb}{vbar}\right) \quad B = 0.104$$

$$\varepsilon := \frac{cc}{(vbar \cdot T^3)} \quad \varepsilon = 2.222 \times 10^{-3}$$

$$p_{BB} := \frac{R_u \cdot T \cdot (1 - \varepsilon)}{vbar^2} \cdot (vbar + B) - \frac{A}{vbar^2} \quad \text{...Beattie Bridgeman eqn.}$$

i.e. $p_{BB} = 2.284 \times 10^5$ **Pa....Pressure by Beattie Bridgeman eqn.... Ans.**

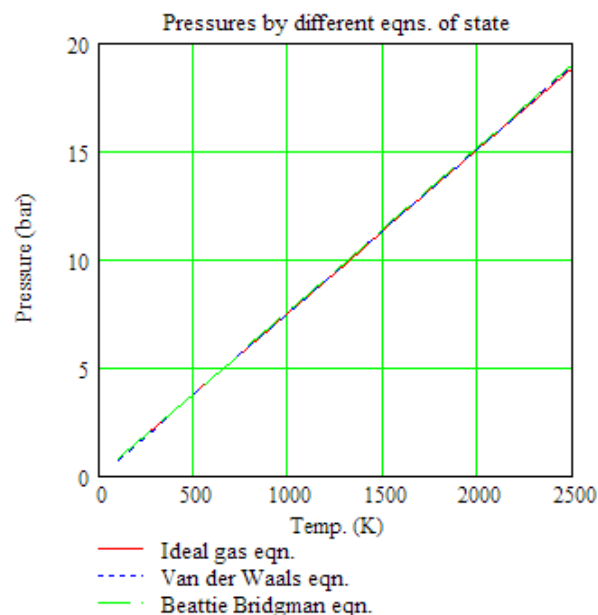
To draw a graph of p for various T:

$$T := 100, 200..2500 \quad \text{....define a range variable}$$

$$p_{ideal}(T) := \frac{m \cdot R \cdot T}{V} \quad \text{....Ideal gas eqn.}$$

$$p_{VW}(T) := \frac{R_u \cdot T}{vbar - b} - \frac{a}{vbar^2} \quad \text{....Van der Waals eqn.}$$

$$p_{BB}(T) := \frac{R_u \cdot T \cdot (1 - \varepsilon)}{vbar^2} \cdot (vbar + B) - \frac{A}{vbar^2} \quad \text{...Beattie Bridgeman eqn.}$$



=====

Prob.9.3. Determine the pressure in a steel vessel having a volume of 15 L and containing 3.4 kg of nitrogen at 400 C using: (i) Ideal gas eqn. (ii) Van der Waals eqn. [VTU – Feb. 2002]

Mathcad Solution:

Data:

$$R_u := 8314.4 \quad \text{J/kgmol.K}$$

$$m := 3.4 \quad \text{kg}$$

$$T := 400 + 273 \quad \text{K}$$

$$V := 15 \cdot 10^{-3} \quad \text{m}^3$$

$$M := 28 \quad \text{Mol. wt of N}_2$$

Calculations:

(i) By Ideal gas eqn.:

$$R := \frac{R_u}{M} \quad \text{i.e.} \quad R = 296.943 \quad \text{J/kg.K}$$

$$p := \frac{m \cdot R \cdot T}{V} \quad \text{Pa..... by Ideal gas eqn.}$$

$$\text{i.e.} \quad p = 4.53 \times 10^7 \quad \text{Pa..... by Ideal gas eqn.}$$

(ii) By Van der Waals eqn.:

For N₂, we have:

$$T_c := 126.2 \quad \text{K} \quad P_c := 3.39 \cdot 10^6 \quad \text{Pa}$$

Therefore:

$$a := \frac{27 \cdot R_u^2 \cdot T_c^2}{64 \cdot P_c} \quad b := \frac{R_u \cdot T_c}{8 \cdot P_c} \quad \text{....Van der Waal's constants}$$

$$\text{i.e.} \quad a = 1.37 \times 10^5 \quad \text{Pa} \cdot (\text{m}^3/\text{kmol})^2 \quad b = 0.039 \quad \text{m}^3/\text{kmol}$$

$$\bar{v} := \frac{V}{\left(\frac{m}{M}\right)} \quad \bar{v} = 0.124 \text{ m}^3/\text{kg.mol}$$

$$p_{\text{VW}} := \frac{R_u \cdot T}{\bar{v} - b} - \frac{a}{\bar{v}^2} \quad \dots \text{Van der Waal's eqn.}$$

$$p_{\text{VW}} = 5.698 \times 10^7 \text{ Pa} \dots \text{by Van der Waals eqn.}$$

Compressibility factor:

$$Z := \frac{p_{\text{VW}} \cdot \bar{v}}{R \cdot T} \quad \dots \text{by definition of } Z$$

i.e. $Z = 4.277$ Ans



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Prob.9.4. Pressure and temp. of a mixture of 3 kg of N₂ and 5 kg of CO₂ are 3 bar and 20 C respectively. For the mixture, determine the following:(i) mole fraction of each component (ii) Avg. Mol. wt. and specific gas constant (iii) partial pressures and partial volumes of CO₂ and N₂, and (iv) volume & density of the mixture.

Mathcad Solution:

Data:

$$\begin{aligned} m_{N_2} &:= 3 \text{ kg} & M_{N_2} &:= 28 \text{ ...Mol. wt. of N}_2 \\ m_{CO_2} &:= 5 \text{ kg} & M_{CO_2} &:= 44 \text{ ...Mol. wt. of CO}_2 \\ p &:= 3 \cdot 10^5 \text{ Pa} & R_u &:= 8314.4 \text{ J/kg.mole.K} \\ T &:= 25 + 273 \text{ K} \end{aligned}$$

Calculations:

(i) Mole fractions:

$$\begin{aligned} n_{N_2} &:= \frac{m_{N_2}}{M_{N_2}} & n_{N_2} &= 0.107 \text{ ...No. of moles of N}_2 \\ n_{CO_2} &:= \frac{m_{CO_2}}{M_{CO_2}} & n_{CO_2} &= 0.114 \text{ ...No. of moles of CO}_2 \\ n &:= n_{CO_2} + n_{N_2} & n &= 0.221 \text{ ..Total no. of moles} \\ y_{CO_2} &:= \frac{n_{CO_2}}{n} & y_{CO_2} &= 0.515 \text{Mole fraction of O}_2\text{....Ans.} \\ y_{N_2} &:= \frac{n_{N_2}}{n} & y_{N_2} &= 0.485 \text{Mole fraction of N}_2\text{....Ans.} \end{aligned}$$

(ii) Avg. Mol. wt.:

$$m_m := m_{CO_2} + m_{N_2} \quad \text{....total mass}$$

$$M_m := \frac{m_m}{n} \quad M_m = 36.235 \quad \text{....Avg. Mol. wt. of mixture....Ans.}$$

(iii) Specific gas constant:

$$R_m := \frac{R_u}{M_m} \quad R_m = 229.456 \quad \text{J/kg.K....Specific gas constant....Ans.}$$

$$\text{Alternatively: } R_{\text{mix}} := \left(\frac{m_{\text{CO}_2}}{m_m} \right) \cdot \left(\frac{R_u}{M_{\text{CO}_2}} \right) + \left(\frac{m_{\text{N}_2}}{m_m} \right) \cdot \left(\frac{R_u}{M_{\text{N}_2}} \right) \quad R_{\text{mix}} = 229.456 \quad \text{....verified.}$$

(iv) Partial pressures and partial Volumes and Density:

$$p_{\text{N}_2} := y_{\text{N}_2} \cdot p \quad p_{\text{N}_2} = 1.456 \times 10^5 \quad \text{Pa....Ans.}$$

$$p_{\text{CO}_2} := y_{\text{CO}_2} \cdot p \quad p_{\text{CO}_2} = 1.544 \times 10^5 \quad \text{Pa....Ans.}$$

$V = V_{\text{CO}_2} + V_{\text{N}_2}$...Mixture vol....by Amagat's Law...at same P & T as mixture

$$V_{\text{CO}_2} := m_{\text{CO}_2} \cdot \frac{R_u}{M_{\text{CO}_2}} \cdot \frac{T}{p} \quad \text{i.e.} \quad V_{\text{CO}_2} = 0.939 \quad \text{m}^3 \text{....partial vol. of CO}_2$$

$$V_{\text{N}_2} := m_{\text{N}_2} \cdot \frac{R_u}{M_{\text{N}_2}} \cdot \frac{T}{p} \quad \text{i.e.} \quad V_{\text{N}_2} = 0.885 \quad \text{m}^3 \text{....partial vol. of N}_2$$

Therefore,

$$V := V_{\text{CO}_2} + V_{\text{N}_2} \quad \text{....total volume}$$

$$\text{i.e.} \quad V = 1.823 \quad \text{m}^3 \text{...Mixture vol...Ans.}$$

$$\text{Verify: } V = \frac{(m \cdot R \cdot T)_{\text{mix}}}{p} = \frac{(m_{\text{CO}_2} + m_{\text{N}_2}) \cdot R_m \cdot T}{p} = 1.823 \quad \text{....verified.}$$

$$\text{Density: } \frac{m_{\text{CO}_2} + m_{\text{N}_2}}{V} = 4.387 \quad \text{kg/m}^3 \text{....Ans.}$$

=====

Prob. 9.5. (a) The above mixture is heated at const. vol. from 25 C to 40 C. Find change in int. energy, enthalpy and entropy of mixture.

(b) if the heating is performed at const. pr. to the same temp. find the change in int. energy, enthalpy and entropy of mixture.

Given: C_p of $N_2 = 1.04 \text{ kJ/kg.K}$ and C_p of $CO_2 = 0.755 \text{ kJ/kg.K}$

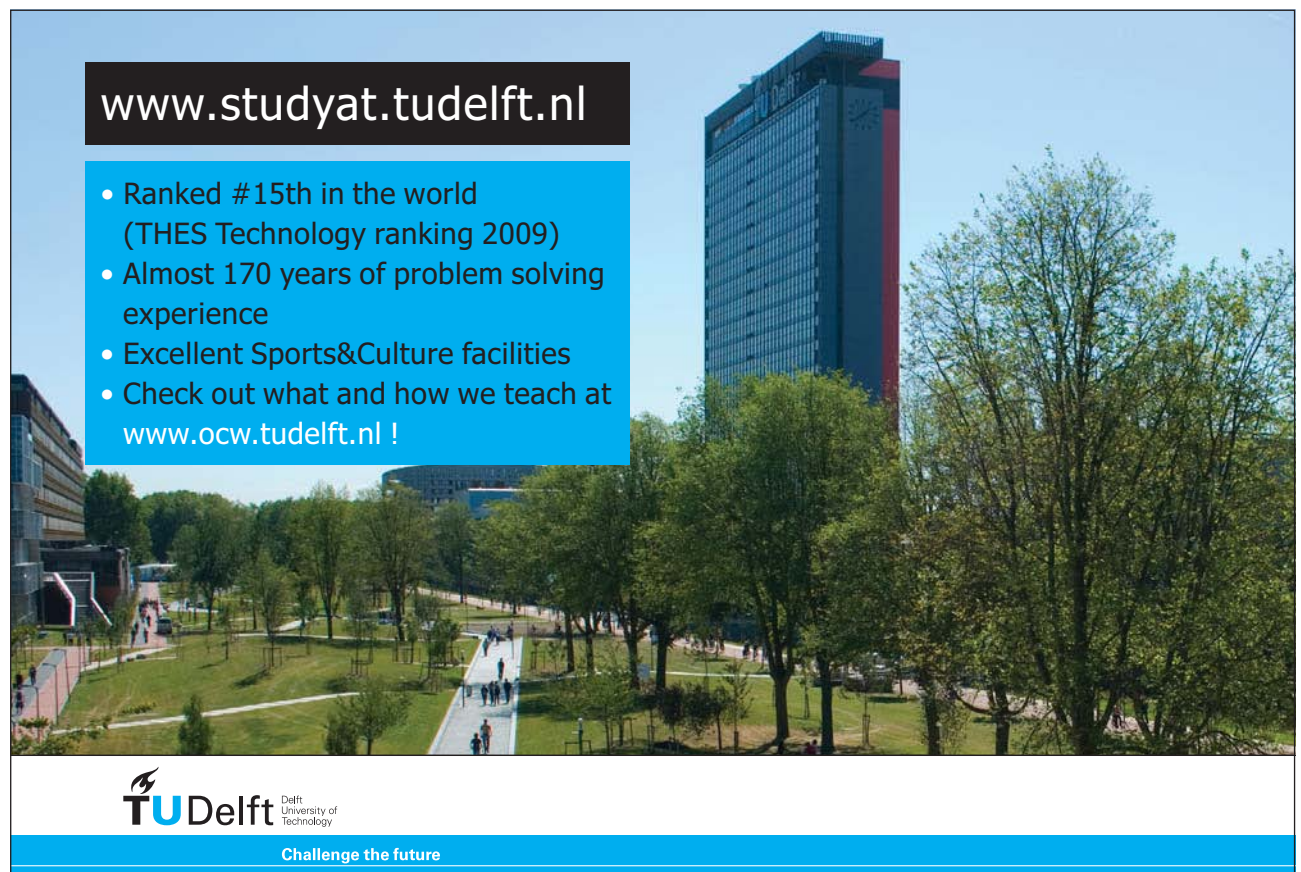
Mathcad Solution:

Data:

$$C_{pN_2} := 1.04 \quad \text{kJ/kg.K}$$

$$C_{pCO_2} := 0.755 \quad \text{kJ/kg.K}$$

$$T_1 := 298 \quad \text{K} \quad T_2 := 313 \quad \text{K}$$



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Calculations:

(i) Sp. heats of mixture:

$$m_m := m_{\text{CO}_2} + m_{\text{N}_2} \quad \text{i.e. } m_m = 8 \quad \text{kg....mass of mixture}$$

Then:

$$C_{p_{\text{mix}}} := \frac{(m_{\text{CO}_2} \cdot C_{p_{\text{CO}_2}} + m_{\text{N}_2} \cdot C_{p_{\text{N}_2}})}{m_m}$$

$$\text{i.e. } C_{p_{\text{mix}}} = 0.862 \quad \text{kJ/kg.K....Ans.}$$

And,

$$C_{v_{\text{CO}_2}} := C_{p_{\text{CO}_2}} - \frac{R_u \cdot 10^{-3}}{M_{\text{CO}_2}}$$

$$\text{i.e. } C_{v_{\text{CO}_2}} = 0.566 \quad \text{kJ/kg.K}$$

$$C_{v_{\text{N}_2}} := C_{p_{\text{N}_2}} - \frac{R_u \cdot 10^{-3}}{M_{\text{N}_2}}$$

$$\text{i.e. } C_{v_{\text{N}_2}} = 0.743 \quad \text{kJ/kg.K}$$

And:

$$C_{v_{\text{mix}}} := \frac{(m_{\text{CO}_2} \cdot C_{v_{\text{CO}_2}} + m_{\text{N}_2} \cdot C_{v_{\text{N}_2}})}{m_m}$$

$$\text{i.e. } C_{v_{\text{mix}}} = 0.632 \quad \text{kJ/kg.K....Ans.}$$

(ii) Changes in int. energy, enthalpy & entropy of mixture:

$$\Delta U := m_m \cdot C_{v_{\text{mix}}} (T_2 - T_1)$$

$$\text{i.e. } \Delta U = 75.89 \quad \text{kJ....Ans.}$$

$$\Delta H := m_m \cdot C_{p_{mix}} (T_2 - T_1)$$

i.e. $\Delta H = 103.425$ **kJ....Ans.**

$$\Delta S := m_m \cdot C_{v_{mix}} \ln \left(\frac{T_2}{T_1} \right) \quad \text{kJ/K....for const. vol. process}$$

i.e. $\Delta S = 0.248$ **kJ/K.....for const. vol. process..Ans.**

(b) Changes in int. energy, enthalpy & entropy of mixture, for const. pressure process:

$$\Delta U := m_m \cdot C_{v_{mix}} (T_2 - T_1)$$

i.e. $\Delta U = 75.89$ **kJ....Ans....same as earlier..**

$$\Delta H := m_m \cdot C_{p_{mix}} (T_2 - T_1)$$

i.e. $\Delta H = 103.425$ **kJ....Ans.....same as earlier..**

$$\Delta S := m_m \cdot C_{p_{mix}} \ln \left(\frac{T_2}{T_1} \right) \quad \text{kJ/K....for const. pressure process}$$

i.e. $\Delta S = 0.339$ **kJ/K....for const. pressure process..Ans.**

=====

Prob.9.6. A mixture of Ideal gases contains 3 kg of N₂ and 5 kg of CO₂. The partial pressure of CO₂ in the mixture is 155 kPa. Find: (i) partial pressure of N₂ (ii) Gas const. for the mixture, and (iii) Mol. wt. of the mixture . [VTU – Jan. 2006]

Mathcad Solution:

Data:

$$\begin{array}{ll} m_{N_2} := 3 \quad \text{kg} & M_{N_2} := 28 \\ m_{CO_2} := 5 \quad \text{kg} & M_{CO_2} := 44 \\ p_{CO_2} := 155 \quad \text{kPa} & R_u := 8314.4 \quad \text{J/kg.mole.K} \end{array}$$

Calculations:

(i) Mole fractions:

$$n_{\text{CO}_2} := \frac{m_{\text{CO}_2}}{M_{\text{CO}_2}} \quad \text{i.e.} \quad n_{\text{CO}_2} = 0.114 \quad \dots \text{No. of moles of CO}_2$$

$$n_{\text{N}_2} := \frac{m_{\text{N}_2}}{M_{\text{N}_2}} \quad \text{i.e.} \quad n_{\text{N}_2} = 0.107 \quad \dots \text{No. of moles of N}_2$$

$$n := n_{\text{CO}_2} + n_{\text{N}_2} \quad \text{i.e.} \quad n = 0.221 \quad \dots \text{Total no. of moles}$$

$$y_{\text{CO}_2} := \frac{n_{\text{CO}_2}}{n} \quad \text{i.e.} \quad y_{\text{CO}_2} = 0.515 \quad \dots \text{Mole fraction of CO}_2 \dots \text{Ans.}$$

$$y_{\text{N}_2} := \frac{n_{\text{N}_2}}{n} \quad \text{i.e.} \quad y_{\text{N}_2} = 0.485 \quad \dots \text{Mole fraction of N}_2 \dots \text{Ans.}$$

$$\text{Therefore, } P_{\text{tot}} := \frac{P_{\text{CO}_2}}{y_{\text{CO}_2}} \quad \text{i.e.} \quad P_{\text{tot}} = 301.143 \quad \text{kPa} \dots \text{Ans.}$$

$$\text{And, } p_{\text{N}_2} := y_{\text{N}_2} \cdot P_{\text{tot}} \quad \text{i.e.} \quad p_{\text{N}_2} = 146.143 \quad \text{kPa} \dots \text{Ans.}$$

(ii) Avg. Mol. wt.:

$$M_m := \frac{m_{\text{CO}_2} + m_{\text{N}_2}}{n} \quad \text{i.e.} \quad M_m = 36.235 \quad \dots \text{Avg. Mol. wt. of mixture} \dots \text{Ans.}$$

(iii) Specific gas constant:

$$R_m := \frac{R_u}{M_m}$$

$$\text{i.e.} \quad R_m = 229.456 \quad \text{J/kg.K} \dots \text{Specific gas constant} \dots \text{Ans.}$$

=====

Prob.9.7. Pressure and temperature of a mixture of 4 kg of O₂ and 6 kg of N₂ are 4 bar and 27 °C respectively. For the mixture, determine the following: (i) mole fraction of each component (ii) Avg. Mol. wt. (iii) specific gas constant (iv) volume and density. [VTU – Jan. 2005]

Mathcad Solution:

Data:

$$\begin{aligned} m_{O_2} &:= 4 \quad \text{kg} & M_{O_2} &:= 32 \\ m_{N_2} &:= 6 \quad \text{kg} & M_{N_2} &:= 28 \\ p &:= 4 \cdot 10^5 \quad \text{Pa} & R_u &:= 8314.4 \quad \text{J/kg.mole.K} \\ T &:= 27 + 273 \quad \text{K} \end{aligned}$$



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Calculations:

(i) Mole fractions:

$$n_{O_2} := \frac{m_{O_2}}{M_{O_2}} \quad \text{i.e.} \quad n_{O_2} = 0.125 \quad \dots \text{No. of moles of } O_2$$

$$n_{N_2} := \frac{m_{N_2}}{M_{N_2}} \quad \text{i.e.} \quad n_{N_2} = 0.214 \quad \dots \text{No. of moles of } N_2$$

$$n := n_{O_2} + n_{N_2} \quad \text{i.e.} \quad n = 0.339 \quad \dots \text{Total no. of moles}$$

$$y_{O_2} := \frac{n_{O_2}}{n} \quad \text{i.e.} \quad y_{O_2} = 0.368 \quad \dots \text{Mole fraction of } O_2 \dots \text{Ans.}$$

$$y_{N_2} := \frac{n_{N_2}}{n} \quad \text{i.e.} \quad y_{N_2} = 0.632 \quad \dots \text{Mole fraction of } N_2 \dots \text{Ans.}$$

(ii) Avg. Mol. wt.:

$$M_m := \frac{m_{O_2} + m_{N_2}}{n} \quad \text{i.e.} \quad M_m = 29.474 \quad \dots \text{Avg. Mol. wt. of mixture} \dots \text{Ans.}$$

(iii) Specific gas constant:

$$R_m := \frac{R_u}{M_m} \quad \text{i.e.} \quad R_m = 282.096 \quad \dots \text{J/kg.K} \dots \text{Ans.}$$

(iv) Volume and Density:

$$V = V_{O_2} + V_{N_2} \quad \dots \text{Mixture vol.} \dots \text{by Amagat's Law} \dots \text{at same } P \text{ \& } T \text{ as mixture}$$

$$V_{O_2} := n_{O_2} \cdot \frac{R_u}{M_{O_2}} \cdot \frac{T}{p} \quad \text{i.e.} \quad V_{O_2} = 0.779 \quad m^3 \dots \text{partial vol. of } O_2$$

$$V_{N_2} := n_{N_2} \cdot \frac{R_u}{M_{N_2}} \cdot \frac{T}{p} \quad \text{i.e.} \quad V_{N_2} = 1.336 \quad m^3 \dots \text{partial vol. of } N_2$$

Therefore,

$$V := V_{O_2} + V_{N_2} \quad \dots \text{mixture volume}$$

i.e. $V = 2.116 \quad \text{m}^3 \dots \text{Mixture vol} \dots \text{Ans.}$

Density:

$$\frac{m_{O_2} + m_{N_2}}{V} = 4.727 \quad \text{kg/m}^3 \dots \text{Ans.}$$

=====

Prob.9.8. A gaseous mixture consists of 1 kg of O₂ and 2 kg of N₂ at a pressure of 150 kPa and temp of 20 C. For the mixture, determine the following: (i) specific gas constant (ii) Avg. Mol. wt. (iii) sp. heats C_p and C_v (iv) change in entropy of the mixture if the mixture is heated at constant volume to a temp. of 100 C. Given: C_v of N₂ = 0.743 kJ/kg.K and C_v of O₂ = 0.65 kJ/kg.K. [VTU – July, 2004]

Mathcad Solution:

Data:

$$m_{O_2} := 1 \quad \text{kg} \quad M_{O_2} := 32$$

$$m_{N_2} := 2 \quad \text{kg} \quad M_{N_2} := 28$$

$$p := 150 \cdot 10^3 \text{ Pa} \quad R_u := 8314.4 \quad \text{J/kg.mole.K}$$

$$T_1 := 20 + 273 \text{ K} \quad T_2 := 100 + 273 \text{ K}$$

$$C_{vO_2} := 0.65 \text{ kJ/kg.K} \quad C_{vN_2} := 0.743 \text{ kJ/kg.K}$$

Calculations:

(i) Mole fractions:

$$n_{O_2} := \frac{m_{O_2}}{M_{O_2}} \quad \text{i.e.} \quad n_{O_2} = 0.031 \quad \dots \text{No. of moles of O}_2$$

$$n_{N_2} := \frac{m_{N_2}}{M_{N_2}} \quad \text{i.e.} \quad n_{N_2} = 0.071 \quad \dots \text{No. of moles of N}_2$$

$$n := n_{O_2} + n_{N_2} \quad \text{i.e.} \quad n = 0.103 \quad \text{..Total no. of moles}$$

$$y_{O_2} := \frac{n_{O_2}}{n} \quad \text{i.e.} \quad y_{O_2} = 0.304 \quad \text{....Mole fraction of O}_2\text{....Ans.}$$

$$y_{N_2} := \frac{n_{N_2}}{n} \quad \text{i.e.} \quad y_{N_2} = 0.696 \quad \text{....Mole fraction of N}_2\text{....Ans.}$$

(ii) Avg. Mol. wt.:

$$M_m := \frac{m_{O_2} + m_{N_2}}{n} \quad \text{i.e.} \quad M_m = 29.217 \quad \text{....Avg. Mol. wt. of mixture....Ans.}$$

(iii) Specific gas constant:

$$R_m := \frac{R_u}{M_m} \quad \text{i.e.} \quad R_m = 284.57 \quad \text{J/kg.K....Specific gas constant....Ans.}$$

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(iv) Sp. heats of mixture:

$$m_m := m_{O_2} + m_{N_2} \quad \text{i.e.} \quad m_m = 3 \quad \text{kg....mass of mixture}$$

$$C_{v_{mix}} := \frac{(m_{O_2} \cdot C_{v_{O_2}} + m_{N_2} \cdot C_{v_{N_2}})}{m_m} \quad \text{i.e.} \quad C_{v_{mix}} = 0.712 \quad \text{kJ/kg.K....Ans.}$$

$$C_{p_{O_2}} := C_{v_{O_2}} + \frac{R_u \cdot 10^{-3}}{M_{O_2}} \quad \text{i.e.} \quad C_{p_{O_2}} = 0.91 \quad \text{kJ/kg.K}$$

$$C_{p_{N_2}} := C_{v_{N_2}} + \frac{R_u \cdot 10^{-3}}{M_{N_2}} \quad \text{i.e.} \quad C_{p_{N_2}} = 1.04 \quad \text{kJ/kg.K}$$

$$C_{p_{mix}} := \frac{(m_{O_2} \cdot C_{p_{O_2}} + m_{N_2} \cdot C_{p_{N_2}})}{m_m} \quad \text{i.e.} \quad C_{p_{mix}} = 0.997 \quad \text{kJ/kg.K....Ans.}$$

(v) Change in entropy:

$$\Delta S := m_m \cdot \left(C_{v_{mix}} \cdot \ln \left(\frac{T_2}{T_1} \right) \right) \quad \text{....at const. volume}$$

$$\text{i.e.} \quad \Delta S = 0.516 \quad \text{kJ/K....Ans.}$$

=====

Prob.9.9. Pressure and temperature of a mixture of 1 kg of O₂ and 2 kg of N₂ are 150 kPa and 20 C respectively. If the mixture is heated at constant pressure to a temp. of 100 C, determine the following:
(i) change in enthalpy (ii) change in entropy (iii) change in int. energy.

Given: C_v of N₂ = 0.743 kJ/kg.K and C_v of O₂ = 0.65 kJ/kg.K. [VTU – Jan, 2005]

Mathcad Solution:

Data:

$$m_{O_2} := 1 \quad \text{kg} \quad M_{O_2} := 32$$

$$m_{N_2} := 2 \quad \text{kg} \quad M_{N_2} := 28$$

$$p := 150 \cdot 10^3 \text{ Pa} \quad R_u := 8314.4 \quad \text{J/kg.mole.K}$$

$$T_1 := 20 + 273 \text{ K} \quad T_2 := 100 + 273 \text{ K}$$

$$C_{vO_2} := 0.65 \text{ kJ/kg.K} \quad C_{vN_2} := 0.743 \text{ kJ/kg.K}$$

Calculations:

(i) Sp. heats of mixture:

$$m_m := m_{O_2} + m_{N_2} \quad \text{i.e.} \quad m_m = 3 \quad \text{kg....mass of mixture}$$

$$C_{v_{\text{mix}}} := \frac{(m_{O_2} \cdot C_{vO_2} + m_{N_2} \cdot C_{vN_2})}{m_m} \quad \text{i.e.} \quad C_{v_{\text{mix}}} = 0.712 \quad \text{kJ/kg.K....Ans.}$$

$$C_{pO_2} := C_{vO_2} + \frac{R_u \cdot 10^{-3}}{M_{O_2}} \quad \text{i.e.} \quad C_{pO_2} = 0.91 \quad \text{kJ/kg.K}$$

$$C_{pN_2} := C_{vN_2} + \frac{R_u \cdot 10^{-3}}{M_{N_2}} \quad \text{i.e.} \quad C_{pN_2} = 1.04 \quad \text{kJ/kg.K}$$

$$C_{p_{\text{mix}}} := \frac{(m_{O_2} \cdot C_{pO_2} + m_{N_2} \cdot C_{pN_2})}{m_m} \quad \text{i.e.} \quad C_{p_{\text{mix}}} = 0.997 \quad \text{kJ/kg.K....Ans.}$$

(ii) Change in enthalpy:

$$\Delta H := m_m \cdot C_{p_{\text{mix}}} \cdot (T_2 - T_1) \quad \text{i.e.} \quad \Delta H = 239.177 \quad \text{kJ....Ans.}$$

(iii) Change in entropy:

$$\Delta S := m_m \cdot \left(C_{p_{\text{mix}}} \cdot \ln \left(\frac{T_2}{T_1} \right) \right) \quad \text{.....at const. pressure}$$

i.e. $\Delta S = 0.722 \quad \text{kJ/K....Ans.}$

(iv) Change in internal energy:

$$\Delta U := m_m \cdot C_{v_{\text{mix}}} \cdot (T_2 - T_1)$$

i.e. $\Delta U = 170.88 \quad \text{kJ....Ans.}$

=====

Prob.9.10. Neon, with Mol. wt : $M=20.183$, and critical properties: $T_c = 44.5 \text{ K}$, $p_c = 2.73 \text{ MPa}$, $V_c = 0.0416 \text{ m}^3/\text{kg.mol}$. Reading from compressibility chart for a reduced pressure $p_r = 2$ and reduced temp $T_r = 1.3$, the compressibility factor is $Z=0.7$. Find corresponding sp. vol., pressure, temp and reduced

Data:

$$M := 20.183 \quad T_c := 44.5 \quad \text{K} \quad p_c := 2.73 \cdot 10^3 \quad \text{kPa} \quad v_c := 0.0416 \quad \text{m}^3/\text{kmol}$$

$$p_r := 2 \quad T_r := 1.3 \quad Z := 0.7 \quad R_u := 8314 \quad \text{J/kmol.K}$$

Calculations:

$$p := p_c \cdot p_r \quad \text{i.e.} \quad p = 5.46 \times 10^3 \quad \text{kPa....Ans.}$$

$$T := T_c \cdot T_r \quad \text{i.e.} \quad T = 57.85 \quad \text{K....Ans.}$$

Now, $Z = \frac{v_{\text{actual}}}{v_{\text{ideal}}}$ and,

$$v_{\text{ideal}} := \frac{\frac{R_u}{M} \cdot T}{p \cdot 10^3} \quad \text{i.e.} \quad v_{\text{ideal}} = 4.365 \times 10^{-3} \quad \text{m}^3/\text{kg}$$

and, $v_{\text{actual}} := Z \cdot v_{\text{ideal}}$ i.e. $v_{\text{actual}} = 3.055 \times 10^{-3}$ **m³/kg...Ans.**

Reduced volume:

$v_r = \frac{v_{\text{actual}}}{v_c}$ i.e. $v_r := \frac{v_{\text{actual}} \cdot M}{v_c}$..volumes in m³/kg.mol

i.e. $v_r = 1.482$ **...Ans.**

=====

Prob.9.11. Find increase in entropy when 2 kg of O₂ at 60 C mixes with 6 kg of N₂ at the same temp. The initial pressure of each constituent is 103 kPa and is the same as that of the mixture. [VTU – Jan. 2005]



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Mathcad Solution:

Data:

$$\begin{aligned} m_{O_2} &:= 2 \text{ kg} & M_{O_2} &:= 32 \\ m_{N_2} &:= 6 \text{ kg} & M_{N_2} &:= 28 \\ p &:= 103 \cdot 10^3 \text{ Pa} & R_u &:= 8314.4 \text{ J/kg.mole.K} \\ T_1 &:= 60 + 273 \text{ K} \end{aligned}$$

Calculations:

(i) Mole fractions:

$$n_{O_2} := \frac{m_{O_2}}{M_{O_2}} \quad \text{i.e.} \quad n_{O_2} = 0.063 \quad \dots \text{No. of moles of } O_2$$

$$n_{N_2} := \frac{m_{N_2}}{M_{N_2}} \quad \text{i.e.} \quad n_{N_2} = 0.214 \quad \dots \text{No. of moles of } N_2$$

$$n := n_{O_2} + n_{N_2} \quad \text{i.e.} \quad n = 0.277 \quad \dots \text{Total no. of moles}$$

$$y_{O_2} := \frac{n_{O_2}}{n} \quad \text{i.e.} \quad y_{O_2} = 0.226 \quad \dots \text{Mole fraction of } O_2 \dots \text{Ans.}$$

$$y_{N_2} := \frac{n_{N_2}}{n} \quad \text{i.e.} \quad y_{N_2} = 0.774 \quad \dots \text{Mole fraction of } N_2 \dots \text{Ans.}$$

(ii) Change in entropy:

$$\Delta S := R_u \cdot \left(n_{O_2} \cdot \ln \left(\frac{1}{y_{O_2}} \right) + n_{N_2} \cdot \ln \left(\frac{1}{y_{N_2}} \right) \right)$$

$$\text{i.e.} \quad \Delta S = 1.229 \times 10^3 \text{ J/kg.mole.K} \dots \text{Ans.}$$

=====

Prob.9.12. Determine the sp. vol. of H₂ gas at 100 K, when its pressure is 60 bar, (i) by using compressibility chart (ii) by Van der Waals eqn. Values of critical properties P_c and T_c for H₂ are given, and also the values of a and b in Van der Waals eqn. [VTU – Jan. 2004]

Mathcad Solution:

Data:

$$T_c := 273 - 239.76 \quad \text{K} \quad P_c := 12.92 \cdot 10^5 \quad \text{Pa} \quad R_u := 8314.4 \quad \text{J/kg.K}$$

$$m := 1 \quad \text{kg} \quad T := 100 \quad \text{K} \quad M := 2 \quad \text{Mol. wt of H}_2$$

$$p_{VW} := 60 \cdot 10^5 \quad \text{Pa}$$

$$p_{ideal} := 60 \cdot 10^5 \quad \text{Pa}$$

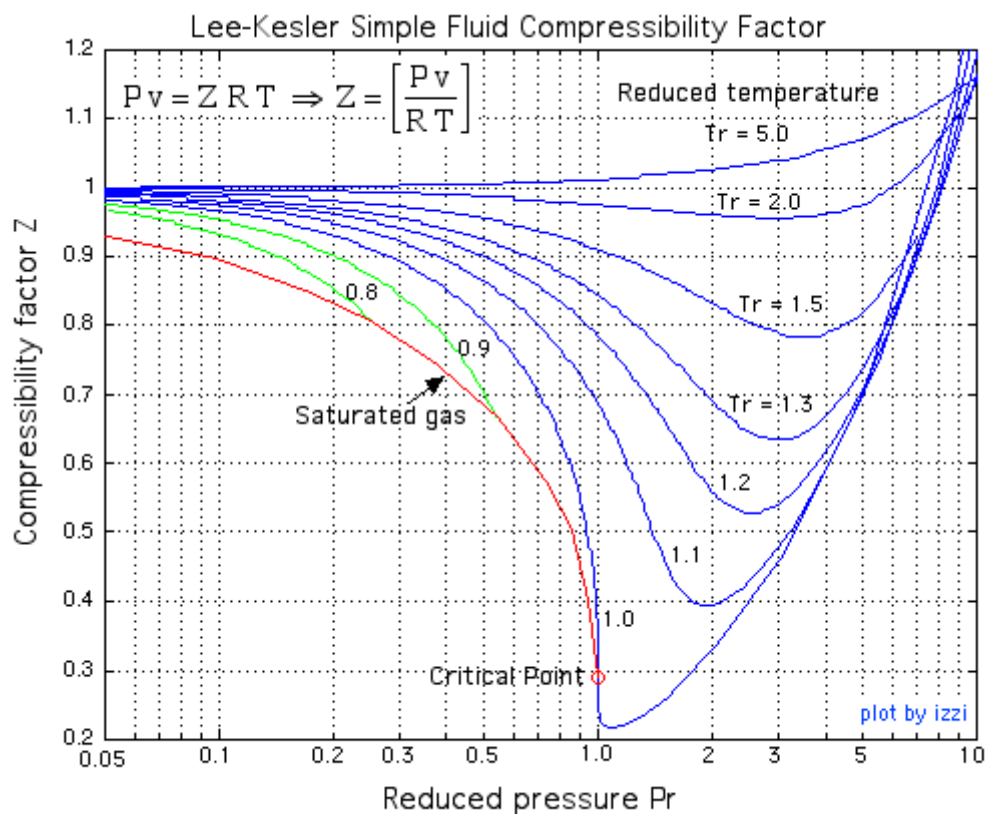
Calculations:

(i) By compressibility chart:

$$T_r := \frac{T}{T_c} \quad \text{i.e.} \quad T_r = 3.008$$

$$p_r := \frac{p_{VW}}{P_c} \quad \text{i.e.} \quad p_r = 4.644$$

Then, read Z from compressibility chart:





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We get: $Z := 0.99$

For Ideal gas: $Z = \frac{p \cdot v}{R \cdot T}$ Then, v can be calculated.

$$\text{Then: } v_{\text{ideal}} := \frac{Z \cdot \frac{R_u}{M} \cdot T}{p_{\text{ideal}}}$$

i.e. $v_{\text{ideal}} = 0.069 \text{ m}^3 \dots \text{sp.vol. according to Ideal gas Law ... Ans.}$

(ii) By Van der Waals eqn.:

For H₂: $a := 25105 \text{ Nm}^4/(\text{kg.mol})^2$

$b := 0.0262 \text{ m}^3/\text{kg.mol}$

$p_{\text{VW}} := 60 \cdot 10^5 \text{ Pa}$

Use the Solve block of Mathcad to find vbar:

$v_{\text{bar}} := 10$ guess value

Given

$$p_{\text{VW}} = \frac{R_u \cdot T}{v_{\text{bar}} - b} - \frac{a}{v_{\text{bar}}^2}$$

Find(v_{bar}) = 0.141

i.e. $v_{\text{bar}} := 0.141$

Now,

$$v_{\text{bar}} = \frac{V}{\left(\frac{m}{M}\right)}$$

Therefore, $V := v_{\text{bar}} \cdot \frac{m}{M}$

i.e. $V = 0.071 \text{ m}^3 \dots \text{sp. vol. according to Van der Waals eqn.....Ans.}$

=====

Prob.9.13. Determine the compressibility factor for Oxygen at (i) 100 bar and -75 C, and (ii) 5 bar and 35 C.

Mathcad Solution:

Data:

For O₂, we have the critical properties:

$$T_c := 154.88 \quad \text{K} \qquad P_c := 50.6 \quad \text{bar} \qquad R_u := 8314.4 \quad \text{J/kg.K}$$

Calculations:

Case 1: P = 100 bar, T = -75 C:

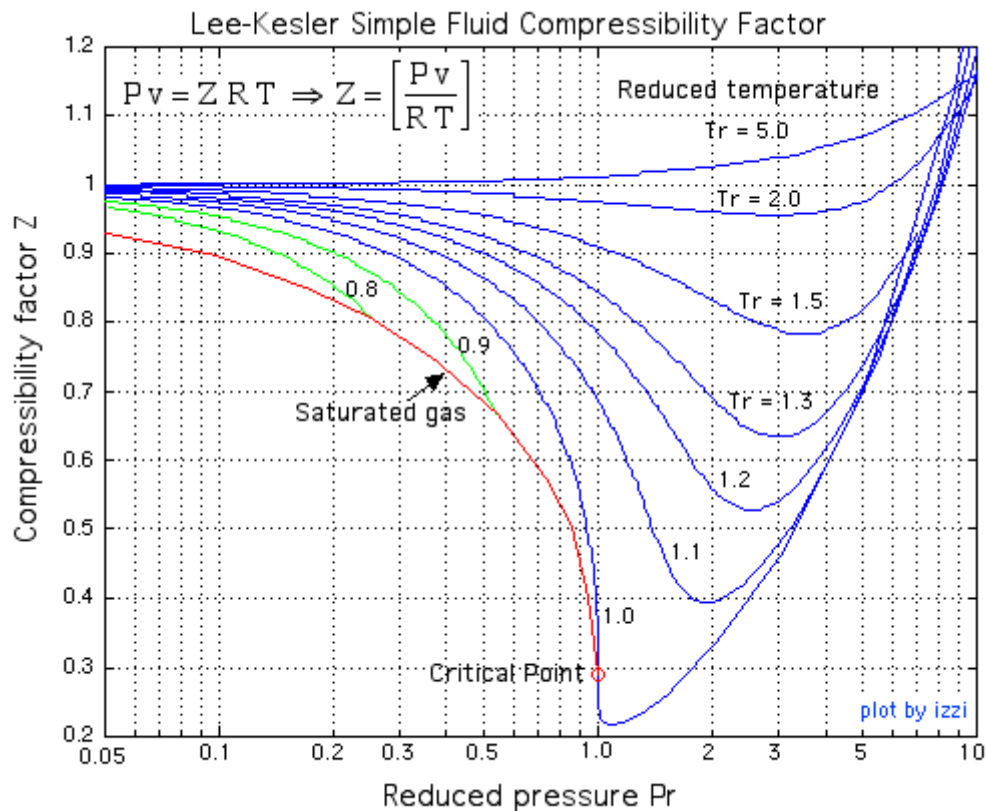
For this case, reduced pressure and reduced temp:

$$T := -75 + 273 \quad \text{K} \qquad P := 100 \quad \text{bar}$$

$$p_r := \frac{P}{P_c} \quad \text{i.e.} \quad p_r = 1.976$$

$$T_r := \frac{T}{T_c} \quad \text{i.e.} \quad T_r = 1.278$$

Now, from compressibility chart, read the value of Z, the compressibility factor:



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We get: $Z = 0.7$...compressibility factor ... Ans.

Case 2: $P = 5 \text{ bar}$, $T = 35 \text{ C}$

For this case, reduced pressure and reduced temp:

For this case, reduced pressure and reduced temp:

$$T := 35 + 273 \quad \text{K} \quad P := 5 \quad \text{bar}$$

$$p_r := \frac{P}{P_c} \quad \text{i.e.} \quad p_r = 0.099$$

$$T_r := \frac{T}{T_c} \quad \text{i.e.} \quad T_r = 1.989$$

Now, from compressibility chart, read the value of Z , the compressibility factor:

We get: $Z = 1$..approx. ...compressibility factor ... Ans.

i.e. at low pressures and high temps, real gas eqn approaches ideal gas eqn.

=====

Prob.9.14. One kg.mol of CO_2 undergoes a reversible, non-flow isothermal compression from $0.2 \text{ m}^3/\text{kg}$ to $0.05 \text{ m}^3/\text{kg}$, and the initial temp is 40 C . If the gas obeys Van der Waals eqn, determine the work done and the final pressure.

Mathcad Solution:

Data:

Critical properties for CO_2 :

$$T_c := 304.2 \quad \text{K} \quad P_c := 73.8 \cdot 10^5 \quad \text{Pa} \quad R_u := 8314.4 \quad \text{J/kg.mol.K}$$

$$T := 40 + 273 \quad \text{K} \quad M := 44 \quad \text{...Mol. wt. of CO}_2$$

sp. volumes:

$$v_1 := 0.2 \cdot M \quad \text{i.e.} \quad v_1 = 8.8 \quad \text{m}^3/\text{kg.mol}$$

$$v_2 := 0.05 \cdot M \quad \text{i.e.} \quad v_2 = 2.2 \quad \text{m}^3/\text{kg.mol}$$

Van der Waals constants for CO₂:

$$a := 364700 \quad \text{Pa} \cdot (\text{m}^3/\text{kmol})^2$$

$$b := 0.0428 \quad \text{m}^3/\text{kmol}$$

Van der Waals eqn:

$$\left(p + \frac{a}{v^2} \right) \cdot (v - b) = R_u \cdot T$$

$$\text{i.e.} \quad p(v) := \frac{R_u \cdot T}{v - b} - \frac{a}{v^2} \quad \dots \text{define pressure as a function of sp. volume, } v.$$

(i) Therefore, Work done, W:

$$W := \int_{v_1}^{v_2} p(v) \, dv$$

$$\text{i.e.} \quad W = -3.522 \times 10^6 \quad \text{J/kg.mol Ans.}$$

Note: the negative sign indicates that work is done on the CO₂.

Note also the ease with which this integration is done in Mathcad.

(ii) Final pressure, P₂:

$$P_2 := p(v_2) \quad \dots \text{using the function for pressure, written above}$$

$$\text{i.e.} \quad P_2 = 1.131 \times 10^6 \quad \text{Pa = 11.31 bar Ans.}$$

=====

9.12 Problems solved with EES:

“Prob. 9.15. An ideal gas cycle consisting of 3 processes uses Argon ($M = 40$) as working substance. Process 1-2 is a reversible adiabatic process from 0.014 m^3 , 700 kPa and 280 C to 0.056 m^3 . Process 2-3 is a reversible isothermal process. Process 3-1 is an isobaric process. Sketch the cycle on P-v and T-s diagrams, and find: (i) the work transfer in process 1-2, (ii) work transfer in process 2-3, (iii) net work output from the cycle (assume $\gamma = 1.67$), and (iv) change in enthalpy for each process. [VTU – July 2004]:”

EES Solution:

“Data:”

$M = 40$ “... Mol. wt. of Argon”

$R_u = 8.314$ “kJ/kg.mol -K”

$R = R_u / M$ “kJ/kg.K Gas const. for Argon”

$V_1 = 0.014 \text{ m}^3$ ”

$P_1 = 700$ “kPa”

$T_1 = 280 + 273$ “K”

$V_2 = 0.056 \text{ m}^3$ ”

$T_2 = T_3$ “...Process 2-3 is Isothermal”

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$Q_{12} = 0$ "...Process 1-2 is adiabatic"

$P_3 = P_1$ "Process 3-1 is isobaric"

$\gamma = 1.67$

"Calculations:"

$c_p / c_v = \gamma$ "...by definition $\gamma = c_p / c_v$ "

$c_p - c_v = R$ "Gas constant"

$m_{Ar} = (P_1 \cdot V_1) / (R \cdot T_1)$ "kg ... mass of Argon"

"Process 1-2:"

$P_1 \cdot V_1^\gamma = P_2 \cdot V_2^\gamma$ "...finds P_2 "

$P_1 \cdot V_1 / T_1 = P_2 \cdot V_2 / T_2$ "...finds T_2 "

$W_{12} = (P_1 \cdot V_1 - P_2 \cdot V_2) / (\gamma - 1)$ "kJ"

$Q_{12} = dU_{12} + W_{12}$ "...finds dU_{12} , change in int. energy during Process 1-2"

"Process 2-3"

$W_{23} = m_{Ar} \cdot R \cdot T_2 \cdot \ln(V_3 / V_2)$ "kJ"

$dU_{23} = 0$ "...since Isothermal"

$Q_{23} = W_{23} + dU_{23}$ "kJ"

$P_2 \cdot V_2 = P_3 \cdot V_3$ "...finds V_3 "

"Process 3-1:"

$W_{31} = P_3 \cdot (V_1 - V_3)$ "kJ ... work in process 3-1"

$Q_{31} = dU_{31} + W_{31}$ "kJ heat transfer in process 3-1"

$dU_{31} = m_{Ar} \cdot c_v \cdot (T_1 - T_3)$ "kJ...change in int. energy during 3-1"

$W_{net} = W_{12} + W_{23} + W_{31}$ "kJ.... net work output"

"Check:"

$Q_{net} = Q_{12} + Q_{23} + Q_{31}$ "...for a closed cycle 1-2-3, this should be equal to W_{net} "

"Changes in enthalpy for each process:"

$dH_{12} = m_{Ar} \cdot c_p \cdot (T_2 - T_1)$ "kJ"

$dH_{23} = 0$ "kJ since $T_2 = T_3$ "

$dH_{31} = m_{Ar} \cdot c_p \cdot (T_1 - T_3)$ "kJ"

Results:

Unit Settings: SI C kPa kJ mass deg

$$c_p = 0.5181 \text{ [kJ/kg-K]}$$

$$c_v = 0.3102 \text{ [kJ/kg-K]}$$

$$dH_{12} = -14.78 \text{ [kJ]}$$

$$dH_{23} = 0 \text{ [kJ]}$$

$$dH_{31} = 14.78 \text{ [kJ]}$$

$$dU_{12} = -8.849 \text{ [kJ]}$$

$$dU_{23} = 0 \text{ [kJ]}$$

$$dU_{31} = 8.849 \text{ [kJ]}$$

$$\gamma = 1.67 \text{ [-]}$$

$$M = 40 \text{ [kg/kg-mole]}$$

$$m_{Ar} = 0.08526 \text{ [kg]}$$

$$P_1 = 700 \text{ [kPa]}$$

$$P_2 = 69.13 \text{ [kPa]}$$

$$P_3 = 700 \text{ [kPa]}$$

$$Q_{12} = 0 \text{ [kJ]}$$

$$Q_{23} = -8.962 \text{ [kJ]}$$

$$Q_{31} = 14.78 \text{ [kJ]}$$

$$Q_{net} = 5.815 \text{ [kJ]}$$

$$R = 0.2079$$

$$R_u = 8.314 \text{ [kJ/kg-mole-K]}$$

$$T_1 = 553 \text{ [K]}$$

$$T_2 = 218.4 \text{ [K]}$$

$$T_3 = 218.4 \text{ [K]}$$

$$V_1 = 0.014 \text{ [m}^3\text{]}$$

$$V_2 = 0.056 \text{ [m}^3\text{]}$$

$$V_3 = 0.00553 \text{ [m}^3\text{]}$$

$$W_{12} = 8.849 \text{ [kJ]}$$

$$W_{23} = -8.962 \text{ [kJ]}$$

$$W_{31} = 5.929 \text{ [kJ]}$$

$$W_{net} = 5.815 \text{ [kJ]}$$

Thus:

Work transfer in process 1-2 = $W_{12} = 8.849 \text{ kJ}$... Ans.

Work transfer in process 2-3 = $W_{23} = -8.962 \text{ kJ}$... negative sign showing that work is done *on* the gas ...Ans.

Net work output from the cycle = $W_{net} = 5.815 \text{ kJ}$ Ans.

Check: $W_{net} = Q_{net} = 5.815 \text{ kJ}$ O.K.

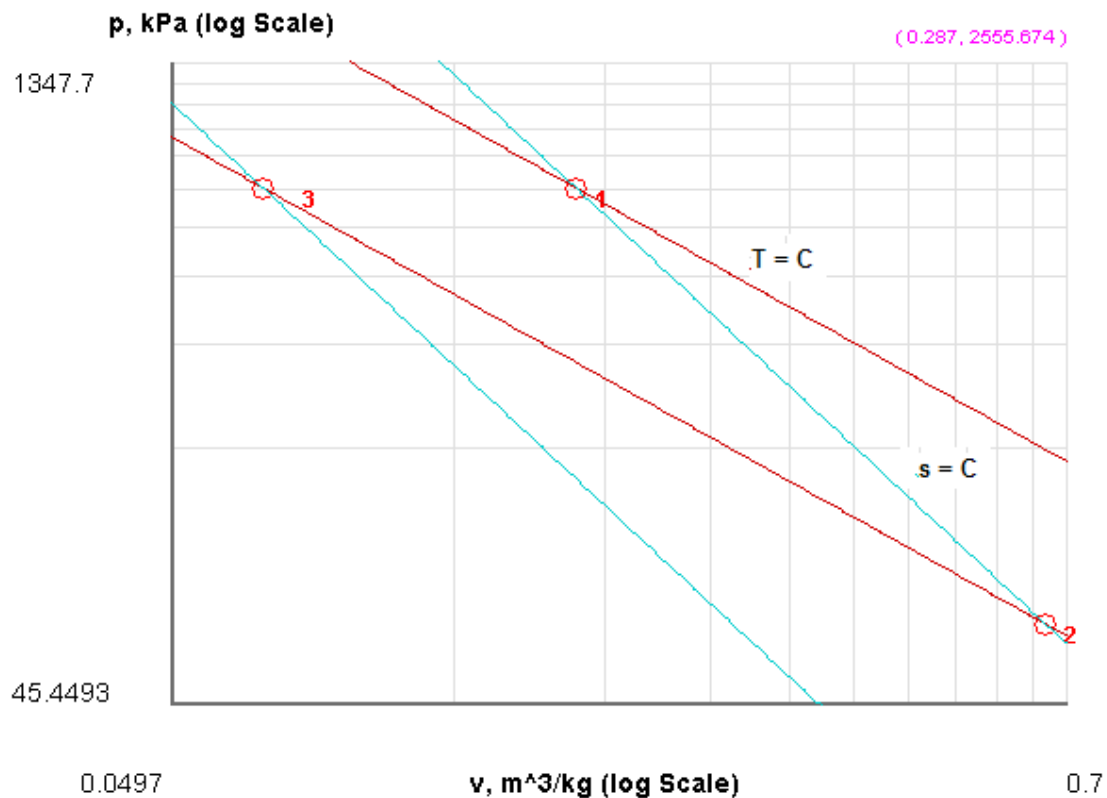
Changes in enthalpy:

Process 1-2: $dH_{12} = -14.78 \text{ kJ}$... Ans.

Process 2-3: $dH_{23} = 0 \text{ kJ}$... Ans.

Process 3-1: $dH_{31} = 14.78 \text{ kJ}$... Ans.

Plot the cycle on P-v and T-s diagrams (from TEST):



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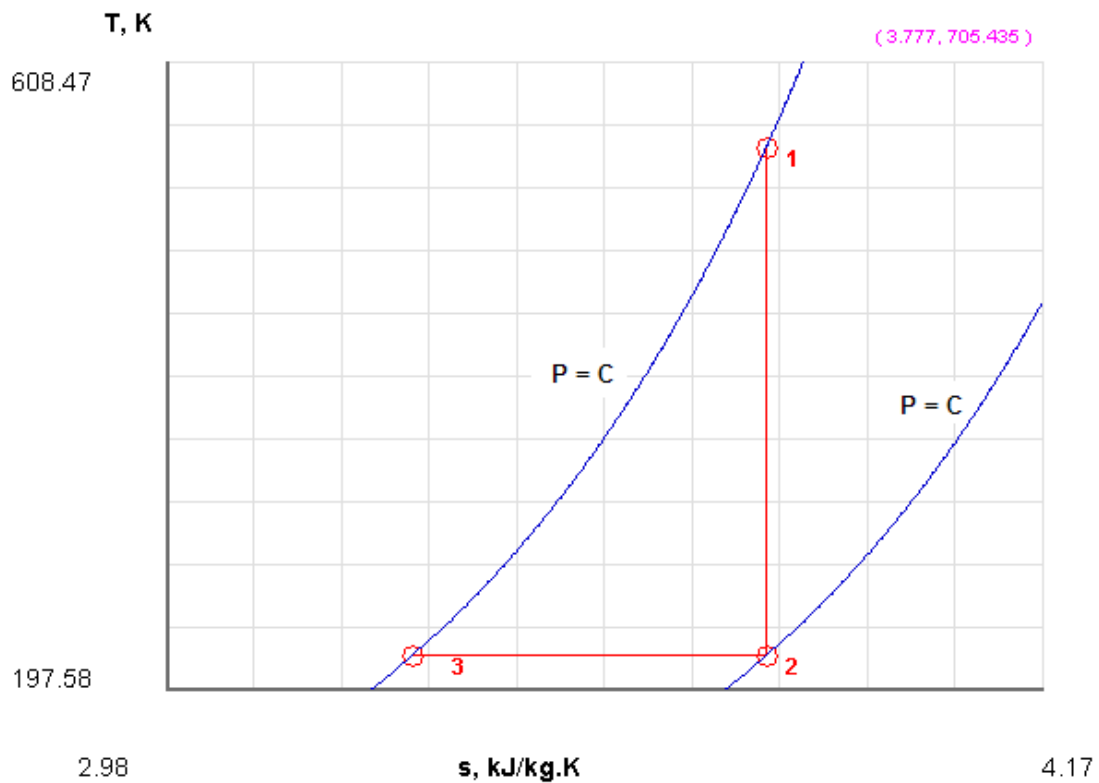
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“Prob.9.16. Determine the pressure exerted by CO₂ in a container of 1.5 m³ capacity when it contains 4 kg at 30 °C (i) using Ideal gas eqn. (ii) using Van der Waal’s eqn, and (iii) using Beattie-Bridgeman eqn.”

EES Solution:

Following are the three Equations of State:

Ideal Gas eqn:

$$p_{\text{ideal}} = \text{mass} \cdot R \cdot \frac{T}{V} \quad \text{Pa}$$

Van der Waal’s eqn:

$$p_{\text{vw}} = \frac{R_u \cdot T}{\bar{v} - b} - \frac{a}{\bar{v}^2} \quad \text{Pa}$$

Beattie Bridgeman eqn:

$$p_{\text{BB}} = \frac{R_u \cdot T \cdot (1 - \varepsilon)}{\bar{v}^2} \cdot (\bar{v} + \text{BBB}) - \frac{\text{AAA}}{\bar{v}^2} \quad \text{Pa}$$

Constants in the above three eqns. are given below:

“Data:”

$$R_u = 8314.4 \text{ “J/kg.mol.K”}$$

$$M = 44 \text{ “Mol. wt.”}$$

$$V = 1.5 \text{ “m}^3\text{”}$$

$$\text{mass} = 4.0 \text{ “kg”}$$

$$T = 303 \text{ “K”}$$

$$a = 3.647\text{E}05 \text{ “Nm}^4/\text{kgmol}^2\text{....const. in Van der Waal's eqn.”}$$

$$b = 0.0428 \text{ “m}^3/\text{kgmol}^2\text{....const. in Van der Waal's eqn.”}$$

$$\epsilon = cc / (v_{\text{bar}} * T^3) \text{ “..factor in Beattie Bridgeman eqn.”}$$

$$AAA = A_0 * (1 - aa / v_{\text{bar}}) \text{ “..factor A in Beattie Bridgeman eqn.”}$$

$$BBB = B_0 * (1 - bb / v_{\text{bar}}) \text{ “..factor B. in Beattie Bridgeman eqn.”}$$

$$A_0 = 507.2836 \text{ “..const. in Beattie Bridgeman eqn.”}$$

$$aa = 0.07132 \text{ “..const. in Beattie Bridgeman eqn.”}$$

$$B_0 = 0.10476 \text{ “..const. in Beattie Bridgeman eqn.”}$$

$$bb = 0.07235 \text{ “..const. in Beattie Bridgeman eqn.”}$$

$$cc = 66\text{E}04 \text{ “..const. in Beattie Bridgeman eqn.”}$$

“-----”

“(i) Ideal gas eqn.:”

$$R = R_u / M \text{ “...specific gas constant”}$$

$$p_{\text{ideal}} = \text{mass} * R * T / V \text{ “Pa”}$$

“(ii) Van der Waal’s eqn.:”

$$v_{\text{bar}} = V / (\text{mass}/M) \text{ “m}^3/\text{kgmole} \dots \text{molar volume”}$$


$$p_{\text{VW}} = ((R_u * T) / (v_{\text{bar}} - b)) - (a / v_{\text{bar}}^2) \text{ “Pa”}$$

“(iii) Beattie Bridgeman eqn.:”

$$p_{\text{BB}} = ((R_u * T * (1 - \epsilon)) / (v_{\text{bar}})^2) * (v_{\text{bar}} + \text{BBB}) - \text{AAA} / (v_{\text{bar}})^2 \text{ “Pa”}$$



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Results:

Unit Settings: SI C kPa kJ mass deg

$a = 364700 \text{ [Nm}^4\text{/kg-mol}^2\text{]}$	$aa = 0.07132$
$AAA = 505.1$	$A_0 = 507.3$
$b = 0.0428 \text{ [m}^3\text{/kgmol]}$	$bb = 0.07235$
$BBB = 0.1043$	$B_0 = 0.1048$
$cc = 660000$	$\epsilon = 0.001438$
$M = 44$	$mass = 4 \text{ [kg]}$
$p_{BB} = 153425 \text{ [Pa]}$	$p_{ideal} = 152683 \text{ [Pa]}$
$p_{VW} = 151740 \text{ [Pa]}$	$R = 189 \text{ [J/kg-K]}$
$R_u = 8314 \text{ [J/kg-mol-K]}$	$T = 303 \text{ [K]}$
$V = 1.5 \text{ [m}^3\text{]}$	$\bar{V} = 16.5 \text{ [m}^3\text{/kg-mol]}$

Thus:

Pressure as per Ideal Gas eqn. = $p_{ideal} = 152683 \text{ Pa}$ Ans.

Pressure as per Van der Waals eqn. = $p_{VW} = 151740 \text{ Pa}$ Ans.

Pressure as per Beattie Bridgeman eqn. = $p_{BB} = 153425 \text{ Pa}$ Ans.

=====

“Prob.9.17. A cylinder 0.01 m^3 volume is filled with 0.727 kg of n-octane (C_8H_{18}) at 427.85 K . Assuming that n-octane obeys the Van der Waals eqn of state, calculate the pressure of the gas in the cylinder. Take constants a and b as $3.789 \text{ Pa (m}^3\text{/mol)}^2$ and $2.37 \text{ E-04 m}^3\text{/mol}$ respectively. [VTU – Dec. 2008–Jan. 2009]”

EES Solution:

“Data:”

$R_u = 8314.4 \text{ “J/kg.mol.K”}$

$M = 114.232 \text{ “Mol. wt.”}$

$V = 0.01 \text{ “m}^3\text{”}$

$mass = 0.727 \text{ “kg.”}$

$$T = 427.85 \text{ "K"}$$

$$a = 3.789\text{E}05 \text{ "Nm}^4/\text{kgmol}^2\text{....const. in Van der Waal's eqn."}$$

$$b = 2.37\text{E}-04 \text{ "m}^3/\text{kgmol}^2\text{....const. in Van der Waal's eqn."}$$

"Initial pressure:"

$$v1_bar = V1 / (\text{mass}/M) \text{ "m}^3/\text{kgmole}^2\text{....molar volume"}$$

$$p1_VW = ((R_u * T) / (v1_bar - b)) - (a / v1_bar^2) \text{ "Pa"}$$

"Final pressure:"

$$V2 = 0.005 \text{ "m}^3\text{"}$$

$$v2_bar = V2 / (\text{mass}/M) \text{ "m}^3/\text{kgmole}^2\text{....molar volume"}$$

$$p2_VW = ((R_u * T) / (v2_bar - b)) - (a / v2_bar^2) \text{ "Pa final pressure"}$$

"Change in entropy: ... at constant T:"

$$dS = - \text{mass} * R * \ln (p2_VW / p1_VW) \text{ "J/K"}$$

Results:

Unit Settings: SI C kPa kJ mass deg

$$a = 378900 \text{ [Nm}^4/\text{kg-mol}^2]$$

$$b = 0.000237 \text{ [m}^3/\text{kgmol}]$$

$$dS = -32.69 \text{ [J/K]}$$

$$M = 114.2$$

$$\text{mass} = 0.727 \text{ [kg]}$$

$$p1_{VW} = 2.111\text{E}+06 \text{ [Pa]}$$

$$p2_{VW} = 3.915\text{E}+06 \text{ [Pa]}$$

$$R = 72.79 \text{ [J/kg-K]}$$

$$R_u = 8314 \text{ [J/kg-mol-K]}$$

$$T = 427.9 \text{ [K]}$$

$$V1 = 0.01 \text{ [m}^3]$$

$$\bar{v}1 = 1.571 \text{ [m}^3/\text{kg-mol}]$$

$$V2 = 0.005 \text{ [m}^3]$$

$$\bar{v}2 = 0.7856 \text{ [m}^3/\text{kg-mol}]$$

Thus:

$$\text{Final pressure} = p2_VW = 3.915\text{E}06 \text{ Pa} = 39.15 \text{ bar ... Ans.}$$

$$\text{Change in entropy} - dS = -32.69 \text{ J/K ...entropy decreases in compression... Ans.}$$

=====

“Prob.9.19. If the temp of the gas in Prob.9.17 changes to 700 K, volume remaining constant at 0.01 m³, find out the final pressure, and changes in enthalpy and entropy.

Given: sp. heat at constant pressure for n-octane is given by:

$$c_p = C_0 + C_1 \cdot \theta + C_2 \cdot \theta^2 + C_3 \cdot \theta^3, \text{ kJ/kg.K where}$$

$\theta = T(\text{Kelvin})/1000$. Values of C_0 , C_1 , C_2 and C_3 are given below. (Ref:2)”

EES Solution:

“Data:”

$$R_u = 8314.4 \text{ “J/kg.mol.K”}$$

$$M = 114.232 \text{ “Mol. wt.”}$$

$$R = R_u / M \text{ “J/kg.K..Gas const. for n-octane”}$$

$$V1 = 0.01 \text{ “m3 ... initial volume”}$$



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$$\text{mass} = 0.727 \text{ "kg."}$$

$$T_1 = 427.85 \text{ "K"}$$

$$T_2 = 700 \text{ "K"}$$

$$a = 3.789\text{E}05 \text{ "Nm}^4/\text{kgmol}^2\text{....const. in Van der Waal's eqn."}$$

$$b = 2.37\text{E-}04 \text{ "m}^3/\text{kgmol}^2\text{....const. in Van der Waal's eqn."}$$

"To find cp of n-octane:"

$$C_0 = -0.053$$

$$C_1 = 6.75$$

$$C_2 = -3.67$$

$$C_3 = 0.775$$

$$T_{\text{avg}} = (T_1 + T_2)/2 \text{ "...find the average temp."}$$

$$\theta = T_{\text{avg}}/1000 \text{ "...at an average temp"}$$

$$c_p = C_0 + C_1 * \theta + C_2 * \theta^2 + C_3 * \theta^3 \text{ "kJ/kg.K ... sp. heat at const. pressure"}$$

$$c_p * 10^3 - c_v = R \text{ "... finds cv in J/kg.K"}$$

"Initial pressure:"

$$v_{1,\text{bar}} = V_1 / (\text{mass}/M) \text{ "m}^3/\text{kgmole}^2\text{....molar volume"}$$

$$p_{1,\text{VW}} = ((R_u * T_1) / (v_{1,\text{bar}} - b)) - (a / v_{1,\text{bar}}^2) \text{ "Pa"}$$

"Final pressure:"

$$p_{2,\text{VW}} = ((R_u * T_2) / (v_{1,\text{bar}} - b)) - (a / v_{1,\text{bar}}^2) \text{ "Pa final pressure"}$$

"Change in internal energy:"

$$dU = \text{mass} * c_v * (T_2 - T_1) \text{ "J"}$$

“Change in enthalpy:”

$$dH = \text{mass} * c_p * (T_2 - T_1) \text{ “J”}$$

“Change in entropy: ... at constant volume:”

$$dS = \text{mass} * c_v * \ln (T_2/T_1) \text{ “J/K”}$$

Results:

Unit Settings: SI C kPa kJ mass deg

$$a = 378900 \text{ [Nm}^4\text{/kg-mol}^2\text{]} \quad b = 0.000237 \text{ [m}^3\text{/kgmol]}$$

$$c_v = 2653 \text{ [J/kg-K]}$$

$$C_2 = -3.67$$

$$dS = 949.4 \text{ [J/K]}$$

$$\text{mass} = 0.727 \text{ [kg]}$$

$$R = 72.79 \text{ [J/kg-K]}$$

$$T_2 = 700 \text{ [K]}$$

$$V_1 = 0.01 \text{ [m}^3\text{]}$$

$$C_0 = -0.053$$

$$C_3 = 0.775$$

$$dU = 524823 \text{ [J]}$$

$$p_{1VW} = 2.111E+06 \text{ [Pa]}$$

$$R_u = 8314 \text{ [J/kg-mol-K]}$$

$$\theta = 0.5639$$

$$\bar{V} = 1.571 \text{ [m}^3\text{/kg-mol]}$$

$$c_p = 2.725 \text{ [kJ/kg-K]}$$

$$C_1 = 6.75$$

$$dH = 539.2 \text{ [J]}$$

$$M = 114.2$$

$$p_{2VW} = 3.551E+06 \text{ [Pa]}$$

$$T_1 = 427.9 \text{ [K]}$$

$$T_{\text{avg}} = 563.9 \text{ [K]}$$

Thus:

Final pressure = $p_{2VW} = 3.551E06 \text{ Pa} = 35.51 \text{ bar} \dots \text{Ans.}$

$c_p = 2.725 \text{ kJ/kg.K} \dots \text{sp. heat at const. pressure.}$

$c_v = 2.653 \text{ kJ/kg.K} \dots \text{sp. heat at const. vol.}$

Change in internal energy = $dU = 524.823 \text{ kJ} \dots \text{Ans.}$

Change in enthalpy = $dH = 539.2 \text{ J} \dots \text{Ans.}$

Change in entropy = $dS = 949.4 \text{ J/K} \dots \text{Ans.}$

=====

“Prob.9.20. A vessel of capacity 3 m^3 contains 1 kgmole of N_2 at 90 C .

Calculate: (i) the pressure and sp. volume of the gas (ii) If the ratio of sp. heats is 1.4, obtain c_p and c_v (iii) Subsequently, the gas cools to atm. temp of 20 C ; evaluate the final pressure of gas (iv) Evaluate the increase in sp. internal energy, the increase in sp. enthalpy, increase in sp. entropy and heat transfer. [VTU – Dec. 2009–Jan. 2010].”

EES Solution:

“Data:”

$M = 28$ “... Mol. wt. of N2”

$R_u = 8314$ “J/kg.mol -K”

$R = R_u / M$ “J/kg.K Gas const. for N2”

$V1 = 3$ “m^3”

$T1 = 90 + 273$ “K”

$T2 = 20 + 273$ “K”

$\gamma = 1.4$ “...ratio of sp. heats”

$\text{mass_N2} = 28$ “kg..mass of N2..since one kmol = M kg”

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“Calculations:”

$c_p / c_v = \gamma$ “...by definition $\gamma = c_p / c_v$ ”

$c_p - c_v = R$ “...finds c_p and c_v ”

$\text{mass}_{\text{N}_2} = (P_1 \cdot V_1) / (R \cdot T_1)$ “finds Pressure P_1 of N_2 , in Pa”

“Therefore: sp. vol. of N_2 ”

$v_{\text{N}_2} = V_1 / \text{mass}_{\text{N}_2}$ “ m^3/kg ... sp. vol. of N_2 ”

“Pressure of gas when temp is T_2 (=20 C):”

$P_1 / T_1 = P_2 / T_2$ “by Ideal gas Law at const. vol....finds P_2 ”

“Increase in specific internal energy: i.e. for 1 kg”

$du = c_v \cdot (T_2 - T_1)$ “J”

“Increase in sp. enthalpy:”

$dh = c_p \cdot (T_2 - T_1)$ “J”

“Increase in sp. entropy: ... at const. vol.”

$ds = c_v \cdot \ln (T_2/T_1)$ “J/K”

“Heat transfer:”

$Q = dU + W$ “. J/kg ...by I Law”

$W = 0$ “...since it is a const. vol. process”

Results:

Unit Settings: SI C kPa kJ mass deg

$$c_p = 1039 \text{ [J/kg-K]}$$

$$ds = -159 \text{ [J/kg-K]}$$

$$M = 28 \text{ [kg/kg-mole]}$$

$$P_2 = 812001 \text{ [Pa]}$$

$$R_u = 8314 \text{ [kJ/kg-mole-K]}$$

$$V_1 = 3 \text{ [m}^3\text{]}$$

$$c_v = 742.3 \text{ [J/kg-K]}$$

$$du = -51962 \text{ [J/kg]}$$

$$\text{mass}_{N_2} = 28 \text{ [kg]}$$

$$Q = -51962 \text{ [J/kg]}$$

$$T_1 = 363 \text{ [K]}$$

$$v_{N_2} = 0.1071 \text{ [m}^3\text{/kg]}$$

$$dh = -72747 \text{ [J/kg]}$$

$$\gamma = 1.4 \text{ [-]}$$

$$P_1 = 1.006E+06 \text{ [Pa]}$$

$$R = 296.9 \text{ [J/kg-K]}$$

$$T_2 = 293 \text{ [K]}$$

$$W = 0 \text{ [J]}$$

Thus:

Pressure of gas = $P_1 = 10.06 \text{ bar}$, sp. vol. = $v_{N_2} = 0.1071 \text{ m}^3\text{/kg}$ Ans.

$c_p = 1039 \text{ J/kg.K}$ and $c_v = 742.3 \text{ J/kg.K}$ Ans.

Pressure of gas when temp is 20°C = $P_2 = 8.12 \text{ bar}$... Ans.

Change in sp. int. energy = $du = -51962 \text{ J/kg}$... decrease since -ve,.... Ans.

Change in sp. enthalpy = $dh = -72747 \text{ J/kg}$... decrease since -ve,.... Ans.

Change in sp. entropy = $ds = -159 \text{ J/kg.K}$... decrease since -ve,.... Ans.

Heat transfer = $Q = du = -51962 \text{ J/kg}$... decrease since -ve,.... Ans.

=====

“Prob. 9.21. Find the gas constant and apparent molar mass of a mixture of 2 kg O₂ and 3 kg of N₂, given that universal gas constant is 8314.3 J/kgmol.K, molar masses of O₂ and N₂ are respectively 32 and 28. [VTU – July 2006].”

EES Solution:

“Data:”

$$M_{N_2} = 28 \text{ “... Mol. wt. of N}_2\text{”}$$

$$M_{O_2} = 32 \text{ “... Mol. wt. of O}_2\text{”}$$

$$\text{mass}_{N_2} = 3 \text{ “kg...mass of N}_2\text{”}$$

$$\text{mass_O2} = 2 \text{ "kg ... mass of O2"}$$

$$R_u = 8314.3 \text{ "J/kg.mol -K"}$$

“Calculations:”

$$\text{mass_mix} = \text{mass_N2} + \text{mass_O2}$$

$$n_{\text{N2}} = \text{mass_N2} / M_{\text{N2}} \text{ "...no. of moles of N2"}$$

$$n_{\text{O2}} = \text{mass_O2} / M_{\text{O2}} \text{ "...no. of moles of O2"}$$

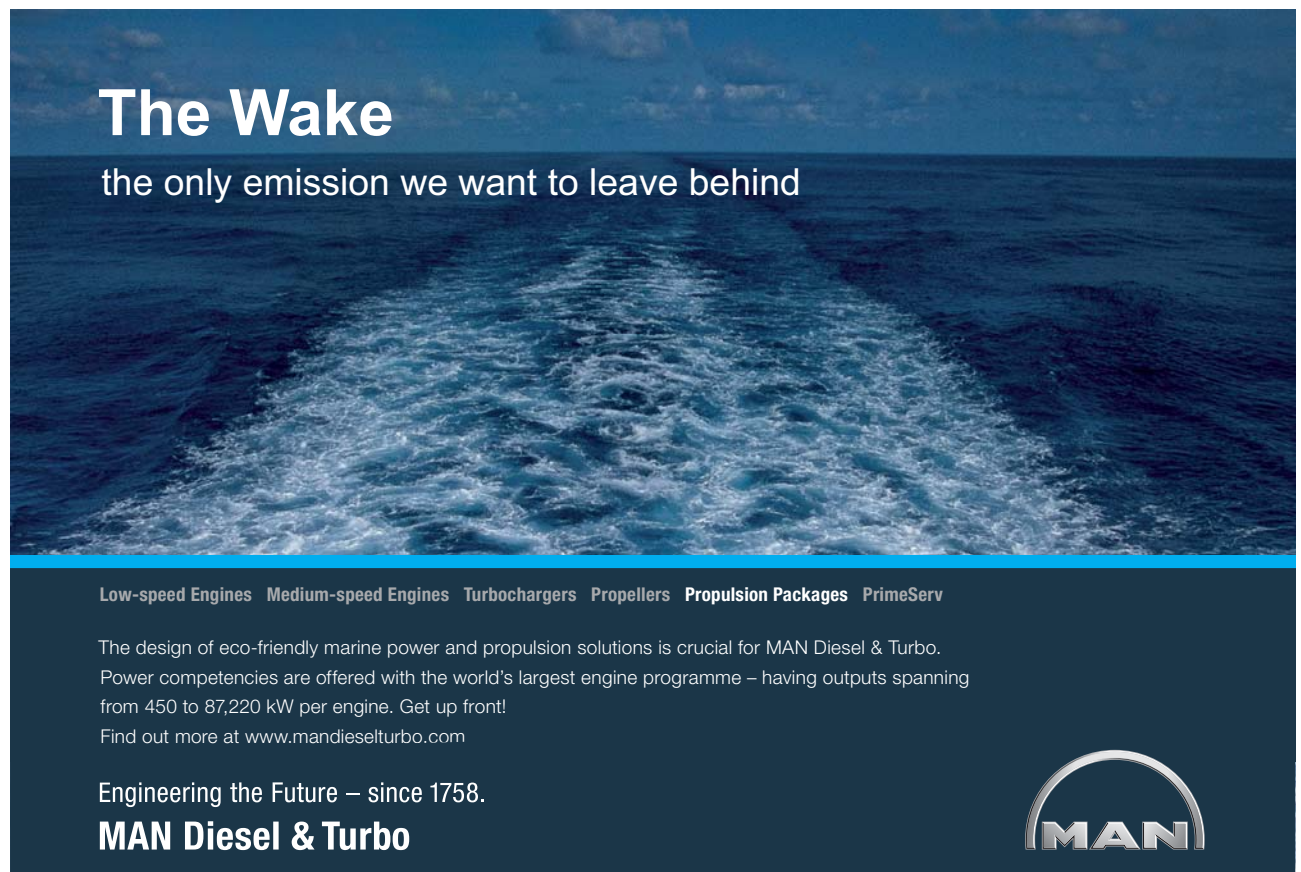
$$n_{\text{tot}} = n_{\text{N2}} + n_{\text{O2}} \text{ "...total no. of moles in mixture"}$$

“Avg. Mol. wt.”

$$M_{\text{mix}} = \text{mass_mix} / n_{\text{tot}}$$

“Sp. gas const. of mixture:”

$$R_{\text{mix}} = R_u / M_{\text{mix}} \text{ "J/kg.K .."}$$




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Results:

Unit Settings: SI C kPa kJ mass deg

$$\text{mass}_{\text{mix}} = 5 \text{ [kg]}$$

$$M_{\text{mix}} = 29.47$$

$$n_{\text{N}_2} = 0.1071$$

$$R_{\text{mix}} = 282.1 \text{ [J/kg-K]}$$

$$\text{mass}_{\text{N}_2} = 3 \text{ [kg]}$$

$$M_{\text{N}_2} = 28$$

$$n_{\text{O}_2} = 0.0625$$

$$R_u = 8314 \text{ [kJ/kg-mole-K]}$$

$$\text{mass}_{\text{O}_2} = 2 \text{ [kg]}$$

$$M_{\text{O}_2} = 32$$

$$n_{\text{tot}} = 0.1696$$

Thus:

Mol. wt. of mixture = $M_{\text{mix}} = 29.47$ Ans.

Gas const. of mixture = $R_{\text{mix}} = 282.1 \text{ J/kg.K}$ Ans.

=====

“Prob. 9.22. A gaseous mixture consists of 1 kg of Oxygen and 2 kg of Nitrogen initially at a pressure of 150 kPa and temp of 20 C. It is heated at constant pressure until its temp reaches 100 C. Determine: (i) change in enthalpy, (ii) change in entropy and (iii) change in internal energy. Given: C_p of $\text{N}_2 = 1.04 \text{ kJ/kg.K}$ and C_p of $\text{O}_2 = 0.922 \text{ kJ/kg.K}$ [VTU – Jan.–Feb. 2005]:”

EES Solution:

“Data:”

$$M_{\text{N}_2} = 28 \text{ “... Mol. wt. of N2”}$$

$$M_{\text{O}_2} = 32 \text{ “... Mol. wt. of O2”}$$

$$\text{mass}_{\text{N}_2} = 2 \text{ “kg...mass of N2”}$$

$$\text{mass}_{\text{O}_2} = 1 \text{ “kg ... mass of O2”}$$

$$R_u = 8314.3 \text{ “J/kg.mol -K”}$$

$$c_{p_{\text{O}_2}} = 0.922 \text{ “kJ/kg.K”}$$

$$c_{p_{\text{N}_2}} = 1.04 \text{ “kJ/kg.K”}$$

$$P_1 = 150 \text{ “kPa ... initial pressure”}$$

$$T1 = 20 + 273 \text{ "K ... initial temp."}$$

$$T2 = 100 + 273 \text{ "K ... final temp."}$$

$$P2 = P1 \text{ "...by data"}$$

"Calculations:"

$$\text{mass_mix} = \text{mass_N2} + \text{mass_O2} \text{ "kg mass of mixture"}$$

"Sp. heats of mixture:"

$$c_{p_mix} = (\text{mass_N2} * c_{p_N2} + \text{mass_O2} * c_{p_O2}) / (\text{mass_N2} + \text{mass_O2}) \text{ "kJ/kg.K"}$$

$$c_{v_N2} = c_{p_N2} - R_u * 10^{(-3)} / M_{N2} \text{ "kJ/kg.K"}$$

$$c_{v_O2} = c_{p_O2} - R_u * 10^{(-3)} / M_{O2} \text{ "kJ/kg.K"}$$

"Therefore: cv of mixture:"

$$c_{v_mix} = (\text{mass_N2} * c_{v_N2} + \text{mass_O2} * c_{v_O2}) / (\text{mass_N2} + \text{mass_O2}) \text{ "kJ/kg.K"}$$

"Change in enthalpy:"

$$dH = \text{mass_mix} * c_{p_mix} * (T2 - T1) \text{ "kJ"}$$

"Change in Int. energy:"

$$dU = \text{mass_mix} * c_{v_mix} * (T2 - T1) \text{ "kJ"}$$

"Change in entropy:"

$$dS = \text{mass_mix} * c_{p_mix} * \ln (T2 / T1) \text{ "kJ/K for constant pressure process"}$$

Results:

Unit Settings: SI C kPa kJ mass deg

$$c_{p_{\text{mix}}} = 1.001 \text{ [kJ/kg-K]}$$

$$c_{v_{\text{mix}}} = 0.7161 \text{ [kJ/kg-K]}$$

$$dH = 240.2 \text{ [kJ]}$$

$$\text{mass}_{\text{mix}} = 3 \text{ [kg]}$$

$$M_{N_2} = 28$$

$$P_2 = 150 \text{ [kPa]}$$

$$T_2 = 373 \text{ [K]}$$

$$c_{p_{N_2}} = 1.04 \text{ [kJ/kg-K]}$$

$$c_{v_{N_2}} = 0.7431 \text{ [kJ/kg-K]}$$

$$dS = 0.7247 \text{ [kJ/K]}$$

$$\text{mass}_{N_2} = 2 \text{ [kg]}$$

$$M_{O_2} = 32$$

$$R_u = 8314 \text{ [kJ/kg-mole-K]}$$

$$c_{p_{O_2}} = 0.922 \text{ [kJ/kg-K]}$$

$$c_{v_{O_2}} = 0.6622 \text{ [kJ/kg-K]}$$

$$dU = 171.9 \text{ [kJ]}$$

$$\text{mass}_{O_2} = 1 \text{ [kg]}$$

$$P_1 = 150 \text{ [kPa]}$$

$$T_1 = 293 \text{ [K]}$$

Thus:

Change in enthalpy = $dH = 240.2 \text{ kJ}$... Ans.

Change in entropy = $dS = 0.7247 \text{ kJ/K}$ Ans.

Change in Int. energy = $dU = 171.9 \text{ kJ}$... Ans.

=====

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“Prob.9.23. 0.1 m³ of H₂, initially at 1.2 MPa and 200 C, undergoes a reversible isothermal expansion to 0.1 MPa. Determine: (i) the work done during the process (ii) heat transferred, and (iii) the change in entropy of gas. Take R = 8.3143 kJ/kg.K, cp = 14.4 kJ/kg.K and Mol. wt = 2.016. [VTU – Dec. 2010]”

EES Solution:

“Data:”

M_H2 = 2.016 “... Mol. wt. of H2”

R_u = 8.3143 “J/kg.mol -K universal gas const.”

cp_H2 = 14.4 “kJ/kg.K sp. heat of H2 at const. pressure”

P1 = 1200 “kPa ... initial pressure”

V1 = 0.1 “m³ ... initial volume”

T1 = 200 + 273 “K ... initial temp.”

T2 = T1 “K ... final temp since isothermal expansion.”

P2 = 100 “kPa...final pressure”

“Calculations:”

R_H2 = R_u / M_H2 “kJ/kg.K gas const. for H2”

mass_H2 = (P1 * V1) / (R_H2 * T1) “kg mass of H2”

“To find final volume, V2:”

P1* V1 = P2 * V2 “ at const. temp finds V2”

“Work done, W:”

W = R_H2 * T1 * ln (V2 / V1) “kJ ... work done”

“Change in Int. energy:”

dU = 0 “kJ since temp is constant”

“Therefore: heat transferred:”

$$Q = dU + W \text{ “kJ by I Law for the process”}$$

“Change in entropy:”

$$dS = \text{mass}_{H2} * R_{H2} * \ln (V2/V1) \text{ “kJ/K for isothermal process”}$$

Results:

Unit Settings: SI C kPa kJ mass deg

$$c_{pH2} = 14.4 \text{ [kJ/kg-K]}$$

$$\text{mass}_{H2} = 0.06152 \text{ [kg]}$$

$$P2 = 100 \text{ [kPa]}$$

$$R_u = 8.314 \text{ [kJ/kg-mole-K]}$$

$$V1 = 0.1 \text{ [m}^3\text{]}$$

$$dS = 0.6304 \text{ [kJ/K]}$$

$$M_{H2} = 2.016$$

$$Q = 4847 \text{ [kJ]}$$

$$T1 = 473 \text{ [K]}$$

$$V2 = 1.2 \text{ [m}^3\text{]}$$

$$dU = 0 \text{ [kJ]}$$

$$P1 = 1200 \text{ [kPa]}$$

$$R_{H2} = 4.124 \text{ [kJ/kg-K]}$$

$$T2 = 473 \text{ [K]}$$

$$W = 4847 \text{ [kJ]}$$

Thus:

Work done = $W = 4847 \text{ kJ}$...work done by the gas, so +ve... Ans.

Heat transferred = $Q = 4847 \text{ kJ}$...heat supplied, since +ve Ans.

Change in entropy = $dS = 0.6304 \text{ kJ/K}$ Ans.

=====

“**Prob.9.24.** Determine the pressure of water vapor at 350 C and $0.03524 \text{ m}^3/\text{kg}$, using (i) ideal gas eqn (ii) generalized compressibility chart. Take for water vapor: $R = 0.4615 \text{ kJ/kg.K}$. [VTU – Dec. 2010]”

EES Solution:

“Data:”

$$T1 = 350 + 273 \text{ “K”}$$

$$V1 = 0.03524 \text{ “m}^3\text{”}$$

$$\text{mass} = 1 \text{ “kg”}$$

$$R_{H2O} = 0.4615 \text{ “kJ/kg.K”}$$

$$M_{H2O} = 18 \text{ “..Mol. wt. of H2O”}$$

“(i) Using Ideal gas eqn.:”

$$P_1 \cdot V_1 = \text{mass} \cdot R_{\text{H}_2\text{O}} \cdot T_1 \quad \text{“... finds } P_1 \text{ in kPa”}$$

“(ii) Using compressibility chart:”

“We have for Water vapor:”

$$P_c = 22090 \text{ “kPa,”}$$

$$T_c = 647.3 \text{ “K”}$$

“Now:”

$$P = (Z \cdot R \cdot T / v). \text{ and}$$

$$p_r = p / p_c = Z \cdot R \cdot T / (p_c \cdot v) = A \cdot Z.$$

$$A = R_{\text{H}_2\text{O}} \cdot T_1 / (P_c \cdot V_1)$$

“We get: $A = 0.3693$ ”

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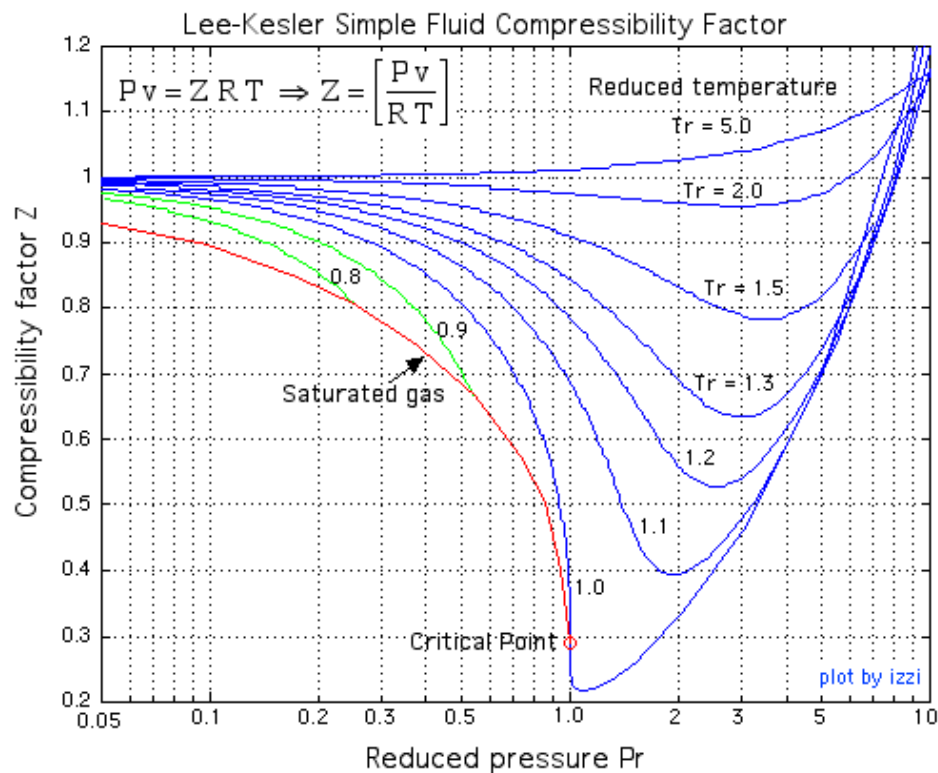
i.e. $P_r = 0.3693 \cdot Z$

$T_r = T_1 / T_c$ "...reduced temp."

"We get $T_r = 0.9625$ "

"Now, go to the Generalized compressibility chart and by *trial and error*, find P_r and Z on

$T_r = 0.9625$ line:



We get: $P_r = 0.34$, $Z = 0.84$

"i.e. $P = 0.34 \cdot P_c = 7510$ kPa."

Results:

Unit Settings: SI C kPa kJ mass deg

$A = 0.3693$

mass = 1 [kg]

$M_{H_2O} = 18$

$P_1 = 8159$ [kPa]

$P_c = 22090$ [kPa]

$R_{H_2O} = 0.4615$ [kJ/kg-K]

$T_1 = 623$ [K]

$T_c = 647.3$ [K]

$T_r = 0.9625$

$V_1 = 0.03524$ [m³]

Thus:

Pressure according to Ideal gas eqn = $P_1 = 8158 \text{ kPa}$ Ans.

Pressure from generalized compressibility chart, = 7510 kPa ... Ans.

=====

“Prob.9.25. A vessel of 1.5 m^3 volume containing oxygen at 8 bar and 50 C is connected to another vessel of 3.5 m^3 volume containing CO at 1 bar and 25 C. A connecting valve is opened and the gases mix adiabatically. Calculate: (i) final temp and pressure of the mixture, and (ii) change in entropy of the system. Take for O₂: $C_v = 21.07 \text{ kJ/mole.K}$, for CO, $C_v = 20.86 \text{ kJ/mole.K}$ ”

EES Solution:

“Data:”

$$P_{\text{O}_2} = 8\text{E}05 \text{ “Pa”}$$

$$P_{\text{CO}} = 1\text{E}05 \text{ “Pa”}$$

$$V_{\text{O}_2} = 1.5 \text{ “m}^3\text{”}$$

$$R_u = 8314 \text{ “J/kg.mole.K”}$$

$$T_{\text{O}_2} = 50+273 \text{ “K”}$$

$$T_{\text{CO}} = 25+273 \text{ “K”}$$

$$V_{\text{CO}} = 3.5 \text{ “m}^3\text{”}$$

$$C_{v_{\text{O}_2}} = 21.07 \text{ “kJ/mole.K”}$$

$$C_{v_{\text{CO}}} = 20.86 \text{ “kJ/mole.K”}$$

“Calculations:”

“No. of moles:”

$$n_{\text{O}_2} = (P_{\text{O}_2} * V_{\text{O}_2}) / (R_u * T_{\text{O}_2}) \text{ “...no. of moles of O}_2\text{”}$$

$$n_{\text{CO}} = (P_{\text{CO}} * V_{\text{CO}}) / (R_u * T_{\text{CO}}) \text{ “...no. of moles of CO”}$$

“Final temp and pressure:”

$$U_1 = n_{O_2} * C_{v,O_2} * T_{O_2} + n_{CO} * C_{v,CO} * T_{CO} \text{ “kJ ...initial int. energy”}$$

$$U_2 = T_f * (n_{O_2} * C_{v,O_2} + n_{CO} * C_{v,CO}) \text{ “kJ ... final int. energy, where } T_f \text{ is the final mixture temp”}$$

“But, $U_1 = U_2$ for this case:”

$$U_1 = U_2 \text{ “...determines mixture temp } T_f \text{”}$$

“Then, final, mixture pressure, P_f :”

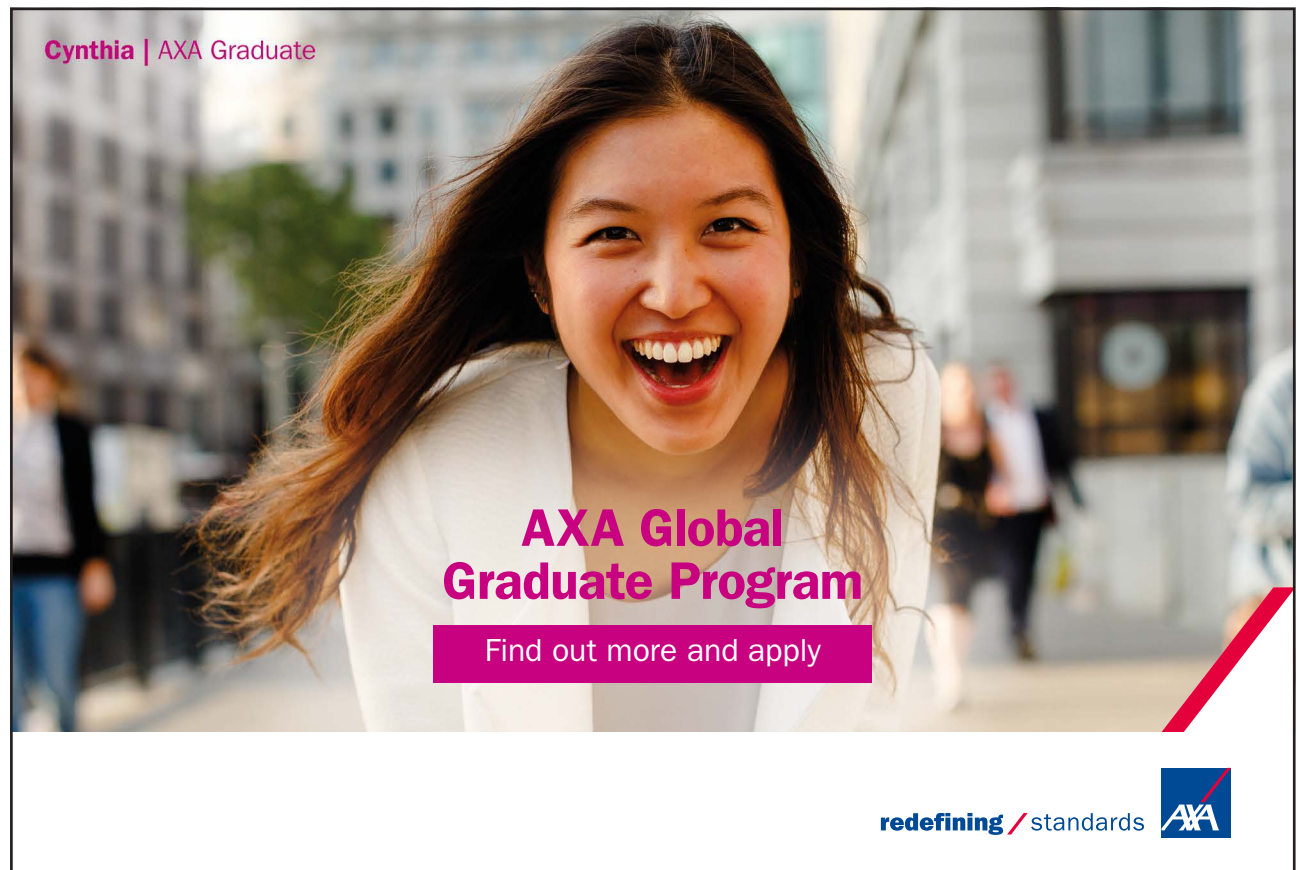
$$P_f = ((n_{O_2} + n_{CO}) * R_u * T_f) / (V_{O_2} + V_{CO}) \text{ “Pa...final, mixture pressure”}$$

$$V_f = V_{O_2} + V_{CO} \text{ “...final vol. of mixture”}$$

“Changes in entropy:”

“For O_2 :”

$$dS_{O_2} = n_{O_2} * C_{v,O_2} * \ln(T_f / T_{O_2}) + n_{O_2} * R_u * 10^{(-3)} * \ln(V_f / V_{O_2}) \text{ “kJ/K”}$$



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“For CO:”

$$dS_{CO} = n_{CO} * C_{v,CO} * \ln(T_f / T_{CO}) + n_{CO} * R_u * 10^{(-3)} * \ln(V_f / V_{CO}) \text{ “kJ/K”}$$

“Total change in entropy for the system:”

$$dS_{sys} = dS_{O2} + dS_{CO} \text{ “kJ/K”}$$

Results:

Unit Settings: SI C kPa kJ mass deg

$$C_{v,CO} = 20.86 \text{ [kJ/mole-K]}$$

$$C_{v,O2} = 21.07 \text{ [kJ/mole-K]}$$

$$dS_{CO} = 0.6014 \text{ [kJ/K]}$$

$$dS_{O2} = 4.298 \text{ [kJ/K]}$$

$$dS_{sys} = 4.899 \text{ [kJ/K]}$$

$$n_{CO} = 0.1413$$

$$n_{O2} = 0.4469$$

$$P_{CO} = 100000 \text{ [Pa]}$$

$$P_f = 310045 \text{ [Pa]}$$

$$P_{O2} = 800000 \text{ [Pa]}$$

$$R_u = 8314 \text{ [kJ/kg-mole-K]}$$

$$T_{CO} = 298 \text{ [K]}$$

$$T_f = 317 \text{ [K]}$$

$$T_{O2} = 323 \text{ [K]}$$

$$U1 = 3919 \text{ [kJ]}$$

$$U2 = 3919 \text{ [kJ]}$$

$$V_{CO} = 3.5 \text{ [m}^3\text{]}$$

$$V_f = 5 \text{ [m}^3\text{]}$$

$$V_{O2} = 1.5 \text{ [m}^3\text{]}$$

Thus:

Final temp of mixture = $T_f = 317 \text{ K}$... Ans.

Final pressure of mixture = $P_f = 310045 \text{ Pa} = 3.1 \text{ bar}$... Ans.

Entropy change for O2 = $dS_{O2} = 4.298 \text{ kJ/K}$... Ans.

Entropy change for CO = $dS_{CO} = 0.6014 \text{ kJ/K}$... Ans.

Entropy change for the system = $dS_{sys} = 4.899 \text{ kJ/K}$.. Ans.

=====

“**Prob.9.26.** 4 kg of CO₂ at 40 C and 1.5 bar are mixed with 8 kg of N₂ at 150 C and 1 bar to form a mixture at a final pressure of 0.8 bar. The process occurs adiabatically in a steady flow apparatus. Calculate: (i) the final temp of mixture, and (ii) change in entropy.

Take: c_p for $\text{CO}_2 = 0.85 \text{ kJ/kg.K}$ and c_p for $\text{N}_2 = 1.04 \text{ kJ/kg.K}$

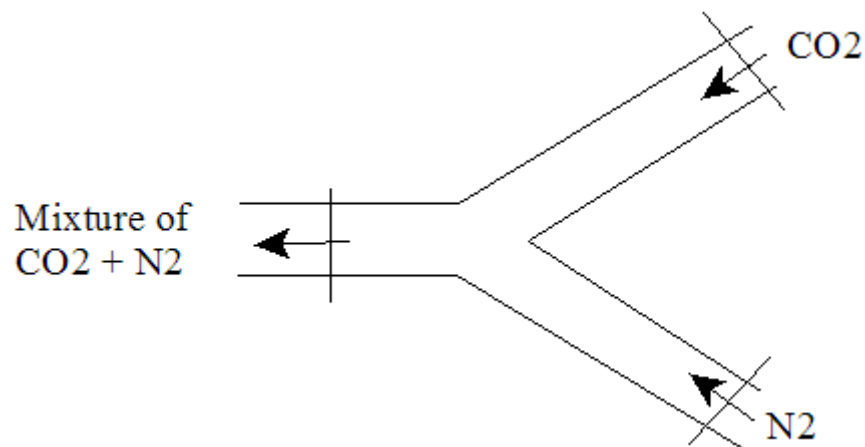


Fig.Prob.9.26

EES Solution:

“Data:”

$$P1_CO2 = 1.5E05 \text{ "Pa"}$$

$$m1_CO2 = 4 \text{ "kg"}$$

$$T1_CO2 = 40 + 273 \text{ "K"}$$

$$P1_N2 = 1E05 \text{ "Pa"}$$

$$m1_N2 = 8 \text{ "kg"}$$

$$T1_N2 = 150 + 273 \text{ "K"}$$

$$P_f = 0.8E05 \text{ "Pa"}$$

$$R_u = 8314 \text{ "J/kg.mole.K"}$$

$$c_p_CO2 = 0.85 \text{ "kJ/kg.K"}$$

$$c_p_N2 = 1.04 \text{ "kJ/kg.K"}$$

$$M_CO2 = 44 \text{ "...Mol. wt. of CO2"}$$

$$M_N2 = 28 \text{ "...Mol.wt. of N2"}$$

“Calculations:”

“No. of moles of CO₂ and N₂:”

$$n_{\text{CO}_2} = m1_{\text{CO}_2} / M_{\text{CO}_2} \text{ “..no. of moles of CO}_2\text{”}$$

$$n_{\text{N}_2} = m1_{\text{N}_2} / M_{\text{N}_2} \text{ “..no. of moles of N}_2\text{”}$$

$$n_{\text{tot}} = n_{\text{CO}_2} + n_{\text{N}_2} \text{ “...total no. of moles”}$$

$$y_{\text{CO}_2} = n_{\text{CO}_2} / n_{\text{tot}} \text{ “...mole fraction of CO}_2\text{”}$$

$$y_{\text{N}_2} = n_{\text{N}_2} / n_{\text{tot}} \text{ “...mole fraction of N}_2\text{”}$$

$$p_{\text{CO}_2} = y_{\text{CO}_2} * P_f \text{ “..Pa ... partial pressure of CO}_2\text{ in final mixture”}$$

$$p_{\text{N}_2} = y_{\text{N}_2} * P_f \text{ “..Pa ... partial pressure of N}_2\text{ in final mixture”}$$

$$R_{\text{CO}_2} = R_u / M_{\text{CO}_2} \text{ “J/kg.K ... Gas const. for CO}_2\text{”}$$

$$R_{\text{N}_2} = R_u / M_{\text{N}_2} \text{ “J/kg.K ... Gas const. for N}_2\text{”}$$

“Final temp is calculated by applying the steady flow energy eqn.:”

“Here Q = 0 and W = 0.

Therefore:”

$$m1_{\text{CO}_2} * cp_{\text{CO}_2} * T1_{\text{CO}_2} + m1_{\text{N}_2} * cp_{\text{N}_2} * T1_{\text{N}_2} = m1_{\text{CO}_2} * cp_{\text{CO}_2} * T_f + m1_{\text{N}_2} * cp_{\text{N}_2} * T_f \text{ “...finds final temp, T}_f\text{”}$$

“Changes in entropy:”

“For CO₂:”

$$dS_{\text{CO}_2} = m1_{\text{CO}_2} * (cp_{\text{CO}_2} * \ln(T_f / T1_{\text{CO}_2})) - m1_{\text{CO}_2} * R_{\text{CO}_2} * 10^{(-3)} * \ln(p_{\text{CO}_2} / P1_{\text{CO}_2}) \text{ “kJ/K”}$$

“For N₂:”

$$dS_{\text{N}_2} = m1_{\text{N}_2} * (cp_{\text{N}_2} * \ln(T_f / T1_{\text{N}_2})) - m1_{\text{N}_2} * R_{\text{N}_2} * 10^{(-3)} * \ln(p_{\text{N}_2} / P1_{\text{N}_2}) \text{ “kJ/K”}$$

“For the system of (CO₂ + N₂):”

$$dS_{\text{sys}} = dS_{\text{CO}_2} + dS_{\text{N}_2} \text{ “kJ/K”}$$

Results:

Unit Settings: SI C kPa kJ mass deg

$$c_{p\text{CO}_2} = 0.85$$

$$dS_{\text{N}_2} = 0.5337 \text{ [kJ/K]}$$

$$m_{\text{N}_2} = 8 \text{ [kg]}$$

$$n_{\text{CO}_2} = 0.09091$$

$$P_{\text{CO}_2} = 150000 \text{ [Pa]}$$

$$P_f = 80000 \text{ [Pa]}$$

$$R_{\text{N}_2} = 296.9 \text{ [J/kg-K]}$$

$$T_{\text{N}_2} = 423 \text{ [K]}$$

$$y_{\text{N}_2} = 0.7586$$

$$c_{p\text{N}_2} = 1.04 \text{ [kJ/kg-K]}$$

$$dS_{\text{sys}} = 2.84 \text{ [kJ/K]}$$

$$M_{\text{CO}_2} = 44$$

$$n_{\text{N}_2} = 0.2857$$

$$P_{\text{N}_2} = 100000 \text{ [Pa]}$$

$$P_{\text{N}_2} = 60690 \text{ [Pa]}$$

$$R_u = 8314 \text{ [kJ/kg-mole-K]}$$

$$T_f = 391.1 \text{ [K]}$$

$$dS_{\text{CO}_2} = 2.307 \text{ [kJ/K]}$$

$$m_{\text{CO}_2} = 4 \text{ [kg]}$$

$$M_{\text{N}_2} = 28$$

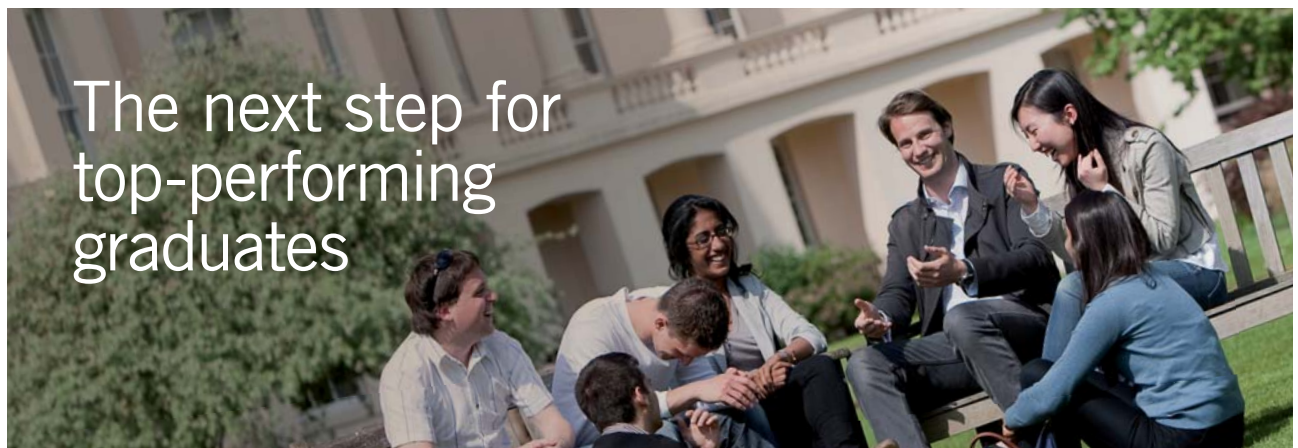
$$n_{\text{tot}} = 0.3766$$

$$p_{\text{CO}_2} = 19310 \text{ [Pa]}$$

$$R_{\text{CO}_2} = 189 \text{ [J/kg-K]}$$

$$T_{\text{CO}_2} = 313 \text{ [K]}$$

$$y_{\text{CO}_2} = 0.2414$$



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Thus:

Final temp of mixture = $T_f = 391.1 \text{ K} \dots \text{Ans.}$

Entropy change for $\text{CO}_2 = dS_{\text{CO}_2} = 2.307 \text{ kJ/K} \dots \text{Ans.}$

Entropy change for $\text{N}_2 = dS_{\text{N}_2} = 0.5337 \text{ kJ/K} \dots \text{Ans.}$

Entropy change for the system = $dS_{\text{sys}} = 2.84 \text{ kJ/K} \dots \text{Ans.}$

=====

9.13 Problems solved with TEST:

Prob.9.27. An ideal gas cycle consisting of 3 processes uses Argon ($M = 40$) as working substance. Process 1-2 is a reversible adiabatic process from 0.014 m^3 , 700 kPa and 280 C to 0.056 m^3 . Process 2-3 is a reversible isothermal process. Process 3-1 is an isobaric process. Sketch the cycle on P-v and T-s diagrams, and find: (i) the work transfer in process 1-2, (ii) work transfer in process 2-3, (iii) net work output from the cycle (assume $\gamma = 1.67$), and (iv) change in enthalpy for each process. [VTU – July 2004]

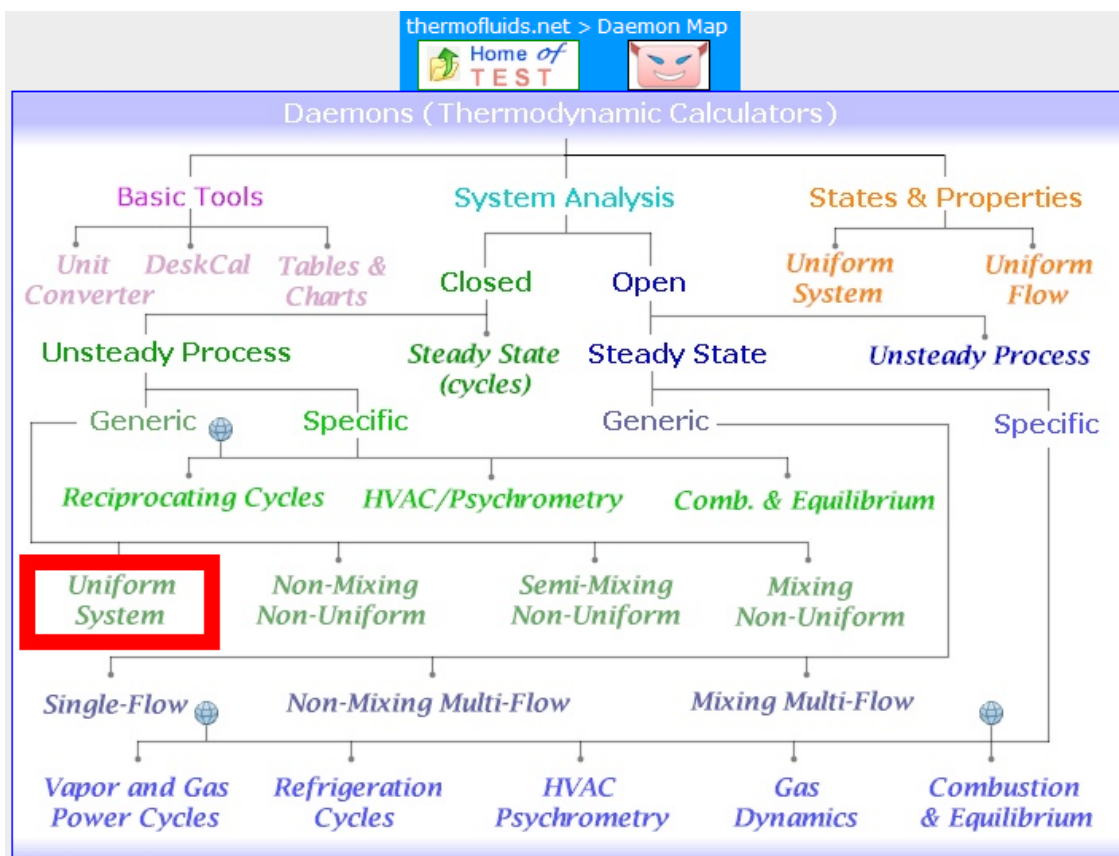
This problem is the same as Prob.9.15, which was solved with EES.

But, see how easily it is solved in TEST:

TEST Solution:

Following are the steps:

1. After going to TEST, in the Daemon tree choose System Analysis –
Colsed _Uniform System:



Hovering the mouse pointer over *Uniform System* brings up the following explanatory pop-up:

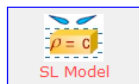
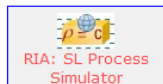
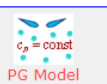
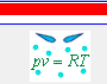

Click to go to page: TEST>Daemons>Systems>Closed>Process>Generic>Uniform Processes

Uniform Processes: Analyze a closed process involving a system that can be described by two unique states, one at the beginning and one at the end of the process. Select a material model that best suits the working substance to launch the daemon.

Chapters 5 and 6 cover analysis of closed processes involving uniform systems.

The pop-up contains two images. On the left is a 3D schematic of a piston-cylinder system with a red dashed line indicating the control volume. The fluid inside is labeled 'f - state'. On the right is a pressure-entropy (p - s) diagram showing a process path from 'f-state' (blue dot) to 'b-state' (red dot). The path is labeled with $p = \text{const}$ and $v = \text{const}$.

2. For Material model, select Ideal Gas (IG) Model, as shown below:

 <p>SL Model</p>	<p>Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characterize the solid/liquid (SL) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p>Examples: A block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. To find the heat transfer necessary for the process. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
 <p>RIA: SL Process Simulator</p>	<p>Process Simulation by RIAs: These rich internet applications (RIAs) can be used to interactively explore a process where a system goes from a beginning state to a final state under some given constrain (say, the temperature remains constant). Unlike the daemons, the RIAs do not require a thorough thermodynamic background and can be used to to gain practical insight alongside learning the underlying theory.</p> <p>Examples: Watch the temperature rise as a block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
<div data-bbox="347 674 496 757">  <p>PG Model</p> </div> <div data-bbox="331 763 512 875" style="border: 2px solid red; padding: 5px;">  <p>IG Model</p> </div>	<div data-bbox="533 725 681 808">  <p>RG Model</p> </div> <p>Pure Gas: A pure gas has a fixed chemical composition across space and time. Oxygen, nitrogen, and air are examples of a pure gas. The PG (perfect gas) model is the simplest gas model which obeys the ideal gas equation ($p v = R T$) and assumes specific heats to be constant. In the IG (ideal gas) model, specific heats are assumed to be function of temperature only. The RG (real gas) model uses generalized compressibility charts and is useful for gases near the critical or super-critical conditions for which PG-model data are not available.</p> <p>Examples: Air is compressed in a piston-cylinder device from a <i>beginning-state</i> to a <i>final-state</i> with no possibility of a phase change. For specific examples, click on the help icon at the bottom margin of the daemon.</p>



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- Choose Argon for the substance, enter p_1 , T_1 , Vol1 for State 1. Hit Enter. Remaining properties are calculated immediately. We get:

Generic, Uniform-System, Closed Process Daemon: *IG Model*

thermofluids.net > Daemons > Systems > Closed > Process > Generic > Uniform > IG-Model

Home of TEST

$v_1 = 0.1644516 \text{ m}^3/\text{kg}$ [Specific volume]

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

State-1 Calculate No-Plots Initialize Formation Enthalpy: No Yes Ar

p_1	T_1	ρ_1	v_1	u_1
700.0 kPa	280.0 deg-C	6.08082 kg/m ³	0.16445 m ³ /kg	17.56037 kJ/kg
h_1	s_1	Vel_1	z_1	e_1
132.6765 kJ/kg	3.7953 kJ/kg.K	0.0 m/s	0.0 m	17.56037 kJ/kg
j_1	ϕ_1	ψ_1	m_1	Vol_1
132.6765 kJ/kg			0.08513 kg	0.014 m ³
MM_1	R_1	c_{p1}		
39.95 kg/kmol	0.20811 kJ/kg.K	0.5203 kJ/kg.K		

- For State 2, enter $s_2 = s_1$ (since isentropic), Vol_2 and $m_2 = m_1$. Hit Enter. We get:

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

State-2 Calculate No-Plots Initialize Formation Enthalpy: No Yes Ar

p_2	T_2	ρ_2	v_2	u_2
69.45394 kPa	-53.61601 deg-C	1.5202 kg/m ³	0.65781 m ³ /kg	-86.59129 kJ/kg
h_2	s_2	Vel_2	z_2	e_2
-40.90404 kJ/kg	=s1 kJ/kg.K	0.0 m/s	0.0 m	-86.59129 kJ/kg
j_2	ϕ_2	ψ_2	m_2	Vol_2
-40.90404 kJ/kg			=m1 kg	0.056 m ³
MM_2	R_2	c_{p2}		
39.95 kg/kmol	0.20811 kJ/kg.K	0.5203 kJ/kg.K		

- For State 3: enter $p_3 = p_1$, $T_3 = T_2$, $m_3 = m_2$ and press Enter. We get:

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

State-3 Calculate No-Plots Initialize Formation Enthalpy: No Yes Ar

p_3	T_3	ρ_3	v_3	u_3
=p1 kPa	=T2 deg-C	15.32156 kg/m ³	0.06527 m ³ /kg	-86.59129 kJ/kg
h_3	s_3	Vel_3	z_3	e_3
-40.90404 kJ/kg	3.31448 kJ/kg.K	0.0 m/s	0.0 m	-86.59129 kJ/kg
j_3	ϕ_3	ψ_3	m_3	Vol_3
-40.90404 kJ/kg			=m2 kg	0.00556 m ³
MM_3	R_3	c_{p3}		
39.95 kg/kmol	0.20811 kJ/kg.K	0.5203 kJ/kg.K		

6. Now, go to Process Panel. For Process A, enter State 1 and State 2 for b-State and f-State, $W_O = 0$ (i.e. work other than Boundary work) and $Q = 0$. Press Calculate (or, hit Enter). We get:

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

Process-A [1-2] b-State: State-1 f-State: State-2 Calculate Initialize s=constant

Q	W_B	W_O	T_B
0.0 kJ	8.86658 kJ	0.0 kJ	298.15 K
S_gen	n	Delta_E	Delta_S
0.0 kJ/K	1.66661 UnitLess	-8.86658 kJ	0.0 kJ/K

Uniform Closed Process -A

Mass: $m_f = m_b = m$

Energy: $m(e_f - e_b) = Q - (W_B + W_O)$
 $\Delta E = E_f - E_b$ W_{ext}

Entropy: $m(s_f - s_b) = \frac{Q}{T_B} + S_{gen}$
 $\Delta S = S_f - S_b$ ≥ 0

Diagram: A piston-cylinder diagram showing a process from b-State (State-1) to f-State (State-2). Heat Q is added to the system, and work W_ext is done by the system. The boundary work W_B is also indicated.

WinHip: Work in negative Heat in positive

$W_{ext} = W_B + W_O$; $W_O = W_{sh} + W_{cl}$

See that: W_B for Process 1-2 is calculated as 8.867 kJ.....Ans.

7. Now, for Process B i.e. Process 2-3: Enter State 2 and State 3 for b-State and f-State respectively. And $W_O = 0$. Hit Enter. We get:

Q = 14.777159 kJ [Net heat transfer]

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

Process-B [2-3] b-State: State-2 f-State: State-3 Calculate Initialize T=constant

Q	W_B	W_O	T_B
-8.98618 kJ	-8.98618 kJ	0.0 kJ	298.15 K
S_gen	n	Delta_E	Delta_S
-0.01079 kJ/K	1.0 UnitLess	0.0 kJ	-0.04093 kJ/K

Uniform Closed Process -B

Mass: $m_f = m_b = m$

Energy: $m(e_f - e_b) = Q - (W_B + W_O)$
 $\Delta E = E_f - E_b$ W_{ext}

Entropy: $m(s_f - s_b) = \frac{Q}{T_B} + S_{gen}$
 $\Delta S = S_f - S_b$ ≥ 0

Diagram: A piston-cylinder diagram showing a process from b-State (State-2) to f-State (State-3). Heat Q is added to the system, and work W_ext is done by the system. The boundary work W_B is also indicated.

WinHip: Work in negative Heat in positive

$W_{ext} = W_B + W_O$; $W_O = W_{sh} + W_{cl}$

Note that for Process 2-3, $W_B = -8.986$ kJ, $Q = -8.986$ kJ ... Ans.

8. Now, for Process 3-1, i.e. Process C: Enter State 3 and State13 for b-State and f-State respectively. And $W_O = 0$. Hit Enter. We get:

Q = -8.986182 kJ [Net heat transfer]

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

Process-C [3-1] b-State: State-3 f-State: State-1 Calculate Initialize p=constant

Q	W_B	W_O	T_B
14.77716 kJ	5.91058 kJ	0.0 kJ	298.15 K
S_gen	n	Delta_E	Delta_S
-0.00863 kJ/K	0.0 UnitLess	8.86658 kJ	0.04093 kJ/K

Uniform Closed Process -C

Mass: $m_f = m_b = m$

Energy: $m(e_f - e_b) = Q - (W_B + W_O)$
 $\Delta E = E_f - E_b$ W_{ext}

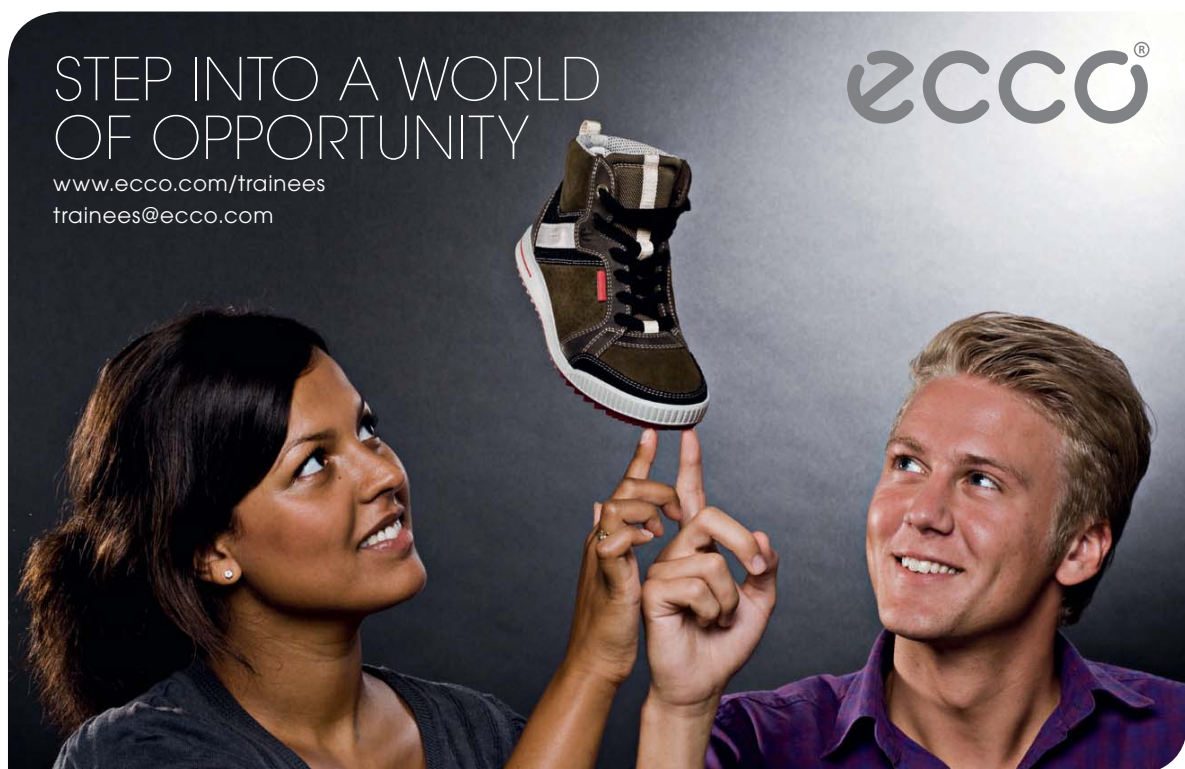
Entropy: $m(s_f - s_b) = \frac{Q}{T_B} + S_{gen}$
 $\Delta S = S_f - S_b$ $S_{gen} \geq 0$

Diagram: b-State = State-3, f-State = State-1, T_B, Q, W_ext, W_O = W_sh + W_el

WinHip: Work in negative Heat in positive

i.e. For Process 3-1: $W_B = 5.9106$ kJ, $Q = 14.777$ kJ ... Ans.

And, net work output of cycle = $8.867 + (-8.986) + 5.916 = 5.797$ kJ ... Ans.

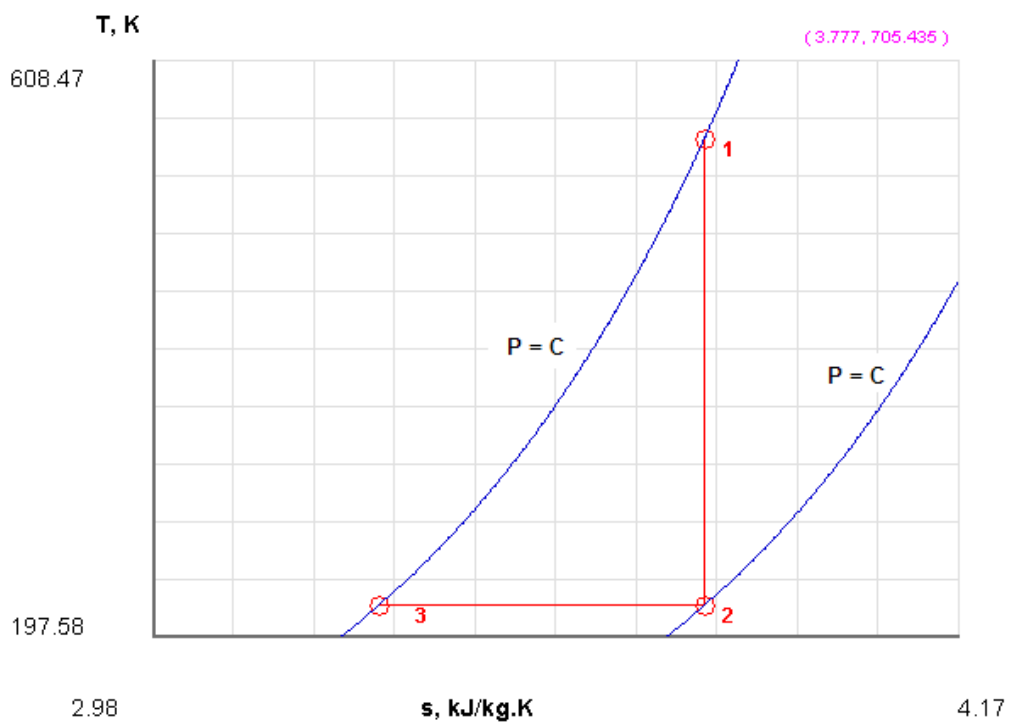
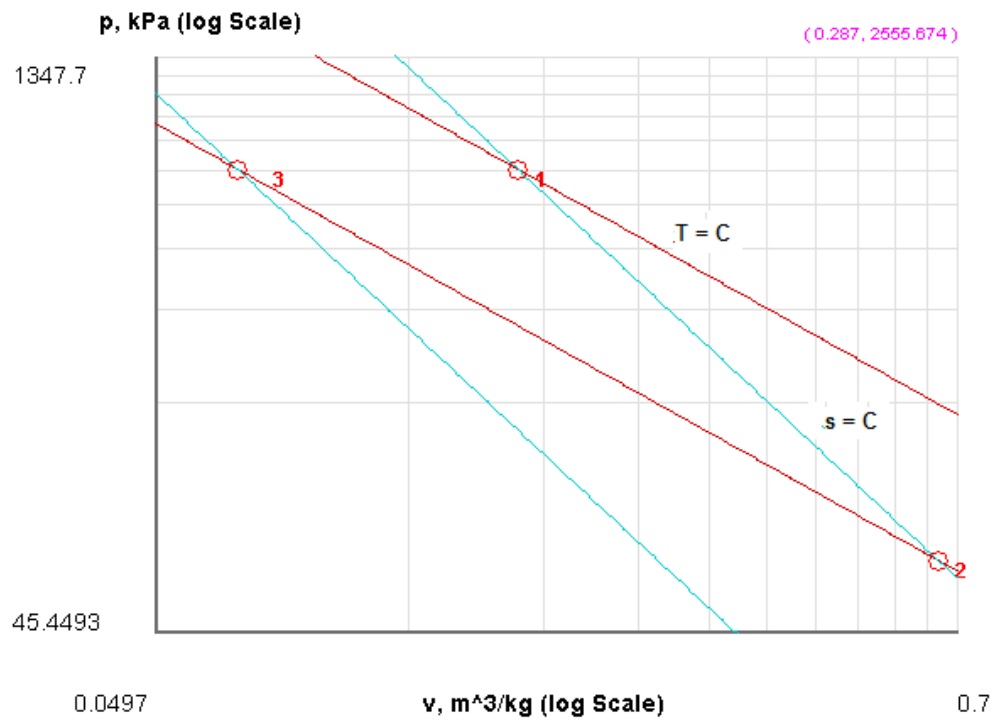


Change in enthalpy for Process 1-2: $(h_2 - h_1) = -173.581 \text{ kJ/kg} \dots \text{Ans.}$

Change in enthalpy for Process 2-3: $(h_3 - h_2) = h_3 - h_2 = 0 \text{ kJ/kg} \dots \text{Ans.}$

Change in enthalpy for Process 3-1: $(h_3 - h_1) = -173.581 \text{ kJ/kg} \dots \text{Ans.}$

9. Get the p-v and T-s plots by electing accordingly from the Plots widget:



10. Click on **SuperCalculate** and get the TEST code etc. from the I/O Panel:

```
#~~~~~OUTPUT OF SUPER-CALCULATE

#

#Daemon Path: Systems>Closed>Process>Generic>Uniform>IG-Model; v-10.ca08

#

#-----Start of TEST-code-----

States {

    State-1: Ar;
    Given: { p1= 700.0 kPa; T1= 280.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.014 m^3; }

    State-2: Ar;
    Given: { s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; Vol2= 0.056 m^3; }

    State-3: Ar;
    Given: { p3= "P1" kPa; T3= "T2" deg-C; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m2" kg; }
}

Analysis {

    Process-A: b-State = State-1; f-State = State-2;
    Given: { Q= 0.0 kJ; W_O= 0.0 kJ; T_B= 298.15 K; }

    Process-B: b-State = State-2; f-State = State-3;
    Given: { W_O= 0.0 kJ; T_B= 298.15 K; }

    Process-C: b-State = State-3; f-State = State-1;
    Given: { W_O= 0.0 kJ; T_B= 298.15 K; }
}

#-----End of TEST-code-----
```

#-----Property spreadsheet starts:

#

#	State	p(kPa)	T(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	700.0	553.2	0.1645	17.56	132.68	3.795
#	2	69.45	219.5	0.6578	-86.59	-40.9	3.795
#	3	700.0	219.5	0.0653	-86.59	-40.9	3.314

#

#-----Property spreadsheet ends-----

Mass, Energy, and Entropy Analysis Results:

#

Process-A: b-State = State-1; f-State = State-2;

Given: Q= 0.0 kJ; W_O= 0.0 kJ; T_B= 298.15 K;

Calculated: **W_B= 8.86658 kJ**; S_gen= -0.0 kJ/K; n= 1.6666132 UnitLess; Delta_E= -8.86658 kJ;
Delta_S= -0.0 kJ/K;

#

Process-B: b-State = State-2; f-State = State-3;

Given: W_O= 0.0 kJ; T_B= 298.15 K;

Calculated: **Q= -8.986182 kJ**; **W_B= -8.986182 kJ**; S_gen= -0.010793186 kJ/K; n= 1.0 UnitLess;
Delta_E= -0.0 kJ; Delta_S= -0.040932987 kJ/K;

#

Process-C: b-State = State-3; f-State = State-1;

Given: W_O= 0.0 kJ; T_B= 298.15 K;

Calculated: **Q= 14.777159 kJ**; **W_B= 5.910579 kJ**; S_gen= -0.008629847 kJ/K; n= 0.0 UnitLess;
Delta_E= 8.86658 kJ; Delta_S= 0.040932987 kJ/K;

#

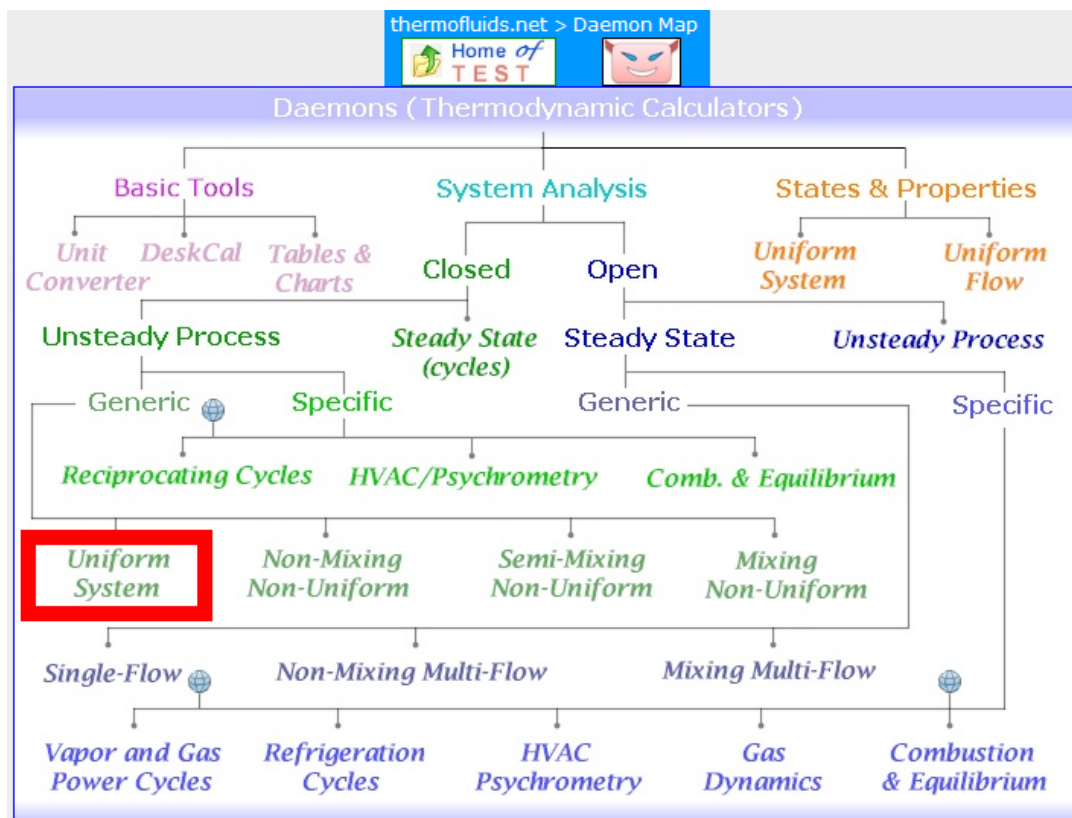
=====

Prob.9.28. 1 kg of air at a pressure of 8 bar and temp 100 C undergoes a reversible, ploytropic process following the law $p.v^{1.2} = \text{constant}$. If the final pressure is 1.8 bar, determine: (i) final sp. volume, temp and increase in entropy, and (ii) work done and heat transfer. [VTU – BTD – Dec. 06–Jan. 07]


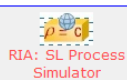

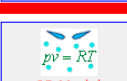
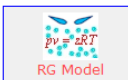
TEST Solution:

Following are the steps:

1. From the Daemons tree, select System Analysis – Closed – Uniform System:



2. For the Material model, select IG Model:

 <p>SL Model</p>	<p>Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characterize the solid/liquid (SL) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p>Examples: A block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. To find the heat transfer necessary for the process. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
 <p>RIA: SL Process Simulator</p>	<p>Process Simulation by RIAs: These rich internet applications (RIAs) can be used to interactively explore a process where a system goes from a beginning state to a final state under some given constrain (say, the temperature remains constant). Unlike the daemons, the RIAs do not require a thorough thermodynamic background and can be used to gain practical insight alongside learning the underlying theory.</p> <p>Examples: Watch the temperature rise as a block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
 <p>PG Model</p>  <p>IG Model</p>	 <p>RG Model</p> <p>Pure Gas: A pure gas has a fixed chemical composition across space and time. Oxygen, nitrogen, and air are examples of a pure gas. The PG (perfect gas) model is the simplest gas model which obeys the ideal gas equation ($p v = R T$) and assumes specific heats to be constant. In the IG (ideal gas) model, specific heats are assumed to be function of temperature only. The RG (real gas) model uses generalized compressibility charts and is useful for gases near the critical or super-critical conditions for which PC-model data are not available.</p> <p>Examples: Air is compressed in a piston-cylinder device from a <i>beginning-state</i> to a <i>final-state</i> with no possibility of a phase change. For specific examples, click on the help icon at the bottom margin of the daemon.</p>

3. Select Air as the substance, enter for State 1 values of p_1 , T_1 and m_1 , and hit Enter. We get:

Generic, Uniform-System, Closed Process Daemon: *IG Model*

thermofluids.net > Daemons > Systems > Closed > Process > Generic > Uniform > IG-Model

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

State-1 Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

p_1	800.0 kPa	T_1	100.0 deg-C	ρ_1	7.47042 kg/m ³	v_1	0.13386 m ³ /kg	u_1	-31.37871 kJ/kg
h_1	75.71031 kJ/kg	s_1	6.51633 kJ/kg.K	Vel_1	0.0 m/s	z_1	0.0 m	e_1	-31.37871 kJ/kg
j_1	75.71031 kJ/kg	ϕ_1		ψ_1		m_1	1.0 kg	Vol_1	0.13386 m ³
MM_1	28.97 kg/kmol	R_1	0.28699 kJ/kg.K	c_{p1}	1.0152 kJ/kg.K				

4. For State 2: enter p_2 , $m_2 = m_1$ and $v_2 = (p_1 * v_1^{1.2} / p_2)$ and hit Enter. We get:

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

State-2 Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

p_2	180.0 kPa	T_2	17.86399 deg-C	ρ_2	2.15525 kg/m ³	v_2	$= (p_1 * v_1^{1.2} / p_2)^{1/1.2}$ m ³ /kg	u_2	-90.66191 kJ/kg
h_2	-7.14481 kJ/kg	s_2	6.69369 kJ/kg.K	Vel_2	0.0 m/s	z_2	0.0 m	e_2	-90.66191 kJ/kg
j_2	-7.14481 kJ/kg	ϕ_2		ψ_2		m_2	$= m_1$ kg	Vol_2	0.46398 m ³
MM_2	28.97 kg/kmol	R_2	0.28699 kJ/kg.K	c_{p2}	1.00347 kJ/kg.K				

5. Go to Process Panel. For Process A, enter State 1 and State 2 for b-State and f-State, and $W_O = 0$ and hit Enter. We get:

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

Process-A [1-2] b-State: State-1 f-State: State-2 Calculate Initialize Polytropic

Q	58.57645 kJ	W_B	117.85965 kJ	W_O	0.0 kJ	T_B	298.15 K
S_{gen}	-0.0191 kJ/K	n	1.2 UnitLess	ΔE	-59.2832 kJ	ΔS	0.17736 kJ/K

Uniform Closed Process - A

Mass: $m_f = m_b = m$

Energy: $m(e_f - e_b) = Q - (W_B + W_O)$
 $\Delta E = E_f - E_b$

Entropy: $m(s_f - s_b) = \frac{Q}{T_B} + S_{gen}$
 $\Delta S = S_f - S_b$

$W_{ext} = W_B + W_O; W_O = W_{sh} + W_{el}$

WinHip: Work in negative Heat in positive

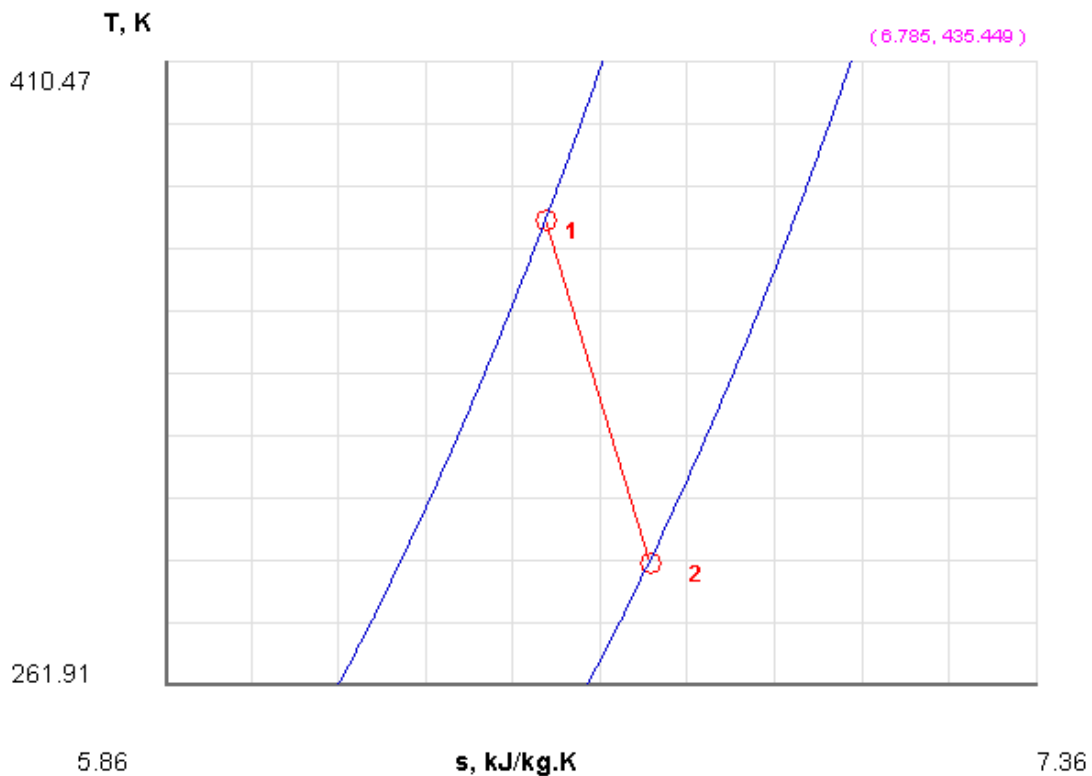
6. Note that Heat transfer, $Q = 58.576 \text{ kJ}$, Work done, $W_B = 117.86 \text{ kJ}$. . Ans.

At State 2:

sp. vol. $v_2 = 0.464 \text{ m}^3$, temp, $T_2 = 17.864 \text{ C}$, and

change in entropy $= (s_2 - s_1) = 0.177 \text{ kJ/K}$ Ans.

7. Draw the T-s diagram from the Plots widget:



8. Click on SuperCalculate, and get the TEST code etc from the I/O panel:

#~~~~~OUTPUT OF SUPER-CALCULATE

#

#Daemon Path: Systems>Closed>Process>Generic>Uniform>IG-Model; v-10.ca08

#

#-----Start of TEST-code-----

States {

State-1: Air;

Given: { $p_1 = 800.0$ kPa; $T_1 = 100.0$ deg-C; $Vel_1 = 0.0$ m/s; $z_1 = 0.0$ m; $m_1 = 1.0$ kg; }

State-2: Air;

Given: { $p_2 = 180.0$ kPa; $v_2 = \frac{(p_1 \cdot v_1^{1.2})}{p_2^{1/1.2}}$ m³/kg; $Vel_2 = 0.0$ m/s; $z_2 = 0.0$ m; $m_2 =$
"m1" kg; }

}

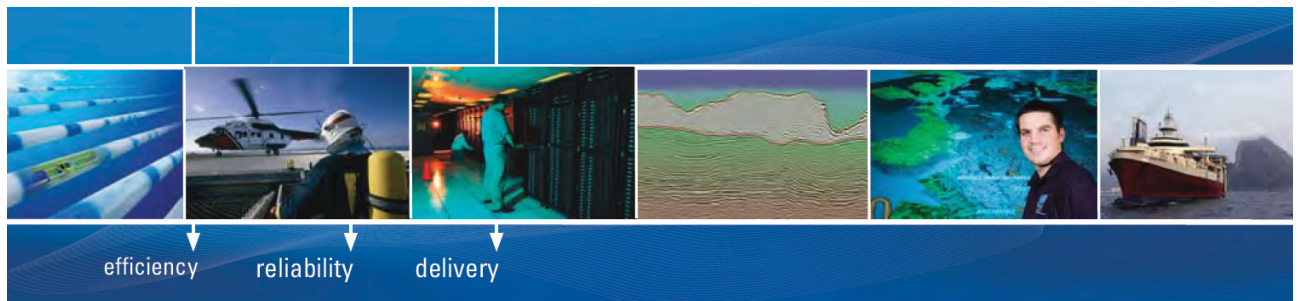
Analysis {

Process-A: b-State = State-1; f-State = State-2;

Given: { $W_O = 0.0$ kJ; $T_B = 298.15$ K; }

}

#-----End of TEST-code-----



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#

#*****DETAILED OUTPUT:

Evaluated States:

#

State-1: Air > IG-Model;

Given: $p_1 = 800.0$ kPa; $T_1 = 100.0$ deg-C; $V_{el1} = 0.0$ m/s;

$z_1 = 0.0$ m; $m_1 = 1.0$ kg;

Calculated: $\rho_{o1} = 7.4704$ kg/m³; $v_1 = 0.1339$ m³/kg; $u_1 = -31.3787$ kJ/kg;

$h_1 = 75.7103$ kJ/kg; $s_1 = 6.5163$ kJ/kg.K; $e_1 = -31.3787$ kJ/kg;

$j_1 = 75.7103$ kJ/kg; $Vol_1 = 0.1339$ m³; $MM_1 = 28.97$ kg/kmol;

$R_1 = 0.287$ kJ/kg.K; $c_{p1} = 1.0152$ kJ/kg.K;

#

State-2: Air > IG-Model;

Given: $p_2 = 180.0$ kPa; $v_2 = (p_1 \cdot v_1^{1.2} / p_2)^{1/1.2}$ m³/kg; $V_{el2} = 0.0$ m/s;

$z_2 = 0.0$ m; $m_2 = "m_1"$ kg;

Calculated: $T_2 = 17.864$ deg-C; $\rho_{o2} = 2.1552$ kg/m³; $u_2 = -90.6619$ kJ/kg;

$h_2 = -7.1448$ kJ/kg; $s_2 = 6.6937$ kJ/kg.K; $e_2 = -90.6619$ kJ/kg;

$j_2 = -7.1448$ kJ/kg; **$Vol_2 = 0.464$ m³**; $MM_2 = 28.97$ kg/kmol;

$R_2 = 0.287$ kJ/kg.K; $c_{p2} = 1.0035$ kJ/kg.K;

#

#-----Property spreadsheet starts: #

#	State	p(kPa)	T(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	800.0	373.2	0.1339	-31.38	75.71	6.516
#	2	180.0	291.0	0.464	-90.66	-7.14	6.694

#

#-----Property spreadsheet ends-----

#

Mass, Energy, and Entropy Analysis Results:

#

Process-A: b-State = State-1; f-State = State-2;

Given: $W_O = 0.0$ kJ; $T_B = 298.15$ K;

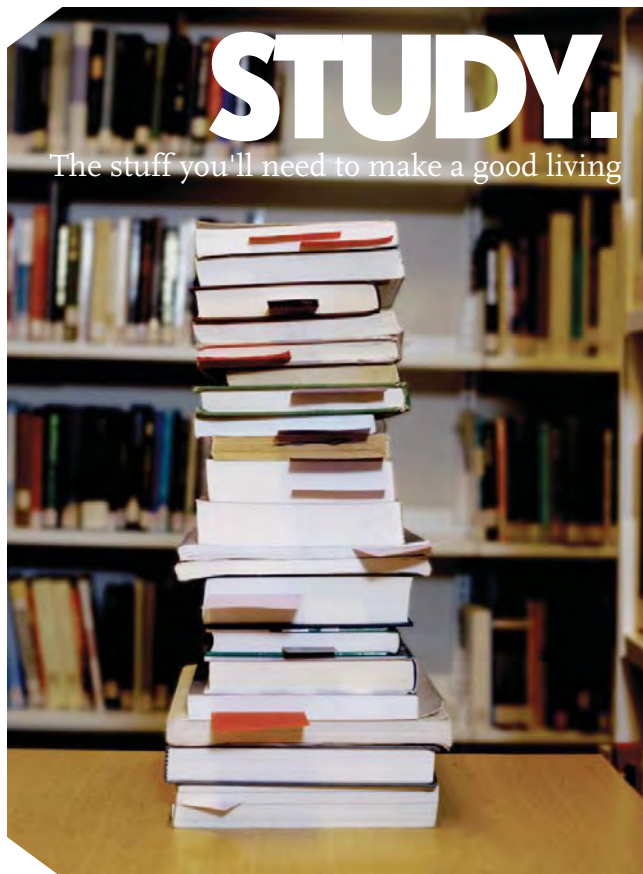
Calculated: $Q = 58.57645$ kJ; $W_B = 117.85965$ kJ; $S_{gen} = -0.019103007$ kJ/K; $n = 1.2$ UnitLess;

$\Delta E = -59.2832$ kJ; $\Delta S = 0.17736337$ kJ/K;

#

=====

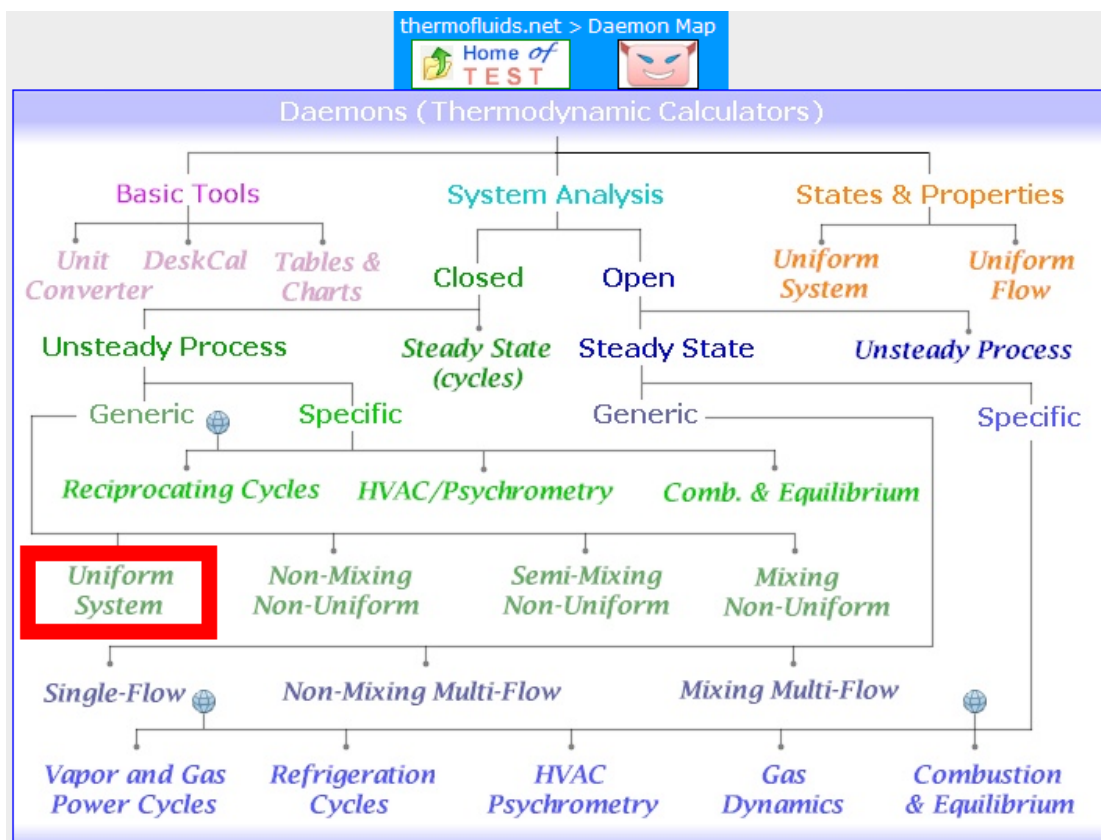
Prob.9.29. 0.5 kg of air is compressed reversibly and adiabatically from 80 kPa, 60 C to 0.4 MPa and is then expanded at const. pressure to the original volume. Sketch these processes on the p-v and T-s planes. Compute the heat transfer and work transfer for the whole path. [VTU – BTD – June–July 08:]




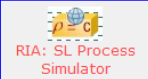
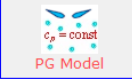

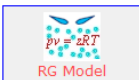
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TEST Solution:

1. From the Daemon tree, select System Analysis – Closed – Uniform System:



2. For the Material model, choose IG model:

 <p>SL Model</p>	<p>Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characterize the solid/liquid (SL) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p>Examples: A block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. To find the heat transfer necessary for the process. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
 <p>RIA: SL Process Simulator</p>	<p>Process Simulation by RIAs: These rich internet applications (RIAs) can be used to interactively explore a process where a system goes from a beginning state to a final state under some given constrain (say, the temperature remains constant). Unlike the daemons, the RIAs do not require a thorough thermodynamic background and can be used to gain practical insight alongside learning the underlying theory.</p> <p>Examples: Watch the temperature rise as a block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
 <p>PG Model</p>  <p>IG Model (highlighted with a red box)</p>	 <p>RG Model</p> <p>Pure Gas: A pure gas has a fixed chemical composition across space and time. Oxygen, nitrogen, and air are examples of a pure gas. The PG (perfect gas) model is the simplest gas model which obeys the ideal gas equation ($p v = R T$) and assumes specific heats to be constant. In the IG (ideal gas) model, specific heats are assumed to be function of temperature only. The RG (real gas) model uses generalized compressibility charts and is useful for gases near the critical or super-critical conditions for which PG-model data are not available.</p> <p>Examples: Air is compressed in a piston-cylinder device from a <i>beginning-state</i> to a <i>final-state</i> with no possibility of a phase change. For specific examples, click on the help icon at the bottom margin of the daemon.</p>

3. Select Air as the working substance, and for State 1, enter values of p_1 , T_1 and m_1 , and hit Enter. We get:

Generic, Uniform-System, Closed Process Daemon: *IG Model*

thermofluids.net > Daemons > Systems > Closed > Process > Generic > Uniform > IG-Model

Move mouse over a variable to display its value with more precision.

Mixed SI English < Case-0 > ☒ Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

< State-1 > Calculate No-Plots Initialize Formation Enthalpy: ☐ No ☒ Yes Air

<input checked="" type="checkbox"/> p_1	<input checked="" type="checkbox"/> T_1	ρ_{o1}	v_1	u_1
80.0 kPa	60.0 deg-C	0.83674 kg/m ³	1.19512 m ³ /kg	-60.37878 kJ/kg
h_1	s_1	<input checked="" type="checkbox"/> Vel_1	<input checked="" type="checkbox"/> z_1	e_1
35.23078 kJ/kg	7.0624 kJ/kg.K	0.0 m/s	0.0 m	-60.37878 kJ/kg
j_1	ϕ_{i1}	ψ_{i1}	m_1	Vol1
35.23078 kJ/kg			0.5 kg	0.59756 m ³
MM_1	R_1	c_{p1}		
28.97 kg/kmol	0.28699 kJ/kg.K	1.00882 kJ/kg.K		

4. For State 2: enter p_2 , $m_2 = m_1$, and $s_2 = s_1$ (since isentropic), hit Enter. We get:

Move mouse over a variable to display its value with more precision.

Mixed SI English < Case-0 > ☒ Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

< State-2 > Calculate No-Plots Initialize Formation Enthalpy: ☐ No ☒ Yes Air

<input checked="" type="checkbox"/> p_2	T_2	ρ_{o2}	v_2	u_2
400.0 kPa	250.01303 deg-C	2.66417 kg/m ³	0.37535 m ³ /kg	79.79284 kJ/kg
h_2	<input checked="" type="checkbox"/> s_2	<input checked="" type="checkbox"/> Vel_2	<input checked="" type="checkbox"/> z_2	e_2
229.93358 kJ/kg	=s1 kJ/kg.K	0.0 m/s	0.0 m	79.79284 kJ/kg
j_2	ϕ_{i2}	ψ_{i2}	<input checked="" type="checkbox"/> m_2	Vol2
229.93358 kJ/kg			=m1 kg	0.18768 m ³
MM_2	R_2	c_{p2}		
28.97 kg/kmol	0.28699 kJ/kg.K	1.04149 kJ/kg.K		

5. For State 3: enter $p_3 = p_2$, $m_3 = m_2$ and Vol3 = Vol1. Hit Enter. We get:

Move mouse over a variable to display its value with more precision.

Mixed SI English < Case-0 > ☒ Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

< State-3 > Calculate No-Plots Initialize Formation Enthalpy: ☐ No ☒ Yes Air

<input checked="" type="checkbox"/> p_3	T_3	ρ_{o3}	v_3	u_3
=p2 kPa	1392.6 deg-C	0.83674 kg/m ³	1.19512 m ³ /kg	1063.576 kJ/kg
h_3	s_3	<input checked="" type="checkbox"/> Vel_3	<input checked="" type="checkbox"/> z_3	e_3
1541.6239 kJ/kg	8.3697 kJ/kg.K	0.0 m/s	0.0 m	1063.576 kJ/kg
j_3	ϕ_{i3}	ψ_{i3}	<input checked="" type="checkbox"/> m_3	<input checked="" type="checkbox"/> Vol3
1541.6239 kJ/kg			=m2 kg	=Vol1 m ³
MM_3	R_3	c_{p3}		
28.97 kg/kmol	0.28699 kJ/kg.K	1.22968 kJ/kg.K		

6. Now, go to Process Panel. For Process A: enter State 1 and State 2 for b-State and f-State, $W_O = 0$ (i.e. Work other than Boundary work), and hit Enter. We get:

Q = 655.84515 kJ [Net heat transfer]

Mixed SI English ©Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

Process-A [1-2] b-State: State-1 f-State: State-2 Calculate Initialize s=constant

Q	W_B	W_O	T_B
655.84515 kJ	-70.08581 kJ	0.0 kJ	298.15 K
S_gen	n	Delta_E	Delta_S
0.0 kJ/K	1.38968 UnitLess	70.08581 kJ	0.0 kJ/K

Uniform Closed Process -A

Mass: $m_f = m_b = m$

Energy: $m(e_f - e_b) = Q - (W_B + W_O)$
 $\Delta E = E_f - E_b$ W_{ext}

Entropy: $m(s_f - s_b) = \frac{Q}{T_B} + S_{gen}$
 $\Delta S = S_f - S_b$ $S_{gen} \geq 0$

Diagram: A piston-cylinder diagram showing a process from State-1 (b-State) to State-2 (f-State). Heat Q is added to the system. Work W_B is done by the system. A note indicates W_O = 0. A WinHip box states: Work in negative, Heat in positive.

WinHip: Work in negative, Heat in positive

$W_{ext} = W_B + W_O$; $W_O = W_{sh} + W_{cl}$

We see that: Work done in Process 1-2 = $W_B = -70.09$ kJ ...(-ve sign means work is done on the gas)... Ans.

7. For Process B: enter State 2 and State 3 for b-State and f-State, $W_O = 0$ (i.e. Work other than Boundary work), and hit Enter. We get:

Q = 0.0 kJ [Net heat transfer]

Mixed SI English ©Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

Process-B [2-3] b-State: State-2 f-State: State-3 Calculate Initialize p=constant

Q	W_B	W_O	T_B
655.84515 kJ	163.95354 kJ	0.0 kJ	298.15 K
S_gen	n	Delta_E	Delta_S
-1.54606 kJ/K	0.0 UnitLess	491.8916 kJ	0.65365 kJ/K

Uniform Closed Process -B

Mass: $m_f = m_b = m$

Energy: $m(e_f - e_b) = Q - (W_B + W_O)$
 $\Delta E = E_f - E_b$ W_{ext}

Entropy: $m(s_f - s_b) = \frac{Q}{T_B} + S_{gen}$
 $\Delta S = S_f - S_b$ $S_{gen} \geq 0$

Diagram: A piston-cylinder diagram showing a process from State-2 (b-State) to State-3 (f-State). Heat Q is added to the system. Work W_B is done by the system. A note indicates W_O = 0. A WinHip box states: Work in negative, Heat in positive.

WinHip: Work in negative, Heat in positive

$W_{ext} = W_B + W_O$; $W_O = W_{sh} + W_{cl}$

We see that: Work done in Process 2-3 = $W_B = 163.95 \text{ kJ}$...(+ve sign means work is done by the gas)... Ans.

Heat transfer, $Q = 655.85 \text{ kJ}$... Ans.

Therefore, for the whole cycle:

$W_{\text{net}} = -70.08 + 163.95 = 93.86 \text{ kJ}$.. Ans.

$Q_{\text{net}} = 0 + 655.85 = 655.85 \text{ kJ}$... Ans.



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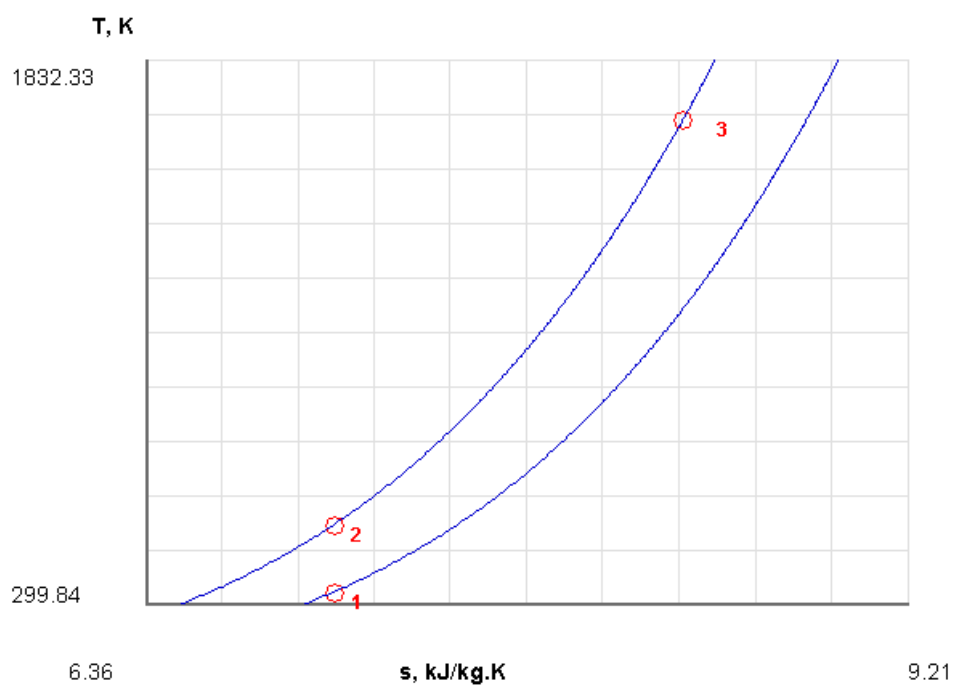
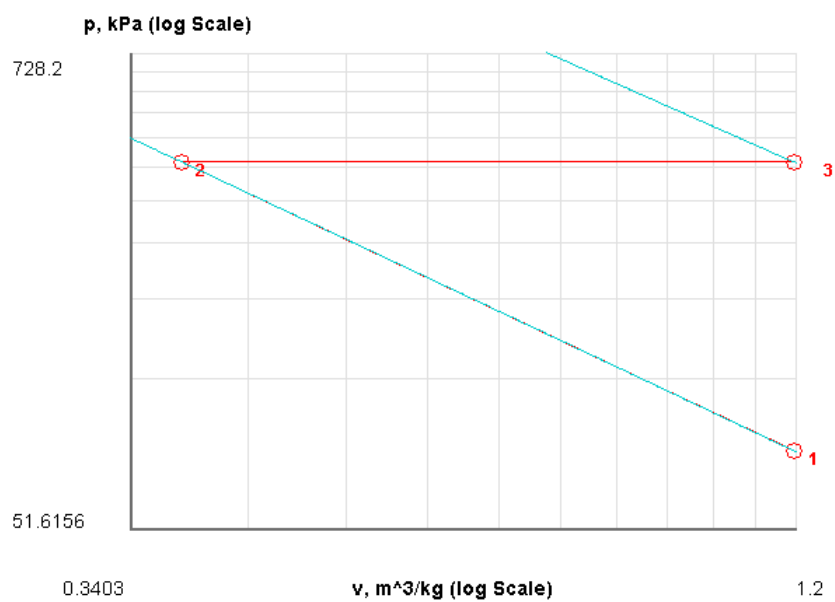
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8. Draw the p-v and T-s diagrams from the Plots widget:



9. Click on SuperCalculate and get the TEST code etc from the I/O panel:

```
#~~~~~OUTPUT OF SUPER-CALCULATE (

#

#Daemon Path: Systems>Closed>Process>Generic>Uniform>IG-Model; v-10.ca08

#

#-----Start of TEST-code-----

States {

    State-1: Air;
    Given: { p1= 80.0 kPa; T1= 60.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 0.5 kg; }

    State-2: Air;
    Given: { p2= 400.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; }

    State-3: Air;
    Given: { p3= "P2" kPa; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m2" kg; Vol3= "Vol1" m^3; }

}

Analysis {

    Process-A: b-State = State-1; f-State = State-2;
    Given: { Q= 0.0 kJ; W_O= 0.0 kJ; T_B= 298.15 K; }

    Process-B: b-State = State-2; f-State = State-3;
    Given: { W_O= 0.0 kJ; T_B= 298.15 K; }

}

#-----End of TEST-code-----
```

#-----Property spreadsheet starts: #

#	State	p(kPa)	T(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	80.0	333.2	1.1951	-60.38	35.23	7.062
#	2	400.0	523.2	0.3754	79.79	229.93	7.062
#	3	400.0	1665.8	1.1951	1063.58	1541.62	8.37
#							

#-----Property spreadsheet ends-----

#

Mass, Energy, and Entropy Analysis Results:

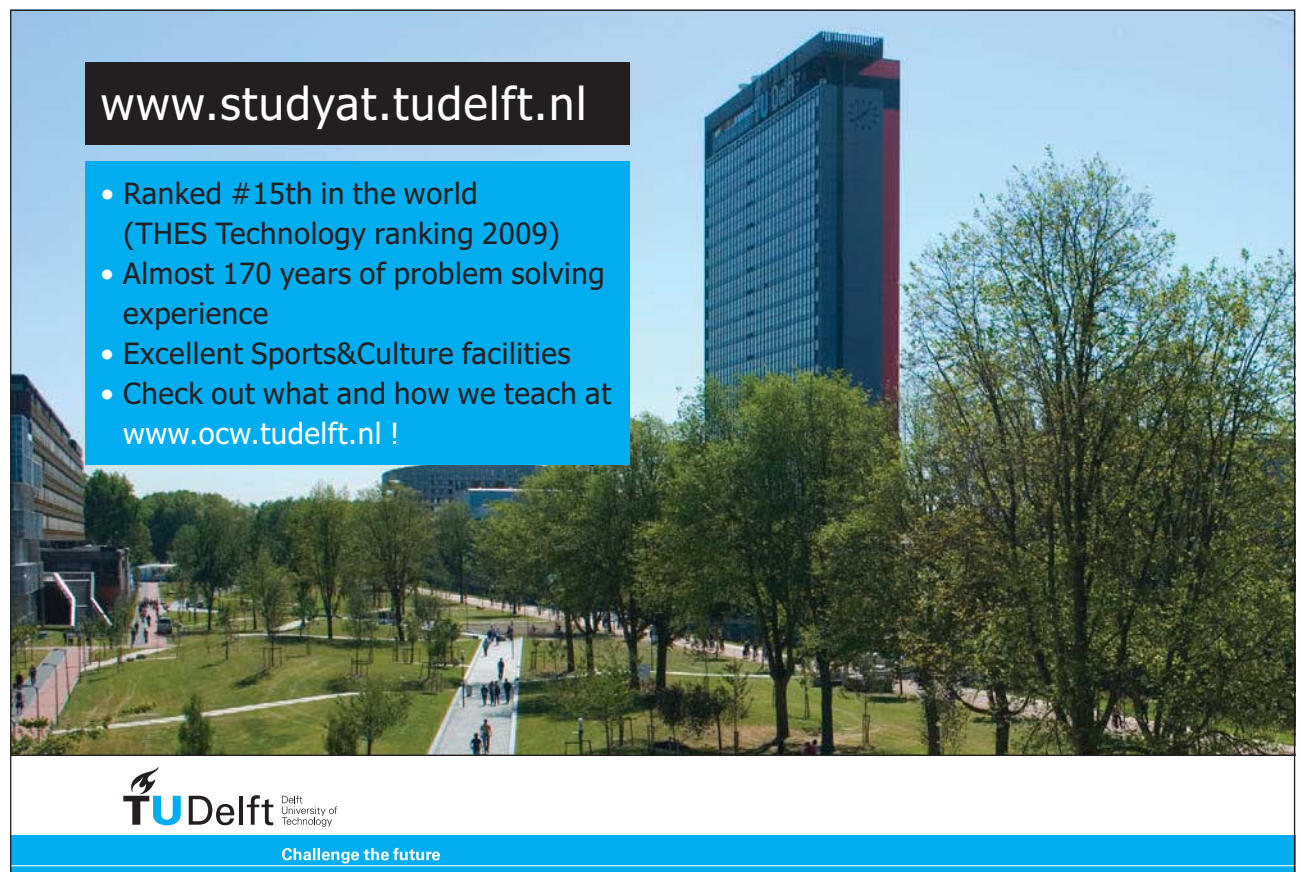
#

Process-A: b-State = State-1; f-State = State-2;

Given: Q= 0.0 kJ; W_O= 0.0 kJ; T_B= 298.15 K;

Calculated: W_B= -70.08581 kJ; S_gen= -0.0 kJ/K; n= 1.3896776 UnitLess; Delta_E= 70.08581 kJ; Delta_S= -0.0 kJ/K;

#



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```
# Process-B: b-State = State-2; f-State = State-3;
# Given: W_O= 0.0 kJ; T_B= 298.15 K;
# Calculated: Q= 655.84515 kJ; W_B= 163.95354 kJ; S_gen= -1.5460639 kJ/K; n= 0.0
UnitLess;
# Delta_E= 491.8916 kJ; Delta_S= 0.6536515 kJ/K;
```

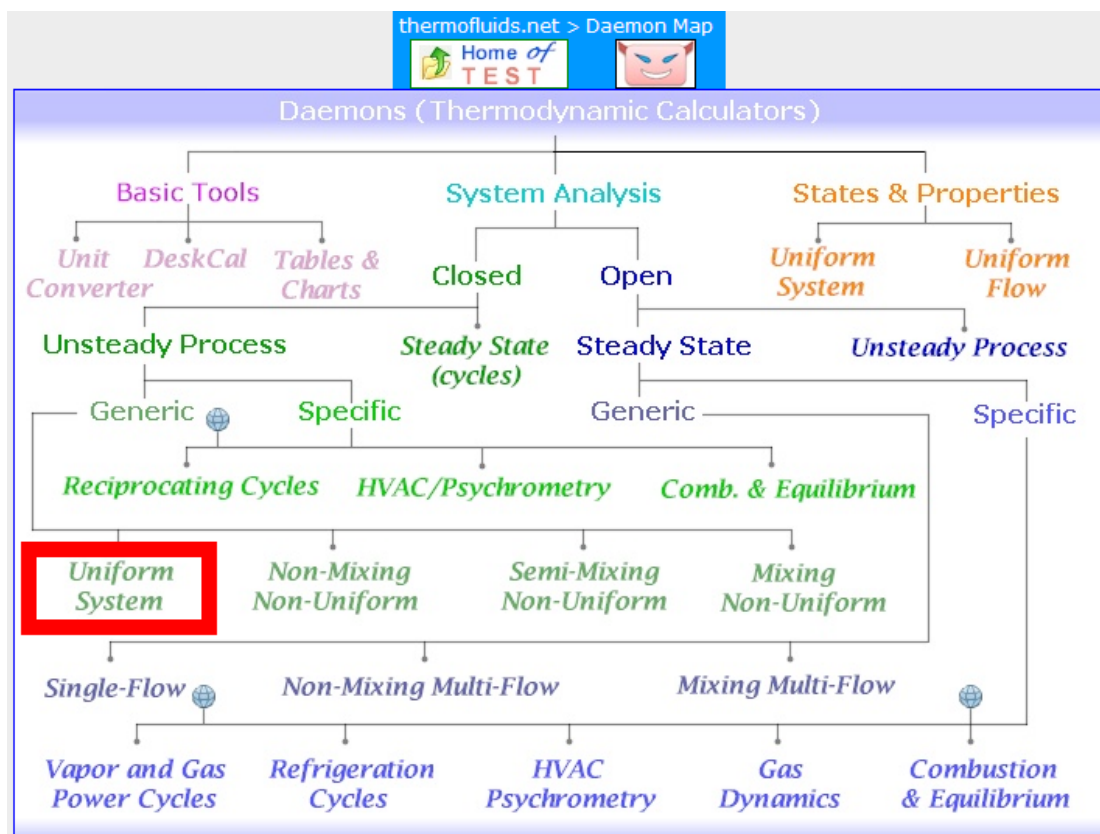
=====

Prob.9.30. A quantity of air at a pressure of 100 kPa, 27 C, occupying a volume of 0.5 m^3 is compressed to a pressure of 500 kPa and volume of 0.12 m^3 according to the law $p.v^n = \text{const}$. Find: (i) value of index n (ii) mass of air (iii) work transfer (iv) heat transferred during the process, and (iv) change in entropy. [VTU – BTD – July 2007.]


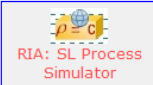
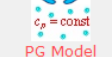
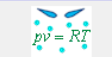
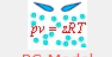
TEST Solution:

Following are the steps:

1. Select the System Analysis-Closed-Uniform System daemon:



2. For Material model, choose IG model:

 <p>SL Model</p>	<p>Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characterize the solid/liquid (SL) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p>Examples: A block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. To find the heat transfer necessary for the process. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
 <p>RIA: SL Process Simulator</p>	<p>Process Simulation by RIAs: These rich internet applications (RIAs) can be used to interactively explore a process where a system goes from a beginning state to a final state under some given constrain (say, the temperature remains constant). Unlike the daemons, the RIAs do not require a thorough thermodynamic background and can be used to gain practical insight alongside learning the underlying theory.</p> <p>Examples: Watch the temperature rise as a block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
<div data-bbox="352 685 496 768">  <p>PG Model</p> </div> <div data-bbox="328 768 520 887" style="border: 2px solid red; padding: 5px;">  <p>IG Model</p> </div>	<div data-bbox="536 730 679 813">  <p>RG Model</p> </div> <p>Pure Gas: A pure gas has a fixed chemical composition across space and time. Oxygen, nitrogen, and air are examples of a pure gas. The PG (perfect gas) model is the simplest gas model which obeys the ideal gas equation ($p v = R T$) and assumes specific heats to be constant. In the IG (ideal gas) model, specific heats are assumed to be function of temperature only. The RG (real gas) model uses generalized compressibility charts and is useful for gases near the critical or super-critical conditions for which PC-model data are not available.</p> <p>Examples: Air is compressed in a piston-cylinder device from a <i>beginning-state</i> to a <i>final-state</i> with no possibility of a phase change. For specific examples, click on the help icon at the bottom margin of the daemon.</p>

3. Select Air as working substance, and for State 1, enter values of p_1 , T_1 and Vol_1 . Hit Enter. Immediately, other properties are calculated:

Generic, Uniform-System, Closed Process Daemon: *IG Model*

thermofluids.net > Daemons > Systems > Closed > Process > Generic > Uniform > IG-Model

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel		Process Panel		Exergy Panel		I/O Panel	
State-1		Calculate		No-Plots		Initialize	
Formation Enthalpy: No Yes						Air	
p_1	100.0 kPa	T_1	27.0 deg-C	ρ_1	1.16091 kg/m ³	v_1	0.86139 m ³ /kg
h_1	2.02326 kJ/kg	s_1	6.8934 kJ/kg.K	Vel_1	0.0 m/s	z_1	0.0 m
j_1	2.02326 kJ/kg	ϕ_1		ψ_1		m_1	0.58046 kg
MM_1	28.97 kg/kmol	R_1	0.28699 kJ/kg.K	c_{p1}	1.00379 kJ/kg.K	Vol_1	0.5 m ³

Observe that: mass of air $m_1 = 0.58046$ kg ... Ans.

4. For State 2: enter p_2 , $m_2 = m_1$, and Vol_2 . Hit Enter. We get:

Generic, Uniform-System, Closed Process Daemon: *IG Model*

thermofluids.net > Daemons > Systems > Closed > Process > Generic > Uniform > IG-Model

Home of TEST

Move mouse over a variable to display its value with more precision.

Mixed SI English < @Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

< @State-2 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> p_2	T_2	ρ_{20}	v_2	u_2
500.0 kPa	87.03 deg-C	4.83714 kg/m ³	0.20673 m ³ /kg	-40.81003 kJ/kg
h_2	s_2	<input checked="" type="checkbox"/> Vel_2	z_2	e_2
62.55678 kJ/kg	6.61534 kJ/kg.K	0.0 m/s	0.0 m	-40.81003 kJ/kg
j_2	ϕ_{i2}	ψ_{i2}	<input checked="" type="checkbox"/> m_2	<input checked="" type="checkbox"/> Vol_2
62.55678 kJ/kg			=m1 kg	0.12 m ³
M_{M2}	R_2	c_{p2}		
28.97 kg/kmol	0.28699 kJ/kg.K	1.0131 kJ/kg.K		

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Jane, Chinese architect

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5. Now, go to Process Panel: For Process A, enter State 1 and State 2 for b-State and f-State.
Also, $W_O = 0$. Hit Enter. We get:

T_B = 298.15 K [Boundary temperature]

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

< Process-A [1-2] > b-State: State-1 f-State: State-2 Calculate Initialize Polytropic

Q	W _B	W _O	T _B
-53.13758 kJ	-78.27469 kJ	0.0 kJ	298.15 K
S _{gen}	n	Delta_E	Delta_S
0.01682 kJ/K	1.12776 UnitLess	25.13711 kJ	-0.1614 kJ/K

Uniform Closed Process -A

Mass: $m_f = m_b = m$

Energy: $m(e_f - e_b) = Q - (W_B + W_O)$
 $\Delta E = E_f - E_b$ W_{ext}

Entropy: $m(s_f - s_b) = \frac{Q}{T_B} + S_{gen}$
 $\Delta S = S_f - S_b$ $S_{gen} \geq 0$

WinHip: Work in negative Heat in positive

$W_{ext} = W_B + W_O$; $W_O = W_{sh} + W_{el}$

Thus:

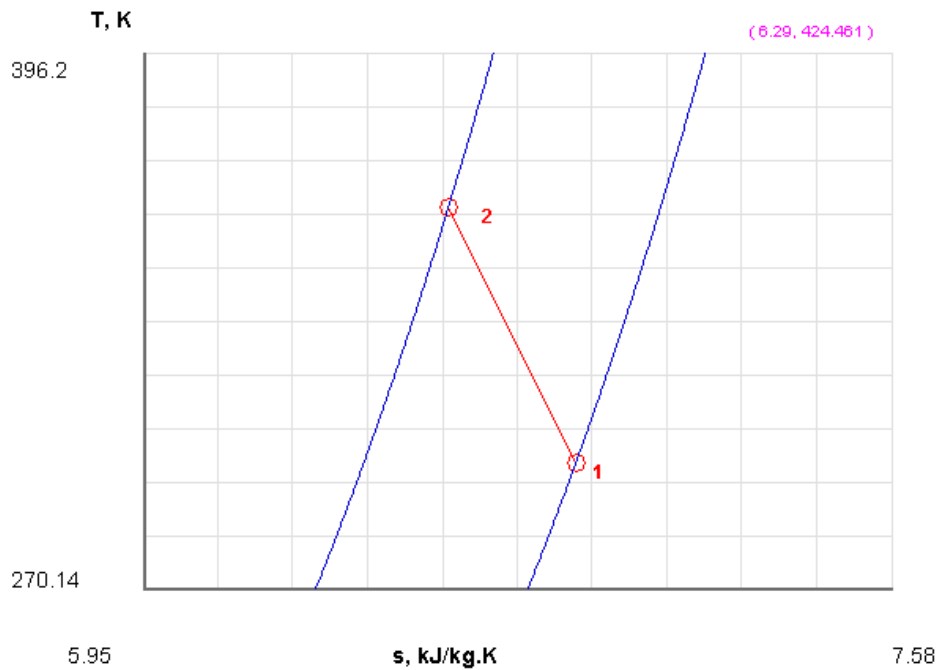
$n = 1.12776$, Mass of air = 0.58046 kg Ans.

$Q = -53.14$ kJ...heat rejected by the system... Ans.

$W = -78.27$ kJwork done on the systemAns.

Change in entropy of gas = $\Delta S = -0.1614$ kJ/K ...Ans.

6. Get the T-s diagram from the Plots widget:



7. Click on SuperCalculate. Get the TEST code etc from the I/O panel:

#~~~~~OUTPUT OF SUPER-CALCULATE

#

#Daemon Path: Systems>Closed>Process>Generic>Uniform>IG-Model; v-10.ca08

#

#-----Start of TEST-code-----

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 27.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.5 m^3; }

State-2: Air;

Given: { p2= 500.0 kPa; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; Vol2= 0.12 m^3; }

}

Analysis {

Process-A: b-State = State-1; f-State = State-2;

Given: { $W_O = 0.0$ kJ; $T_B = 298.15$ K; }

}

#-----End of TEST-code-----

#

#-----Property spreadsheet starts: #

#	State	p(kPa)	T(K)	$v(m^3/kg)$	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	100.0	300.2	0.8614	-84.12	2.02	6.893
#	2	500.0	360.2	0.2067	-40.81	62.56	6.615

#

#-----Property spreadsheet ends-----

#

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Mass, Energy, and Entropy Analysis Results:

#

Process-A: b-State = State-1; f-State = State-2;

Given: $W_O = 0.0$ kJ; $T_B = 298.15$ K;

Calculated: $Q = -53.13758$ kJ; $W_B = -78.27469$ kJ; $S_{gen} = 0.01682128$ kJ/K;

$n = 1.1277552$ UnitLess;

$\Delta_E = 25.137112$ kJ; **$\Delta_S = -0.16140303$ kJ/K;**

#

=====

Prob.9.31. Pressure and temperature of a mixture of 1 kg of O₂ and 2 kg of N₂ are 150 kPa and 20 C respectively. If the mixture is heated at constant pressure to a temp. of 100 C, determine the following: (i) change in enthalpy (ii) change in entropy (iii) change in int. energy.

Given: C_v of N₂ = 0.743 kJ/kg.K and C_v of O₂ = 0.65 kJ/kg.K. [VTU – BTD-Jan. 2005]

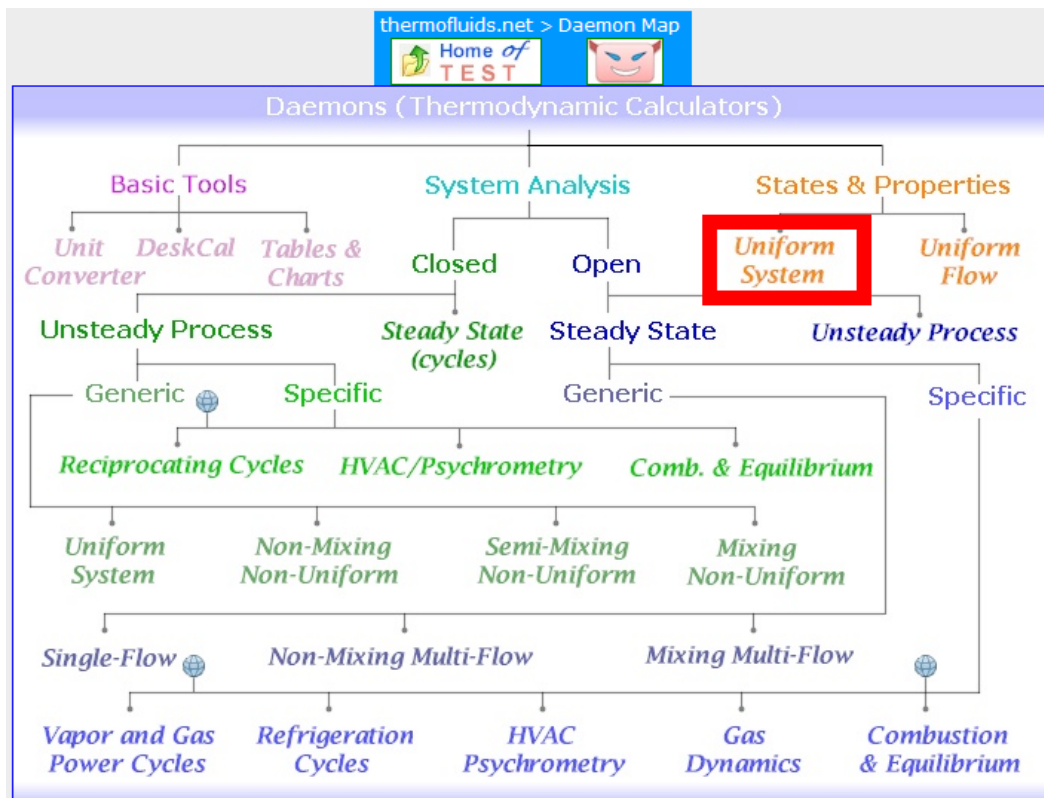
Note: This prob. Is the same as Prob.9.9 solved with Mathcad.

However, now we shall solve it with TEST. *Appreciate how easy it is to solve ideal gas mixture problems in TEST.*

TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



Hovering the mouse pointer on 'Uniform System' brings the following explanatory pop-up:


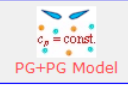


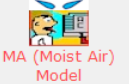


Click to go to page: [TEST>Daemons>States>Uniform System](#)

System State: A system state is an extended set of properties that describe the equilibrium condition of a working substance inside a fixed control volume. Select a material model to launch a system state daemon. To calculate a state, select a working substance, enter the known properties, and click Calculate. Display the state on a thermodynamic plot for better insight.

System states are the building block of most closed system daemons.

Chapters 1, 3, 11, and 14 deal with properties of working substances in equilibrium.

2. For Material model, select Binary mixtures – IG + IG model as shown below:

Gases:	 RG Model	number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy. Examples: Evaluate the change in entropy of a fixed mass of propane, compressed from a given initial pressure and temperature to a given final pressure at the super critical region. For specific examples, click on the help icon at the bottom margin of the daemon.	
	 PG+PG Model	 RG+RG Model	Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor. Examples: Evaluate properties of a flow of a mixture of two gases, O ₂ and CO ₂ , given the mass or mole fraction of O ₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.
	 IG+IG Model	 MA (Moist Air) Model	
	 n-PG Model	 n-IG Model	General Mixture: Mixture can contain an unlimited number, <i>n</i> , of species. Composition can be specified through mass, volume, mass fraction, or mole fraction. Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.

3. Select O₂ for Gas-A and N₂ for Gas-B. For State1, enter p₁, T₁, m₁ (=3 kg for mixture), and x_{A1} = mass fraction of Gas-A = 1/3 = 0.333. Remember that we have to enter either mass fraction x_{A1} or mole fraction y_{A1} for Gas-A only. Hit Enter. Immediately, all mixture properties are calculated.

System State Daemon: *Binary Mixture of Ideal Gases - IG/IG Model*

thermofluids.net > Daemons > States > System > IG/IG

Home of TEST

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< State-1 > Calculate No-Plots Initialize Gas-A: O₂ Gas-B: N₂

✓ p ₁	✓ T ₁	v ₁	u ₁	h ₁
150.0 kPa	20.0 deg-C	0.55614 m ³ /kg	-88.81897 kJ/kg	-5.39759 kJ/kg
s ₁	✓ Vel ₁	z ₁	e ₁	j ₁
6.7431 kJ/kg.K	0.0 m/s	0.0 m	-88.81897 kJ/kg	-5.39759 kJ/kg
phi ₁	psi ₁	✓ m ₁	Vol ₁	MM ₁
		3.0 kg	1.66843 m ³	29.21612 kg/kmol
R ₁	c _{p1}	✓ x _{A1}	y _{A1}	
0.28457 kJ/kg.K	0.98949 kJ/kg.K	0.333 fraction	0.30403 fraction	

Note from the above screen shot that mixture properties such as Mean Mol. wt. MM₁, sp. heat of mixture, c_{p1}, Total volume of mixture, Vol₁, entropy of mixture, s₁ etc are immediately presented.

4. Now, go to State 2. Enter $p_2 = p_1$, T_2 , $m_2 = m_1$, $x_{A2} = x_{A1}$, and hit Enter. We get for State 2 of the mixture:

System State Daemon: *Binary Mixture of Ideal Gases - IG/IG Model*

thermofluids.net > Daemons > States > System > IG/IG

Home of TEST

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< State-2 > Calculate No-Plots Initialize Gas-A: O2 Gas-B: N2

<input checked="" type="checkbox"/> p_2	<input checked="" type="checkbox"/> T_2	<input type="checkbox"/> v_2	<input type="checkbox"/> u_2	<input type="checkbox"/> h_2
= p_1 kPa	100.0 deg-C	0.70791 m ³ /kg	-31.64933 kJ/kg	74.53756 kJ/kg
<input type="checkbox"/> s_2	<input checked="" type="checkbox"/> Vel_2	<input checked="" type="checkbox"/> z_2	<input type="checkbox"/> e_2	<input type="checkbox"/> j_2
6.98429 kJ/kg.K	0.0 m/s	0.0 m	-31.64933 kJ/kg	74.53756 kJ/kg
<input type="checkbox"/> ϕ_2	<input type="checkbox"/> ψ_2	<input checked="" type="checkbox"/> m_2	<input type="checkbox"/> Vol_2	<input type="checkbox"/> MM_2
kJ/kg	kJ/kg	= m_1 kg	2.12374 m ³	29.21612 kg/kmol
<input type="checkbox"/> R_2	<input type="checkbox"/> c_{p2}	<input checked="" type="checkbox"/> x_{A2}	<input type="checkbox"/> y_{A2}	
0.28457 kJ/kg.K	1.01021 kJ/kg.K	= x_{A1} fraction	0.30403 fraction	



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5. Click on **SuperCalculate** and get the TEST code etc from the I/O panel:

```
#~~~~~OUTPUT OF SUPER-CALCULATE

#

#   Daemon Path: States>System>IG-BinMixModel; v-10.ca08

#

#-----Start of TEST-code-----

States  {

    State-1: O2, N2;

    Given: { p1= 150.0 kPa; T1= 20.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 3.0 kg; x_A1= 0.333
fraction; }

    State-2: O2, N2;

    Given: { p2= "P1" kPa; T2= 100.0 deg-C; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; x_A2= "x_A1"
fraction; }

    }

#-----End of TEST-code-----

#

#*****DETAILED OUTPUT:

#

# Evaluated States:

#

#   State-1: O2, N2 > IG-BinMixModel;
#       Given: p1= 150.0 kPa; T1= 20.0 deg-C; Vel1= 0.0 m/s;
#       z1= 0.0 m; m1= 3.0 kg; x_A1= 0.333 fraction;
#
```



```
#          Calculated: v1= 0.5561 m^3/kg; u1= -88.819 kJ/kg; h1= -5.3976 kJ/kg;
#          s1= 6.7431 kJ/kg.K; e1= -88.819 kJ/kg; j1= -5.3976 kJ/kg;
#          Vol1= 1.6684 m^3; MM1= 29.2161 kg/kmol; R1= 0.2846 kJ/kg.K;
#          c_p1= 0.9895 kJ/kg.K; y_A1= 0.304 fraction;
#
#          State-2: O2, N2 > IG-BinMixModel;
#          Given: p2= "P1" kPa; T2= 100.0 deg-C; Vel2= 0.0 m/s;
#          z2= 0.0 m; m2= "m1" kg; x_A2= "x_A1" fraction;
#
#          Calculated: v2= 0.7079 m^3/kg; u2= -31.6493 kJ/kg; h2= 74.5376 kJ/kg;
#          s2= 6.9843 kJ/kg.K; e2= -31.6493 kJ/kg; j2= 74.5376 kJ/kg;
#          Vol2= 2.1237 m^3; MM2= 29.2161 kg/kmol; R2= 0.2846 kJ/kg.K;
#          c_p2= 1.0102 kJ/kg.K; y_A2= 0.304 fraction;
#
#-----Property spreadsheet starts: #

# State  x_A   y_A   p(kPa) T(K)   v(m3/kg)      u(kJ/kg)      h(kJ/kg)      s(kJ/kg)
# 1      0.33   0.3    150.0  293.1  0.5561      -88.82       -5.4          6.743
# 2      0.33      0.3    150.0  373.1  0.7079  -31.65       74.54         6.984

#

#*****CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)',
#=' sqrt(4*A1/PI)', etc.) and press the Enter key)*****

#
```

Calculate change in enthalpy etc. in the I/O panel, using it as a calculator:

Change in enthalpy = $m1 \cdot (h2 - h1) = 239.80544471740723 = 239.81 \text{ kJ} \dots \text{Ans.}$

Change in entropy = $m1 \cdot (s2 - s1) = 0.7235612869262695 = 0.724 \text{ kJ/K} \dots \text{Ans.}$

Change in int. energy = $m1 \cdot (u2 - u1) = 171.50891876220703 = 171.51 \text{ kJ} \dots \text{Ans.}$

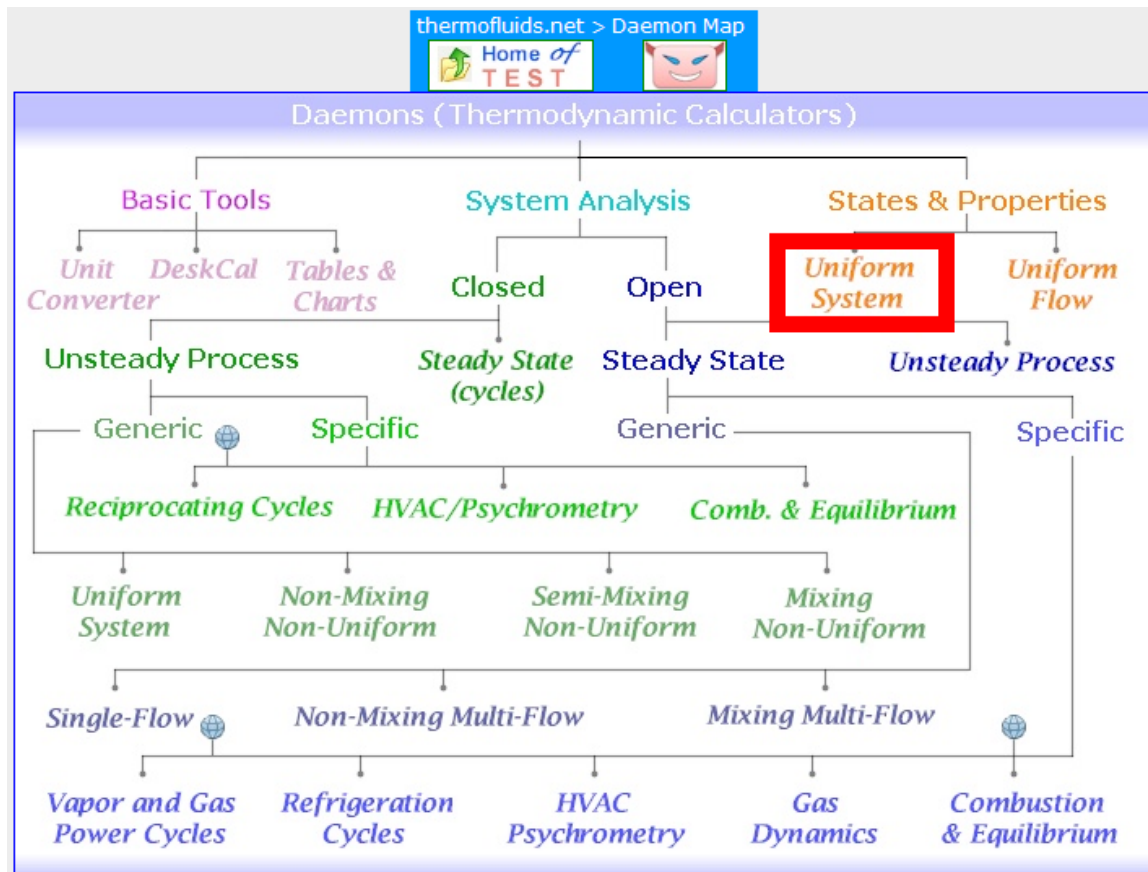
=====

Prob.9.32. A gas mixture consists of 6 kmol of H₂ and 4 kmol of N₂. Determine the mass of each gas and the Gas const. of the mixture. [VTU – BTD – Jan. 2004]

TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select Binary mixtures – IG + IG model as shown below:

Gases:	<p>RG Model</p>	<p>number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy.</p> <p>Examples: Evaluate the change in entropy of a fixed mass of propane, compressed from a given initial pressure and temperature to a given final pressure at the super critical region. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
	<p>PG+PG Model</p>	<p>Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor.</p> <p>Examples: Evaluate properties of a flow of a mixture of two gases, O₂ and CO₂, given the mass or mole fraction of O₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.</p>
	<p>IG+IG Model</p>	
	<p>MA (Moist Air) Model</p>	<p>General Mixture: Mixture can contain an unlimited number, n, of species. Composition can be specified through mass, volume, mass fraction, or mole fraction.</p> <p>Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
<p>n-PG Model</p>	<p>n-IG Model</p>	

3. Select H2 for Gas-A and N2 for Gas-B. For State1, enter $y_{A1} = 0.6$ (i.e. mole fraction for Gas-A), and hit Enter. Immediately, Gas const. for mixture (i.e. R_1) and Mol. wt. for the mixture, MM_1 are calculated.

System State Daemon: *Binary Mixture of Ideal Gases - IG/IG Model*

thermofluids.net > Daemons > States > System > IG/IG

Home of TEST

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

State-1 Calculate No-Plots Initialize Gas-A: H2 Gas-B: N2

p_1	T_1	v_1	u_1	h_1
kPa	K	m ³ /kg	kJ/kg	kJ/kg
s_1	Vel1	z_1	e_1	f_1
kJ/kg.K	0.0 m/s	0.0 m	kJ/kg	kJ/kg
ϕ_{i1}	ψ_{i1}	m_1	Vol1	MM_1
kJ/kg	kJ/kg	kg	m ³	12.40948 kg/kmol
R_1	c_{p1}	x_{A1}	y_{A1}	
0.66997 kJ/kg.K		0.09746 fraction	0.6 fraction	

Note from the above screen shot that for the mixture:

Mean Mol. wt. $MM_1 = 12.409 \text{ kg/mol} \dots \text{Ans.}$

Gas const. for mixture, $R_1 = 0.66997 \text{ kJ/kg.K} \dots \text{Ans.}$



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Mass of H₂ and N₂:

We see that mass fraction, x_{A1} for H₂ is 0.09746.

i.e. If the mixture mass is 1 kg,

Mass of H₂ in the mixture = 0.09746 kg ... Ans.

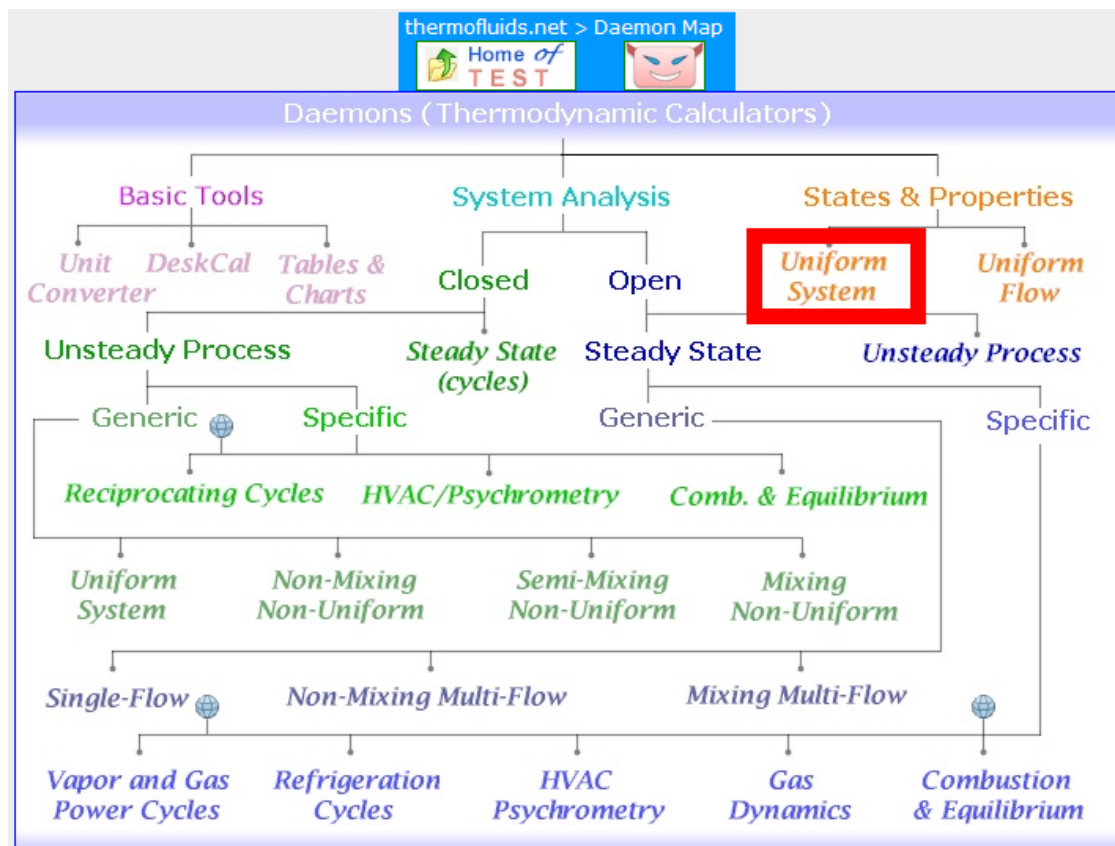
Mass of N₂ in the mixture = $1 - 0.09746 = 0.9025$ kg Ans.

Prob.9.33. The gravimetric analysis of dry air is: O₂ = 23%, and N₂ = 77%. Calculate for air at 100 kPa and 15 C: (i) Mole fractions of components, (ii) The Gas const. (iii) Mol. wt. (iv) The respective partial pressures. [VTU – BTD – July 2003]








TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select Binary mixtures – IG + IG model as shown below:

Gases:	 RG Model	number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy. Examples: Evaluate the change in entropy of a fixed mass of propane, compressed from a given initial pressure and temperature to a given final pressure at the super critical region. For specific examples, click on the help icon at the bottom margin of the daemon.		
	 PG+PG Model	 RG+RG Model	Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor. Examples: Evaluate properties of a flow of a mixture of two gases, O ₂ and CO ₂ , given the mass or mole fraction of O ₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.	
	 IG+IG Model	 MA (Moist Air) Model		
	 n-PG Model	 n-IG Model	General Mixture: Mixture can contain an unlimited number, <i>n</i> , of species. Composition can be specified through mass, volume, mass fraction, or mole fraction. Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.	

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3. Select O2 for Gas-A and N2 for Gas-B. For State1, enter values of p_1 , T_1 , and mass fraction of O2 = $x_{A1} = 0.23$ and hit Enter. Immediately, mole fraction y_{A1} for O2, Gas const. for mixture (i.e. R_1) and Mol. wt. for the mixture, MM_1 are calculated.

System State Daemon: *Binary Mixture of Ideal Gases - IG/IG Model*

thermofluids.net > Daemons > States > System > IG/IG

Home of TEST

T1 = 15.0 deg-C [Absolute temperature]

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< State-1 > Calculate No-Plots Initialize Gas-A: O2 Gas-B: N2

<input checked="" type="checkbox"/> p_1	100.0	kPa	<input checked="" type="checkbox"/> T_1	15.0	deg-C	<input checked="" type="checkbox"/> v_1	0.831	m ³ /kg	<input checked="" type="checkbox"/> u_1	-93.5517	kJ/kg	<input checked="" type="checkbox"/> h_1	-10.45158	kJ/kg
<input checked="" type="checkbox"/> s_1	6.85826	kJ/kg.K	<input checked="" type="checkbox"/> Vel_1	0.0	m/s	<input checked="" type="checkbox"/> z_1	0.0	m	<input checked="" type="checkbox"/> e_1	-93.5517	kJ/kg	<input checked="" type="checkbox"/> j_1	-10.45158	kJ/kg
<input checked="" type="checkbox"/> ϕ_1		kJ/kg	<input checked="" type="checkbox"/> ψ_1		kJ/kg	<input checked="" type="checkbox"/> m_1		kg	<input checked="" type="checkbox"/> Vol_1		m ³	<input checked="" type="checkbox"/> MM_1	28.82883	kg/kmol
<input checked="" type="checkbox"/> R_1	0.28839	kJ/kg.K	<input checked="" type="checkbox"/> c_{p1}	1.00202	kJ/kg.K	<input checked="" type="checkbox"/> x_{A1}	0.23	fraction	<input checked="" type="checkbox"/> y_{A1}	0.20721	fraction			

We see from the above screen shot that:

Mole fraction of O2 = $y_{A1} = 0.20721 = 20.72\% \dots$ Ans.

Therefore, mole fraction of N2 = $1 - 0.20721 = 0.79279 = 79.28\%$

Gas const. for the mixture = $R_1 = 0.28839$ kJ/kg.K ... Ans.

Partial pressures:

For O2: $p_{O2} = 0.20721 \times 100 = 20.721$ kPa ... Ans.

For N2: $p_{N2} = 0.79279 \times 100 = 79.279$ kPa ... Ans.

4. Click on **SuperCalculate** to get the TEST code etc:

```
#~~~~~OUTPUT OF SUPER-CALCULATE

#

#   Daemon Path: States>System>IG-BinMixModel; v-10.ca08

#

#-----Start of TEST-code-----

States  {

    State-1: O2, N2;

    Given: { p1= 100.0 kPa; T1= 15.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; x_A1= 0.23 fraction; }

    }

#-----End of TEST-code-----

#*****DETAILED OUTPUT:

#

# Evaluated States:

#

#   State-1: O2, N2 > IG-BinMixModel;
#       Given: p1= 100.0 kPa; T1= 15.0 deg-C; Vel1= 0.0 m/s;
#           z1= 0.0 m; x_A1= 0.23 fraction;
#       Calculated: v1= 0.831 m^3/kg; u1= -93.5517 kJ/kg; h1= -10.4516 kJ/kg;
#           s1= 6.8583 kJ/kg.K; e1= -93.5517 kJ/kg; j1= -10.4516 kJ/kg;
#           MM1= 28.8288 kg/kmol; R1= 0.2884 kJ/kg.K; c_p1= 1.002 kJ/kg.K;
#           y_A1= 0.2072 fraction;
#
```

=====

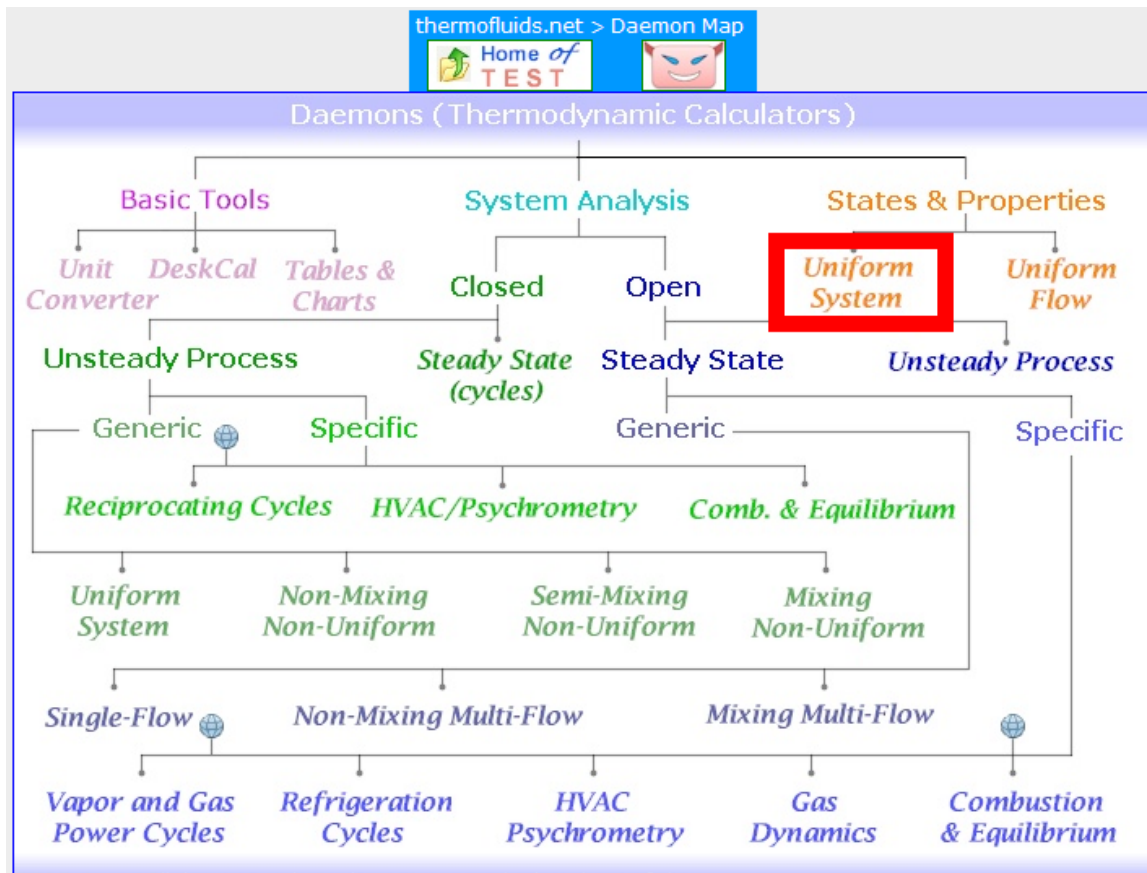
Prob.9.34. Determine the sp.vol.of H₂ gas when its pressure is 60 bar and temp is 100 K, by using the compressibility chart. [VTU – BTD – Jan. 2003]

TEST Solution:

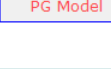
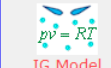

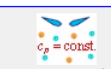
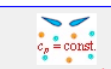
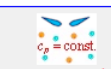
Result of using the compressibility chart is obtained very easily with TEST:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select Gases – RG (Real Gas) model as shown below. **Observe that it is based on generalized compressibility chart.**

Gases:		PG Model	Examples: Evaluate the change in entropy of a fixed volume of argon, heated from a given initial pressure and temperature to a given final state. For specific examples, click on the help icon at the bottom margin of the daemon.
		IG Model	Pure Ideal Gas: An ideal gas (IG) is a gas that obeys the ideal gas equation of state ($p\nu=RT$). Specific heats are temperature dependent. As a result the IG model is more accurate than the PG model when variation in temperature is significant. Choose from an wide selection of gases. Examples: Evaluate the change in internal energy of a fixed volume of carbon dioxide, heated from a given initial pressure and temperature to a given final state. For specific examples, click on the help icon at the bottom margin of the daemon.
		RG Model	Pure Real Gas: Based on the <u>generalized compressibility chart</u> ($p\nu=ZRT$), the <i>real gas</i> (RG) model can handle a large number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy. Examples: Evaluate the change in entropy of a fixed mass of propane, compressed from a given initial pressure and temperature to a given final pressure at the super critical region. For specific examples, click on the help icon at the bottom margin of the daemon.
		PG+PG Model	Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor. Examples: Evaluate properties of a flow of a mixture of two gases, O ₂ and CO ₂ , given the mass or mole fraction of O ₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.
		RG+RG Model	
		MA (Moist Air) Model	



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3. Select H2 for the substance. For State1, enter values of p1, T1 hit Enter. Immediately, many properties of H2 are calculated:

System State Daemon: *Real Gas (RG) Model*
thermofluids.net > Daemons > States > System > RG-Model

Home of TEST

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

State-1 Calculate No-Plots Initialize Choose Fluid: H2

Select RG Sub-Model: Lee-Kesler Nelson-Obert Phase: Superheated Vapor

<input checked="" type="checkbox"/> p1	<input type="checkbox"/> p_r1	<input checked="" type="checkbox"/> T1	<input type="checkbox"/> T_r1	<input type="checkbox"/> Z1
60.0 bar	4.61538 UnitLess	100.0 K	3.01205 UnitLess	1.05699 UnitLess
<input type="checkbox"/> Z_h1	<input type="checkbox"/> Z_s1	<input type="checkbox"/> x1	<input type="checkbox"/> y1	<input type="checkbox"/> v1
0.38662 UnitLess	0.17058 UnitLess	fraction	fraction	0.07265 m^3/kg
<input type="checkbox"/> u1	<input type="checkbox"/> h1	<input type="checkbox"/> s1	<input checked="" type="checkbox"/> Vel1	<input checked="" type="checkbox"/> z1
-3304.394 kJ/kg	-2868.4888 kJ/kg	31.76466 kJ/kg.K	0.0 m/s	0.0 m
<input type="checkbox"/> e1	<input type="checkbox"/> j1	<input type="checkbox"/> phi1	<input type="checkbox"/> psi1	<input type="checkbox"/> m1
-3304.394 kJ/kg	-2868.4888 kJ/kg	kJ/kg	kJ/kg	kg
<input type="checkbox"/> Vol1				
m^3				

Observe that sp. volume = $v1 = 0.07265 \text{ m}^3/\text{kg}$... Ans.

4. Click on **SuperCalculate**, and get the TEST code etc from the I/O panel:

#~~~~~OUTPUT OF SUPER-CALCULATE

Daemon Path: States>System>RG-Model; v-10.ca08

#

#-----Start of TEST-code-----

States {

State-1: H2;

Given: { p1= 60.0 bar; T1= 100.0 K; Vel1= 0.0 m/s; z1= 0.0 m; }

}

#-----End of TEST-code-----

#

#*****DETAILED OUTPUT:

#

Evaluated States:

#

State-1: H2 > Superheated Vapor;

Given: $p_1 = 60.0$ bar; $T_1 = 100.0$ K; $V_{el1} = 0.0$ m/s;

$z_1 = 0.0$ m;

Calculated: $p_{r1} = 4.6154$ UnitLess; $T_{r1} = 3.012$ UnitLess; $Z_1 = 1.057$ UnitLess;

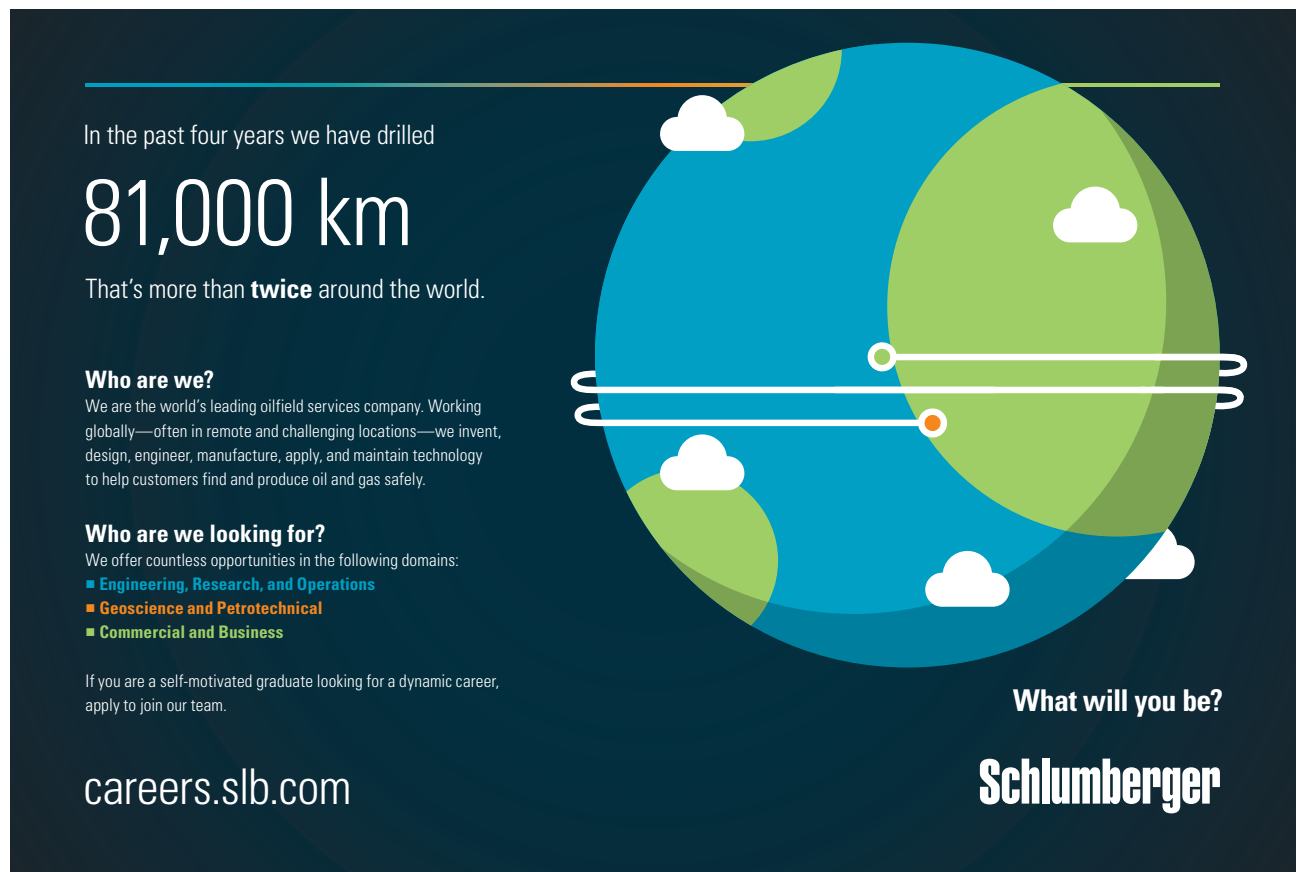
$Z_{h1} = 0.3866$ UnitLess; $Z_{s1} = 0.1706$ UnitLess; $\mathbf{v_1 = 0.0727 \text{ m}^3/\text{kg}}$;

$u_1 = -3304.394$ kJ/kg; $h_1 = -2868.4888$ kJ/kg; $s_1 = 31.7647$ kJ/kg.K;

$e_1 = -3304.394$ kJ/kg; $j_1 = -2868.4888$ kJ/kg;

#

=====



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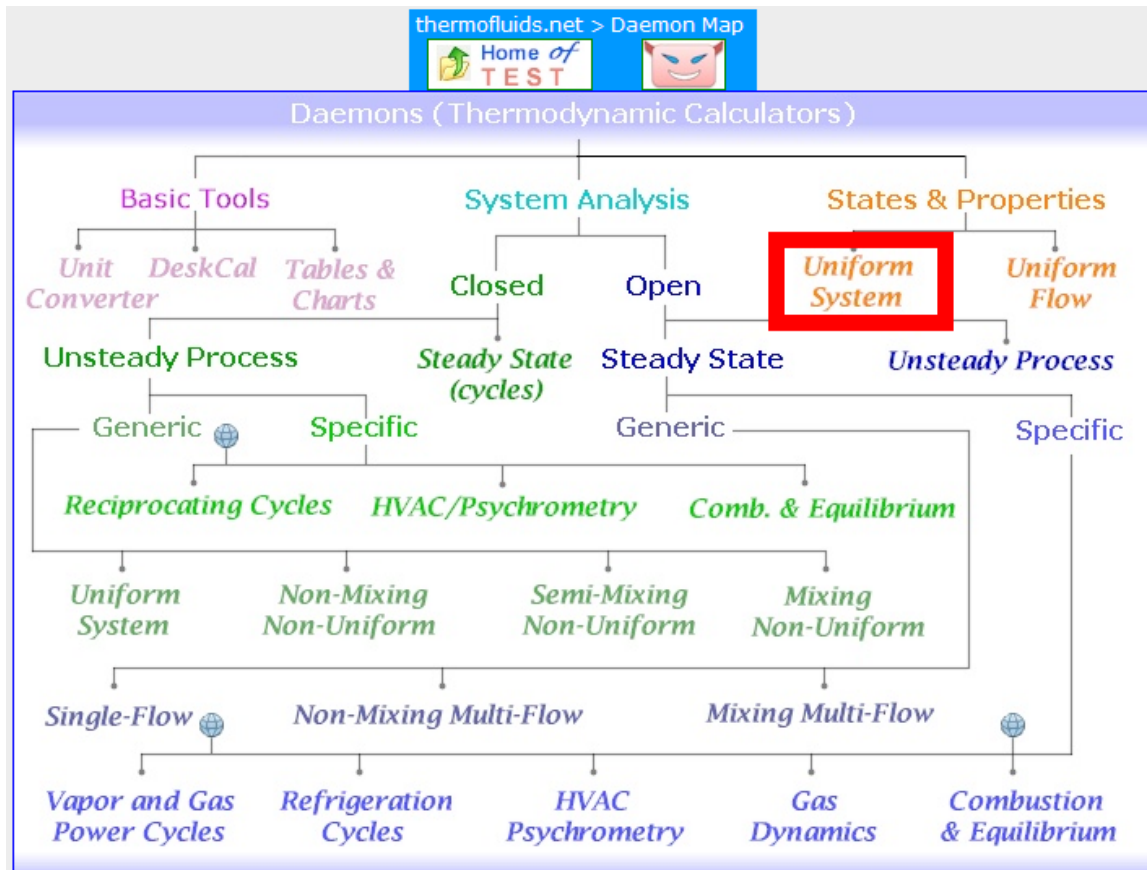


Prob.9.35. A mixture of H₂ and O₂ is in the ratio 2 to 1 by volume. Find the mass of H₂ required and the volume of container per kg of O₂ if the temp and pressure of the mixture are to be 300 K and 100 kPa respectively. [VTU – BTD – July 2002]


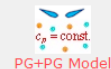
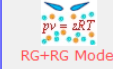
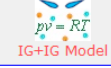
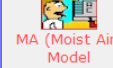


TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select Binary mixtures – IG + IG model as shown below:

Gases:	 RG Model	number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy. Examples: Evaluate the change in entropy of a fixed mass of propane, compressed from a given initial pressure and temperature to a given final pressure at the super critical region. For specific examples, click on the help icon at the bottom margin of the daemon.	
	 PG+PG Model	 RG+RG Model	Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor. Examples: Evaluate properties of a flow of a mixture of two gases, O ₂ and CO ₂ , given the mass or mole fraction of O ₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.
	 IG+IG Model	 MA (Moist Air) Model	
	 n-PG Model	 n-IG Model	General Mixture: Mixture can contain an unlimited number, n , of species. Composition can be specified through mass, volume, mass fraction, or mole fraction. Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.

3. Select H2 for Gas-A and O2 for Gas-B. For State1, enter values of p_1 , T_1 , and mole fraction of H2 = $y_{A1} = 2/3 = 0.6667$ and hit Enter. Immediately, mass fraction x_{A1} for H2, Gas const. for mixture (i.e. R1) and Mol. wt. for the mixture, MM1 are calculated.

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

State-1 Calculate No-Plots Initialize Gas-A: H2 Gas-B: O2

p_1	T_1	v_1	u_1	h_1
100.0 kPa	300.0 K	2.07685 m ³ /kg	-203.75261 kJ/kg	3.93237 kJ/kg
s_1	Vel_1	z_1	e_1	j_1
13.40953 kJ/kg.K	0.0 m/s	0.0 m	-203.75262 kJ/kg	3.93237 kJ/kg
ϕ_1	ψ_1	m_1	Vol_1	MM_1
		kg	m ³	12.00953 kg/kmol
R_1	c_{p1}	x_{A1}	y_{A1}	
0.69228 kJ/kg.K	2.40818 kJ/kg.K	0.11191 fraction	0.6667 fraction	

We observe that:

Mass fraction of H2 = $x_{A1} = 0.11191$

Then, mass fraction of O2 = $1 - 0.11191 = 0.88809$

Therefore, for 1 kg of O2:

Mass of mixture = $1/0.88809 = 1.126$ kg.

And, Mass of H2 = $1.126 - 1 = 0.126$ kg Ans.

Now, go to the above State panel, and enter mass of mixture, $m_1 = 1.126$ kg, and hit Enter.

We get:

The screenshot shows a software interface for thermodynamic calculations. The top bar indicates $T_1 = 300.0$ K [Absolute temperature]. The interface is divided into a 'State Panel' and an 'I/O Panel'. The 'State Panel' has tabs for 'Case-0', 'Case-1', and 'Case-2'. The 'Case-1' tab is active, showing a grid of properties for a gas mixture of H₂ and O₂. The properties are organized into rows and columns, with some values highlighted in green or red. The mass m_1 is entered as 1.126 kg, and the resulting volume Vol_1 is 2.33853 m³.

Property	Value	Unit
p_1	100.0	kPa
T_1	300.0	K
v_1	2.07685	m ³ /kg
u_1	-203.75261	kJ/kg
h_1	3.93237	kJ/kg
s_1	13.40953	kJ/kg.K
Vel_1	0.0	m/s
z_1	0.0	m
e_1	-203.75262	kJ/kg
j_1	3.93237	kJ/kg
ϕ_1		kJ/kg
ψ_1		kJ/kg
m_1	1.126	kg
Vol_1	2.33853	m ³
MM_1	12.00953	kg/kmol
R_1	0.69228	kJ/kg.K
c_{p1}	2.40818	kJ/kg.K
x_{A1}	0.11191	fraction
y_{A1}	0.6667	fraction


Thus:

Volume of mixture (i.e. volume of container required) = $Vol_1 = 2.33853$ m³ ... Ans.

=====



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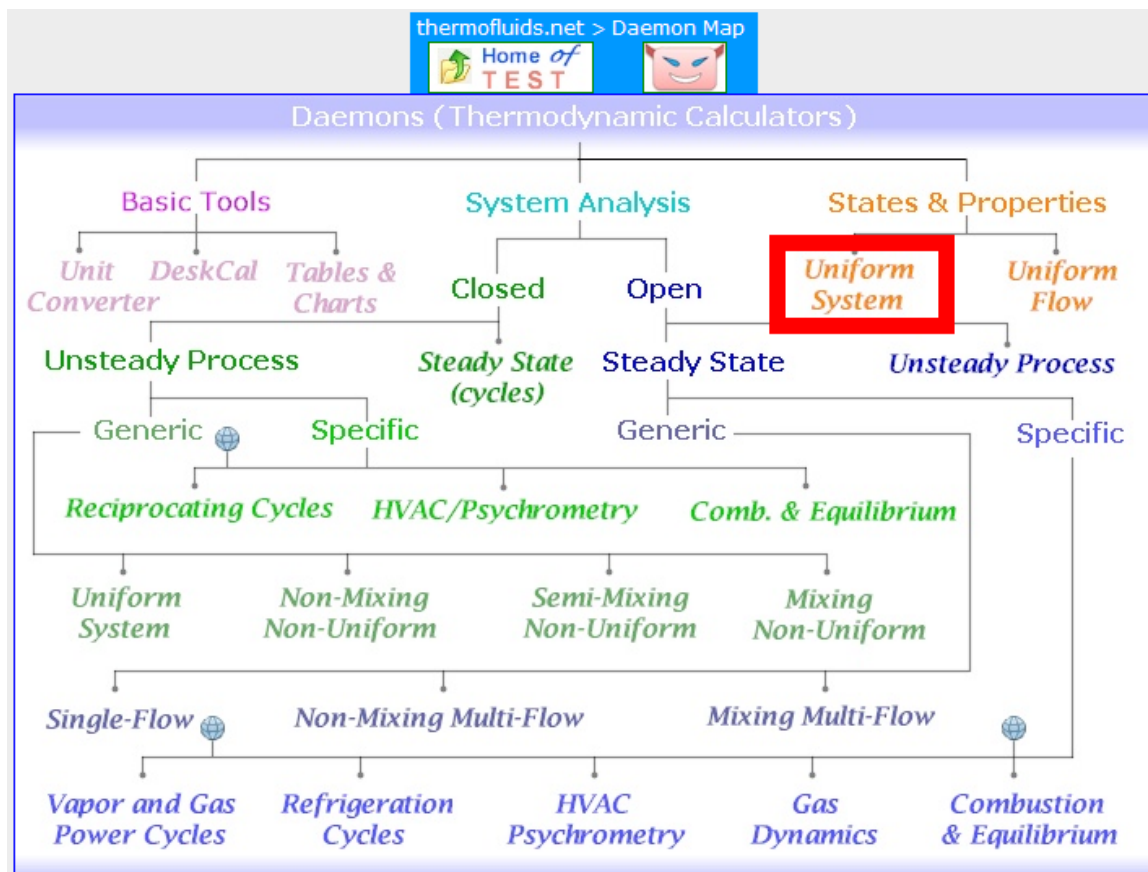


Prob.9.36. A mixture of 0.5 kg of CO₂ and 0.3 kg of N₂ is compressed from $P_1 = 1$ bar, $T_1 = 20$ C to $P_2 = 5$ bar in a polytropic process for which $n = 1.3$. Find (i) the final temp (ii) work (iii) heat transfer (iv) change in entropy of the mixture. [VTU – BTD – Dec. 2012]


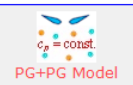


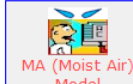
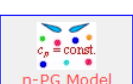
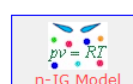
TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select Binary mixtures – IG + IG model as shown below:

Gases:		number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy. Examples: Evaluate the change in entropy of a fixed mass of propane, compressed from a given initial pressure and temperature to a given final pressure at the super critical region. For specific examples, click on the help icon at the bottom margin of the daemon.	
			Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor. Examples: Evaluate properties of a flow of a mixture of two gases, O ₂ and CO ₂ , given the mass or mole fraction of O ₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.
			
			General Mixture: Mixture can contain an unlimited number, <i>n</i> , of species. Composition can be specified through mass, volume, mass fraction, or mole fraction. Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.

3. Select CO₂ for Gas-A and N₂ for Gas-B. For State1, enter values of *p*₁, *T*₁, and mass fraction of CO₂ = *x*_{A1} = 5/8, and mass of mixture, *m*₁ = 0.8 kg, and hit Enter. Immediately, mole fraction *y*_{A1} for CO₂, Gas const. for mixture (i.e. *R*₁) and Mol. wt. for the mixture, *MM*₁, mixture volume, *Vol*₁ are calculated:

System State Daemon: *Binary Mixture of Ideal Gases - IG/IG Model*

thermofluids.net > Daemons > States > System > IG/IG

Move mouse over a variable to display its value with more precision.

State Panel				I/O Panel			
Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize							
State-1 Calculate No-Plots Initialize Gas-A: CO ₂ Gas-B: N ₂							
<i>p</i> ₁	<i>T</i> ₁	<i>v</i> ₁	<i>u</i> ₁	<i>h</i> ₁			
100.0 kPa	20.0 deg-C	0.67254 m ³ /kg	-5660.5386 kJ/kg	-5593.285 kJ/kg			
<i>s</i> ₁	<i>Vel</i> ₁	<i>z</i> ₁	<i>e</i> ₁	<i>j</i> ₁			
5.74758 kJ/kg.K	0.0 m/s	0.0 m	-5660.5386 kJ/kg	-5593.285 kJ/kg			
<i>phi</i> ₁	<i>psi</i> ₁	<i>m</i> ₁	<i>Vol</i> ₁	<i>MM</i> ₁			
		0.8 kg	0.53803 m ³	36.23953 kg/kmol			
<i>R</i> ₁	<i>c_p</i> ₁	<i>x</i> _{A1}	<i>y</i> _{A1}				
0.22942 kJ/kg.K	0.9159 kJ/kg.K	5/8 fraction	0.51465 fraction				

4. For State 2, enter values of p_2 , $v_2 = [(p_1/p_2) * v_1^{1.3}]^{(1/1.3)}$, $m_2 = m_1$, $x_{A2} = x_{A1}$, and hit Enter. We get:

Move mouse over a variable to display its value with more precision.

☒ Mixed
 ☐ SI
 ☐ English
 < Case-0 >
 ☒ Help Messages On
 Super-Iterate
 Super-Calculate
 Load
 Super-Initialize

State Panel I/O Panel

< @State-2 >
 Calculate
 No-Plots
 Initialize
 Gas-A: CO2
 Gas-B: N2

<input checked="" type="checkbox"/> p_2	<input type="checkbox"/> T_2	<input checked="" type="checkbox"/> v_2	<input type="checkbox"/> u_2	<input type="checkbox"/> h_2
500.0 kPa	151.85194 deg-C	$=(p_1/p_2)*v_1^{1.3}$ m ³ /kg	-5564.966 kJ/kg	-5467.4624 kJ/kg
<input type="checkbox"/> s_2	<input checked="" type="checkbox"/> Vel_2	<input checked="" type="checkbox"/> z_2	<input type="checkbox"/> e_2	<input type="checkbox"/> j_2
5.73232 kJ/kg.K	0.0 m/s	0.0 m	-5564.966 kJ/kg	-5467.4624 kJ/kg
<input type="checkbox"/> ϕ_2	<input type="checkbox"/> ψ_2	<input checked="" type="checkbox"/> m_2	<input type="checkbox"/> Vol_2	<input type="checkbox"/> MM_2
		$=m_1$ kg	0.156 m ³	36.23953 kg/kmol
<input type="checkbox"/> R_2	<input type="checkbox"/> c_{p_2}	<input checked="" type="checkbox"/> x_{A2}	<input type="checkbox"/> y_{A2}	
0.22942 kJ/kg.K	0.99449 kJ/kg.K	$=x_{A1}$ fraction	0.51465 fraction	

Thus:

Final temp = $T_2 = 151.85\text{ C} \dots \text{Ans.}$

Work done = $(p_1 * Vol_1 - p_2 * Vol_2) / (1.3 - 1) = -80.664\text{ kJ} \dots \text{work done on the system, since -ve... Ans.}$



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Heat transfer:

By I Law: $Q = dU + W$

Now, $dU = m1 \cdot (u2 - u1) = 76.458 \text{ kJ}$

Therefore, $Q = 76.458 + (-80.664) = -4.206 \text{ kJ} \dots \text{heat rejected} \dots \text{Ans.}$

Change in entropy: $dS = m1 \cdot (s2 - s1) = 0.0128 \text{ kJ/K} \dots \text{Ans.}$

5. Click on **SuperCalculate** and get the TEST code etc from the I/O panel:

#~~~~~OUTPUT OF SUPER-CALCULATE

#

Daemon Path: States>System>IG-BinMixModel; v-10.ca08

#

#-----Start of TEST-code-----

States {

State-1: CO2, N2;

Given: { $p1 = 100.0 \text{ kPa}$; $T1 = 20.0 \text{ deg-C}$; $Vel1 = 0.0 \text{ m/s}$; $z1 = 0.0 \text{ m}$; $m1 = 0.8 \text{ kg}$; $x_{A1} = "5/8"$ fraction; }

State-2: CO2, N2;

Given: { $p2 = 500.0 \text{ kPa}$; $v2 = "((p1/p2) \cdot v1^{1.3})^{(1/1.3)} \text{ m}^3/\text{kg}$; $Vel2 = 0.0 \text{ m/s}$; $z2 = 0.0 \text{ m}$; $m2 = "m1" \text{ kg}$; $x_{A2} = "x_{A1}"$ fraction; }

}

#-----End of TEST-code-----

#

*****DETAILED OUTPUT:

#

Evaluated States:

#

State-1: CO₂, N₂ > IG-BinMixModel;

Given: p₁= 100.0 kPa; T₁= 20.0 deg-C; Vel₁= 0.0 m/s;

z₁= 0.0 m; **m₁= 0.8 kg**; x_{A1}= "5/8" fraction;

#

Calculated: v₁= 0.6725 m³/kg; **u₁= -5660.5386 kJ/kg**; h₁= -5593.285 kJ/kg;

s₁= 5.7476 kJ/kg.K; e₁= -5660.5386 kJ/kg; j₁= -5593.285 kJ/kg;

Vol₁= 0.538 m³; MM₁= 36.2395 kg/kmol; R₁= 0.2294 kJ/kg.K;

c_{p1}= 0.9159 kJ/kg.K; y_{A1}= 0.5147 fraction;

#

State-2: CO₂, N₂ > IG-BinMixModel;

Given: p₂= 500.0 kPa; v₂= "((p₁/p₂)*v₁^{1.3})^(1/1.3)" m³/kg; Vel₂= 0.0 m/s;

z₂= 0.0 m; m₂= "m₁" kg; x_{A2}= "x_{A1}" fraction;

#

Calculated: **T₂= 151.8519 deg-C**; **u₂= -5564.966 kJ/kg**; h₂= -5467.4624 kJ/kg;

s₂= 5.7323 kJ/kg.K; e₂= -5564.966 kJ/kg; j₂= -5467.4624 kJ/kg;

Vol₂= 0.156 m³; MM₂= 36.2395 kg/kmol; R₂= 0.2294 kJ/kg.K;

c_{p2}= 0.9945 kJ/kg.K; y_{A2}= 0.5147 fraction;

#

#-----Property spreadsheet starts:

# State	x _A	y _A	p(kPa)	T(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 1	0.62	0.51	100.0	293.1	0.6725	-5660.54	-5593.29	5.748
# 2	0.62	0.51	500.0	425.0	0.195	-5564.97	-5467.46	5.732

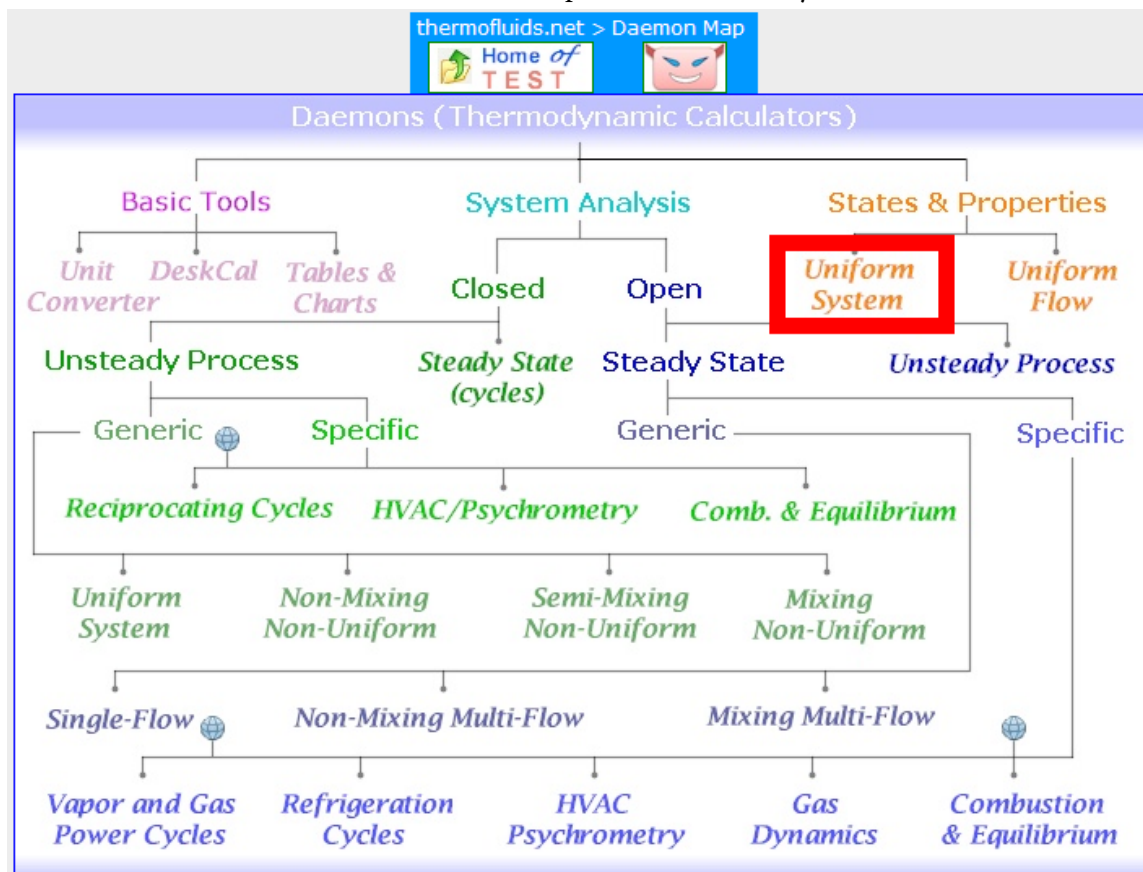
=====

Prob.9.37. A mixture of ideal gases consists of 3 kg of N₂ and 5 kg of CO₂ at a pressure of 300 kPa and temp of 20 C. Find: (i) mole fraction of each component (ii) equivalent mol. wt. of the mixture (iii) equivalent gas constant of the mixture, and (iv) the partial pressure and partial volume. [VTU – BTD – June–July 2008]

TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select Binary mixtures – IG + IG model as shown below:

<p>RG Model</p>	<p>number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy.</p> <p>Examples: Evaluate the change in entropy of a fixed mass of propane, compressed from a given initial pressure and temperature to a given final pressure at the super critical region. For specific examples, click on the help icon at the bottom margin of the daemon.</p>	
<p>PG+PG Model</p>	<p>RG+RG Model</p>	<p>Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor.</p>
<p>IG+IG Model</p>	<p>MA (Moist Air) Model</p>	<p>Examples: Evaluate properties of a flow of a mixture of two gases, O₂ and CO₂, given the mass or mole fraction of O₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.</p>
<p>n-PG Model</p>	<p>n-IG Model</p>	<p>General Mixture: Mixture can contain an unlimited number, n, of species. Composition can be specified through mass, volume, mass fraction, or mole fraction.</p> <p>Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.</p>

3. Select N2 for Gas-A and CO2 for Gas-B. For State1, enter values of p_1 , T_1 , and mass fraction of N2 = $x_{A1} = 3/8$, and mass of mixture, $m_1 = 8$ kg, and hit Enter. Immediately, mole fraction y_{A1} for N2, Gas const. for mixture (i.e. R_1) and Mol. wt. for the mixture, MM_1 , mixture volume, Vol_1 are calculated:

Move mouse over a variable to display its value with more precision.

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

State-1 Calculate No-Plots Initialize Gas-A: N2 Gas-B: CO2

p_1	T_1	v_1	u_1	h_1
300.0 kPa	19.999567 deg-C	0.22418 m³/kg	-5660.5386 kJ/kg	-5593.285 kJ/kg
s_1	Vel_1	z_1	e_1	j_1
5.49554 kJ/kg.K	0.0 m/s	0.0 m	-5660.5386 kJ/kg	-5593.285 kJ/kg
ϕ_1	ψ_1	m_1	Vol_1	MM_1
		8.0 kg	1.79344 m³	36.23953 kg/kmol
R_1	c_{p1}	x_{A1}	y_{A1}	
0.22942 kJ/kg.K	0.9159 kJ/kg.K	3/8 fraction	0.48535 fraction	

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Thus:

Mole fraction of N₂ = $y_{A1} = 0.48535$ C Ans.

Therefore, Mole fraction of CO₂ = $1 - 0.4853 = 0.5147$ Ans.

Equiv. mol. wt. of mixture = $MM1 = 36.2395$ kg/kmol... Ans.

Equiv. Gas const. of mixture = $R1 = 0.22942$ kJ/kg.K ... Ans.

Partial pressure of N₂ = $y_{A1} * p1 = 145.6$ kPa Ans.

Partial pressure of CO₂ = $300 - 145.6 = 154.4$ kPa Ans.

Partial volume of N₂ = $y_{A1} * Vol1 = 0.87$ m³ Ans.

Partial volume of CO₂ = $Vol1 - 0.87 = 0.923$ m³.... Ans.

4. Click on **SuperCalculate** and get the TEST code etc from the I/O panel:

#~~~~~OUTPUT OF SUPER-CALCULATE

#

Daemon Path: States>System>IG-BinMixModel; v-10.ca08

#

#-----Start of TEST-code-----

States {

State-1: N₂, CO₂;

Given: { $p1 = 300.0$ kPa; $T1 = 20.0$ deg-C; $Vel1 = 0.0$ m/s; $z1 = 0.0$ m; $m1 = 8.0$ kg; $x_{A1} = "3/8"$ fraction; }

}

#-----End of TEST-code-----

#

#*****DETAILED OUTPUT:

#

Evaluated States:

#

State-1: N2, CO2 > IG-BinMixModel;

Given: $p_1 = 300.0$ kPa; $T_1 = 20.0$ deg-C; $V_{el1} = 0.0$ m/s;

$z_1 = 0.0$ m; $m_1 = 8.0$ kg; $x_{A1} = "3/8"$ fraction;

#

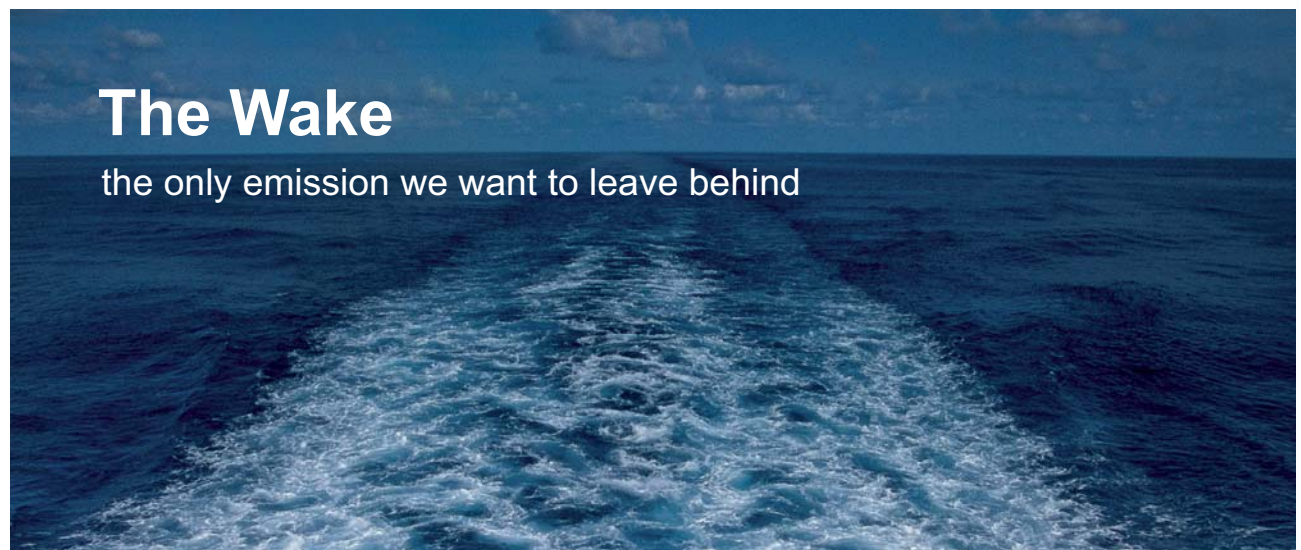
Calculated: $v_1 = 0.2242$ m³/kg; $u_1 = -5660.5386$ kJ/kg; $h_1 = -5593.285$ kJ/kg;

$s_1 = 5.4955$ kJ/kg.K; $e_1 = -5660.5386$ kJ/kg; $j_1 = -5593.285$ kJ/kg;

$V_{ol1} = 1.7934$ m³; $MM_1 = 36.2395$ kg/kmol; $R_1 = 0.2294$ kJ/kg.K;

$c_{p1} = 0.9159$ kJ/kg.K; $y_{A1} = 0.4854$ fraction;

#



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#-----Property spreadsheet starts:

#

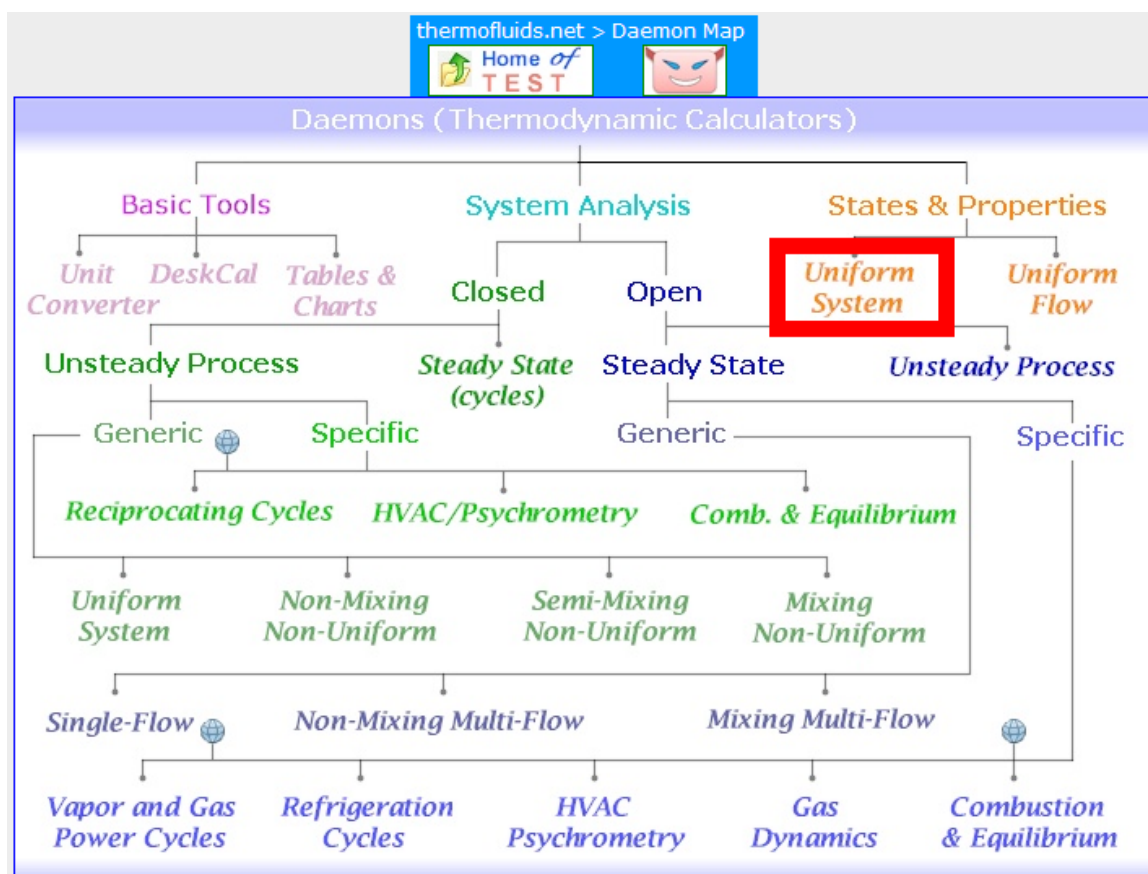
#	State	x_A	y_A	p(kPa)	T(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 1		0.38	0.49	300.0	293.1	0.2242	-5660.54	-5593.29	5.496

Prob.9.38. A mixture of gases has the following volumetric composition: CO₂ = 12%, O₂ = 4%, N₂ = 82% and CO = 2%. Calculate: (i) the gravimetric composition (ii) Mol. wt. of mixture (iii) Gas const. R for the mixture [VTU – BTD – March, 2001]

TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



- For Material model, select General mixture – n- IG model as shown below. It can contain an unlimited number, n , of species.

Gases:

 $c_p = \text{const.}$ PG+PG Model	 RG+RG Model	Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor. Examples: Evaluate properties of a flow of a mixture of two gases, O_2 and CO_2 , given the mass or mole fraction of O_2 (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.
 $pV = RT$ IG+IG Model	 MA (Moist Air) Model	
 $c_p = \text{const.}$ n-PG Model	 $pV = RT$ n-IG Model	General Mixture: Mixture can contain an unlimited number, n , of species. Composition can be specified through mass, volume, mass fraction, or mole fraction. Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases For specific examples, click on the help icon at the bottom margin of the daemon.

- Now, form the mixture:** To do this, Instructions are given in the blue window:

% by Mass
 Formation Enthalpy: ☐ No ☒ Yes

-----INSTRUCTIONS: COMPOSING A GAS MIXTURE-----

Create a frozen gas mixture in this panel, which serves as the working substance for all states. To create the mixture, repeat the following:

i) Select a gas; ii) Enter an amount in mass, mole, or percent; iii) The composition of the mixture is displayed as you add each new component; To remove a component from the mixture, add zero amount of that component; iv) Evaluate a state to obtain the partial specific properties.

After the mixture is formed, you can evaluate any state by entering known properties. As you select a new state, the composition is frozen and carried over. A table of partial properties (partial specific enthalpy, entropy, Gibbs function (chemical potential), and the corresponding molar properties) is displayed in this panel. As you add or remove a component or change any input properties, the table is updated.

- i.e. To form the mixture, go to the lower blue portion of the window, and select the gas from the widget, enter its % by volume or mass etc. as shown and click on Add/Modify. Then that gas gets entered in the blue window below. Do this for each component, and click on Calculate. We get:

thermofluids.net > Daemons > States > System > n-IG

Home of TEST

Move mouse over a variable to display its value with more precision.

☒ Mixed ☐ SI ☐ English ☒ Help Messages On

State Panel I/O Panel

p_1	T_1	v_1	u_1	h_1
kPa	K	m^3/kg	kJ/kg	kJ/kg
s_1	g_1	Vel_1	z_1	e_1
$kJ/kg.K$	kJ/kg	m/s	m	kJ/kg
j_1	m_1	Vol_1	MM_1	c_{p1}
kJ/kg	kg	m^3	$kg/kmol$	$kJ/kg.K$

% by Vol
 Formation Enthalpy: ☒ No ☐ Yes

Composition and Partial Properties (partial properties calculated only after mixture pressure and temperature are entered or calculated.):

MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)	h_k(kJ/kg)	h_bar_k(kJ/kmol)	p_k(kPa)	s0_k(kJ/kg.K)	s0_bar_k(kJ/kmol.K)	s_k(kJ/kg.K)	s_bar_k(kJ/kmol.K)	g_k(kJ/kg)	g_bar_k(kJ/kmol)
032.00	128.000	04.000	0.0426	0.0400	0000000.0	00000000.0	0000.000	-100	-100				
028.00	2298.000	82.000	0.7633	0.8200	0000000.0	00000000.0	0000.000	-100	-100				
044.01	528.120	12.000	0.1756	0.1200	0000000.0	00000000.0	0000.000	-100	-100				
028.01	56.020	02.000	0.0186	0.0200	0000000.0	00000000.0	0000.000	-100	-100				

Total mass (kg): 3008.140, Total mole (kmol): 100.000

Thus:

Gravimetric composition, i.e. x_{A1} etc. See the x_k column in the blue window above:

We get: O₂: 0.0426, N₂: 0.7633, CO₂:0.1756, and CO:0.0186 Ans.

Mol. wt. of mixture = MM1 = 30.0814 kg/kmol... Ans.

Gas const. for mixture = $R1 = R_u / MM1 = 8.314 / 30.0814 = 0.27638 \text{ kJ/kg.K}$... Ans.

5. Click on **SuperCalculate** and get the TEST code etc from the I/O panel:

#~~~~~OUTPUT OF SUPER-CALCULATE

#

Daemon Path: States>System>IG-GenMixModel; v-10.ca08

#

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#-----Start of TEST-code-----

```
States {
    State-1: mixture, ;
    Given: { Vel1= 0.0 m/s; z1= 0.0 m; }

}
```

#-----End of TEST-code-----

#

*****DETAILED OUTPUT:

#

Mixture composition:

#

# k	MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)
# O2	32.0	128.0	4.0	0.04255	0.04
# N2	28.0	2296.0	82.0	0.76326	0.82
# CO2	44.01	528.12	12.0	0.17556	0.12
# CO	28.01	56.02	2.0	0.01862	0.02
# Total	30.08	3008.14	100.0		

#

Evaluated States:

#

```
#      State-1: mixture, > ;
#      Given: Vel1= 0.0 m/s; z1= 0.0 m;
#      Calculated: MM1= 30.0814 kg/kmol;
#
```

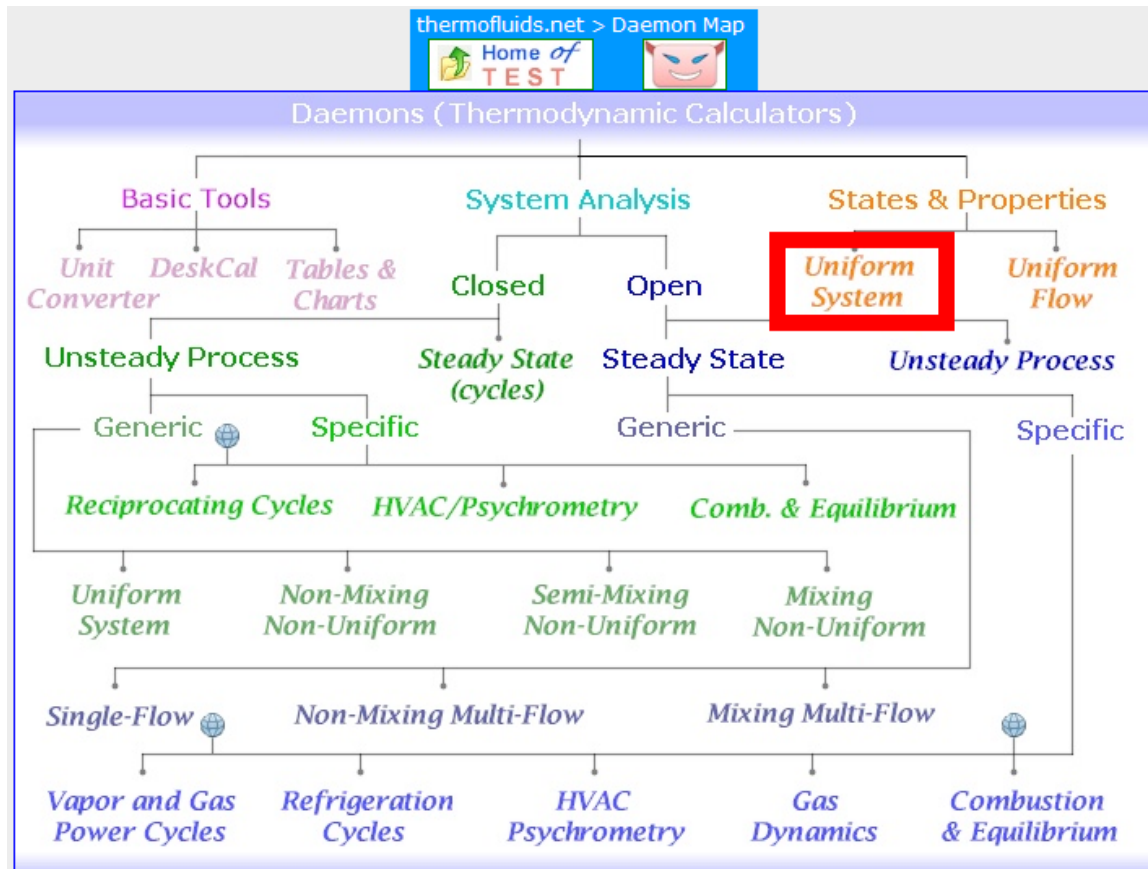
=====

Prob.9.39. A 2 kg mixture of 25% N₂, 50% O₂ and 25% CO₂ by mass is at 150 kPa and 300 K. Find the mixture gas const. and the total volume. [Ref: 2]

TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select General mixture – n- IG model as shown below. It can contain an unlimited number, n, of species.

Gases:		
$c_p = \text{const.}$ PG+PG Model	$c_p = \text{const.}$ RG+RG Model	Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor. Examples: Evaluate properties of a flow of a mixture of two gases, O ₂ and CO ₂ , given the mass or mole fraction of O ₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.
$p v = R T$ IG+IG Model	MA (Moist Air) Model	
$c_p = \text{const.}$ n-PG Model	$p v = R T$ n-IG Model (highlighted in red)	General Mixture: Mixture can contain an unlimited number, n , of species. Composition can be specified through mass, volume, mass fraction, or mole fraction. Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.

3. **Now, form the mixture:** To do this, Instructions are given in the blue window:

O2 1.0 % by Mass Add/Modify Formation Enthalpy: ☐ No ☒ Yes

-----INSTRUCTIONS: COMPOSING A GAS MIXTURE-----

Create a frozen gas mixture in this panel, which serves as the working substance for all states. To create the mixture, repeat the following:

i) Select a gas; ii) Enter an amount in mass, mole, or percent; iii) The composition of the mixture is displayed as you add each new component; To remove a component from the mixture, add zero amount of that component; iv) Evaluate a state to obtain the partial specific properties.

After the mixture is formed, you can evaluate any state by entering known properties. As you select a new state, the composition is frozen and carried over. A table of partial properties (partial specific enthalpy, entropy, Gibbs function (chemical potential), and the corresponding molar properties) is displayed in this panel. As you add or remove a component or change any input properties, the table is updated.

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4. i.e. to form the mixture, go down to the lower blue window, and select the gas from the widget, enter its % by mass or volume etc. as shown and click on Add/Modify. Then that gas gets entered in the blue window below. Do this for each component, and also enter for State 1 (in the State panel) values for p_1 , T_1 and m_1 . Then, click on Calculate. Many properties of the mixture are calculated immediately:

thermofluids.net > Daemons > States > System > n-IG

Home of TEST

Move mouse over a variable to display its value with more precision.

☒ Mixed ☐ SI ☐ English ☒ Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< @State-1 > Calculate No-Plots Initialize

☒ p_1 150.0 kPa ☒ T_1 300.0 K v_1 0.50273 m³/kg u_1 -2309.525 kJ/kg h_1 -2234.115 kJ/kg

s_1 6.29096 kJ/kg.K g_1 -4121.404 kJ/kg ☒ Vel_1 0.0 m/s ☒ z_1 0.0 m e_1 -2309.525 kJ/kg

j_1 -2234.115 kJ/kg ☒ m_1 2.0 kg Vol_1 1.00547 m³ MM_1 33.07524 kg/kmol c_{p1} 0.92373 kJ/kg.K

CO2 25.0 % by Mass Add/Modify Formation Enthalpy: ☐ No ☒ Yes

Composition and Partial Properties (partial properties calculated only after mixture pressure and temperature are entered or calculated.):

MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)	h_k(kJ/kg)	hbar_k(kJ/kmol)	p_k(kPa)	s0_k(kJ/kg.K)	s0bar_k(kJ/kmol.K)	s_k(kJ/kg.K)	sbar_k(kJ/kmol.K)	g_k(kJ/
032.00	01.000	00.031	0.5000	0.5168	0000001.1	00000034.2	0077.520	06.41401	205.248	06.48359	207.475	-0194
028.00	00.500	00.018	0.2500	0.2953	0000001.5	00000042.6	0044.297	06.84776	191.737	07.09344	198.616	-02126
044.01	00.500	00.011	0.2500	0.1879	-0008940.2	-00393456.6	0028.183	04.86293	214.018	05.10467	224.656	-104

Total mass (kg): 02.000, Total mole (kmol): 00.060

Thus:

Mixture Mol. wt. = $MM_1 = 33.07524 \text{ kg/kmol}$ Ans.

Mixture Gas Const. = $R_u / MM_1 = 0.2514 \text{ kJ/kg.K}$... Ans.

Mixture volume = $Vol_1 = 1.00547 \text{ m}^3$... Ans.

5. Click on **SuperCalculate** and get the TEST code etc from the I/O panel:

#~~~~~OUTPUT OF SUPER-CALCULATE:

#

Daemon Path: States>System>IG-GenMixModel; v-10.ca08

#

#-----Start of TEST-code-----

```
States {
    State-1: mixture, ;
    Given: { p1= 150.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s; z1= 0.0 m; m1= 2.0 kg; }

}
```

#-----End of TEST-code-----

*****DETAILED OUTPUT:

#

Mixture composition:

#

# k	MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)
#					
#	O2 32.0	1.0	0.03125	0.5	0.5168
#	N2 28.0	0.5	0.01786	0.25	0.29531
#	CO2 44.01	0.5	0.01136	0.25	0.18788
#	Total 33.08	2.0	0.06047		

#

Evaluated States:

#

State-1: mixture, > ;

Given: p1= 150.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s;

z1= 0.0 m; m1= 2.0 kg;

Calculated: v1= 0.5027 m³/kg; u1= -2309.525 kJ/kg; h1= -2234.115 kJ/kg;

s1= 6.291 kJ/kg.K; g1= -4121.404 kJ/kg; e1= -2309.525 kJ/kg;

j1= -2234.115 kJ/kg; **Vol1= 1.0055 m³; MM1= 33.0752 kg/kmol;**

c_p1= 0.9237 kJ/kg.K;

#

#-----Property spreadsheet starts:


#

# State	p(kPa)	(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 1	150.0	300.0	0.5027	-2309.52	-2234.11	6.291

=====

Prob.9.40. A mixture of ideal gases has the following composition by mass: N₂ = 75%, O₂ = 13%, CO₂ = 12%. 2 kg of the mixture, initially at 3 bar and 127 °C is compressed polytropically to 10 bar. The index of compression is 1.3. Calculate: (i) work done (ii) change in enthalpy, and (iii) change in internal energy. [M.U. – April 1996]

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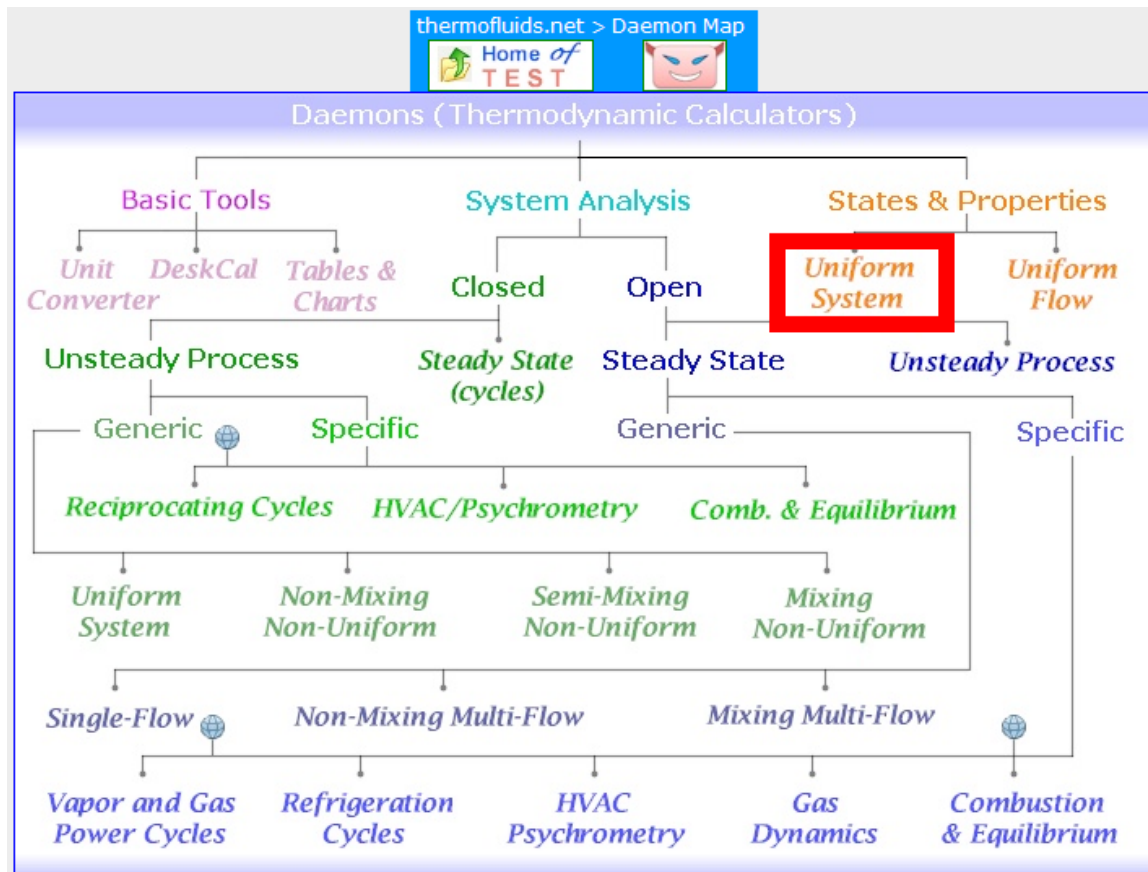
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TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select General mixture – n- IG model as shown below. It can contain an unlimited number, n, of species.

Gases:	$c_p = \text{const.}$ PG+PG Model	 RG+RG Model	<p>Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor.</p> <p>Examples: Evaluate properties of a flow of a mixture of two gases, O₂ and CO₂, given the mass or mole fraction of O₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.</p>
	$p\nu = RT$ IG+IG Model	 MA (Moist Air) Model	
	$c_p = \text{const.}$ n-PG Model	 n-IG Model	

General Mixture: Mixture can contain an unlimited number, n, of species. Composition can be specified through mass, volume, mass fraction, or mole fraction.

Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.

3. **Now, form the mixture:** To do this, follow Instructions given in the blue window:

i.e. to form the mixture, go down to the lower blue window, and select the gas from the widget, enter its % by mass or volume etc. as shown and click on Add/Modify. Then that gas gets entered in the blue window below. Do this for each component, and also enter **for State 1** (in the State panel) values for p_1 , T_1 and m_1 . Then, click on Calculate. Many properties of the mixture are calculated immediately:

Move mouse over a variable to display its value with more precision.

Mixed SI English Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< State-1 > Calculate No-Plots Initialize

<input checked="" type="checkbox"/> p_1	3.0 bar	<input checked="" type="checkbox"/> T_1	127.0 deg-C	<input checked="" type="checkbox"/> v_1	0.37233 m ³ /kg	<input checked="" type="checkbox"/> u_1	-1082.2665 kJ/kg	<input checked="" type="checkbox"/> h_1	-970.568 kJ/kg
<input type="checkbox"/> s_1	6.71872 kJ/kg.K	<input type="checkbox"/> g_1	-3659.0637 kJ/kg	<input checked="" type="checkbox"/> Vel_1	0.0 m/s	<input checked="" type="checkbox"/> z_1	0.0 m	<input type="checkbox"/> e_1	-1082.2665 kJ/kg
<input type="checkbox"/> j_1	-970.568 kJ/kg	<input checked="" type="checkbox"/> m_1	2.0 kg	<input type="checkbox"/> Vol_1	0.74466 m ³	<input type="checkbox"/> MM_1	29.78418 kg/kmol	<input type="checkbox"/> c_{p1}	1.02308 kJ/kg.K

CO2 12.0 % by Mass Add/Modify Formation Enthalpy: No Yes

Composition and Partial Properties (partial properties calculated only after mixture pressure and temperature are entered or calculated.):

MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)	h_k(kJ/kg)	hbar_k(kJ/kmol)	p_k(kPa)	s0_k(kJ/kg.K)	s0bar_k(kJ/kmol.K)	s_k(kJ/kg.K)	sbar_k(kJ/kmol.K)	g_k(kJ/
032.00	00.260	00.008	0.1300	0.1210	0000094.4	00003022.2	0036.299	06.68224	213.832	06.94894	222.366	-02686
028.00	01.500	00.054	0.7500	0.7978	0000105.6	00002957.3	0239.337	07.14704	200.117	06.89182	192.971	-02652
044.01	00.240	00.005	0.1200	0.0812	-0008850.6	-00389513.7	0024.363	05.11997	225.330	05.38921	237.179	-110

Total mass (kg): 02.000, Total mole (kmol): 00.067

Note from the above that Mixture vol. = 0.74466 m³, Mixture Mol. wt. = 29.78418 kg/kmol, Mixture c_p = 1.02308 kJ/kg.K.

4. Enter p_2 , $m_2 = m_1$ and $v_2 = [(p_1 * v_1^{1.3}) / p_2]^{(1/1.3)}$ for State 2, and hit Enter:

Move mouse over a variable to display its value with more precision.

Mixed SI English Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< State-2 > Calculate No-Plots Initialize

<input checked="" type="checkbox"/> p_2	10.0 bar	<input type="checkbox"/> T_2	255.15787 deg-C	<input checked="" type="checkbox"/> v_2	=((p1*v1^1.3)/p2) m ³ /kg	<input type="checkbox"/> u_2	-984.6251 kJ/kg	<input type="checkbox"/> h_2	-837.1525 kJ/kg
<input type="checkbox"/> s_2	6.67178 kJ/kg.K	<input type="checkbox"/> g_2	-4361.908 kJ/kg	<input checked="" type="checkbox"/> Vel_2	0.0 m/s	<input checked="" type="checkbox"/> z_2	0.0 m	<input type="checkbox"/> e_2	-984.6252 kJ/kg
<input type="checkbox"/> j_2	-837.1525 kJ/kg	<input checked="" type="checkbox"/> m_2	=m1 kg	<input type="checkbox"/> Vol_2	0.29495 m ³	<input type="checkbox"/> MM_2	29.78418 kg/kmol	<input type="checkbox"/> c_{p2}	1.05837 kJ/kg.K

O2 1.0 % by Mass Add/Modify Formation Enthalpy: No Yes

Composition and Partial Properties (partial properties calculated only after mixture pressure and temperature are entered or calculated.):

MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)	h_k(kJ/kg)	hbar_k(kJ/kmol)	p_k(kPa)	s0_k(kJ/kg.K)	s0bar_k(kJ/kmol.K)	s_k(kJ/kg.K)	sbar_k(kJ/kmol.K)	g_k(kJ/
032.00	00.260	00.008	0.1300	0.1210	0000219.5	00007023.5	0120.998	06.95307	222.498	06.90697	221.023	-03426
028.00	01.500	00.054	0.7500	0.7978	0000241.6	00006764.2	0797.791	07.44164	208.366	06.82892	191.210	-03366
044.01	00.240	00.005	0.1200	0.0812	-0008724.0	-00383942.2	0081.211	05.39383	237.382	05.43563	239.222	-115

We see from the above that properties in State 2 are calculated.

5. Now, click on **SuperCalculate** and go to I/O panel. TEST code etc are available there. Also, we can use the I/O panel as a calculator to calculate the required quantities. Here, the advantage of using I/O panel is that you can transfer the quantities from the States panel just by entering the names of variables:

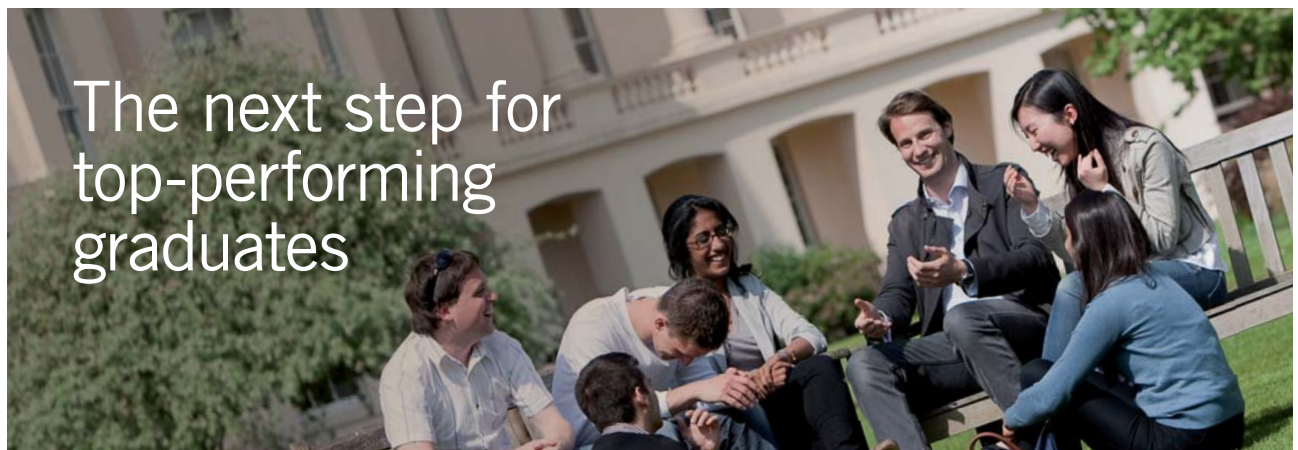
i.e. We get:

Work done: $W = m1 * (p1 * v1 - p2 * v2)/(1.3 - 1) = -238.495 \text{ kJ} \dots \text{work}$

done on the gas, so -ve.... Ans.

#Change in Enthalpy: $dH = m1 * (h2 - h1) = 266.831 \text{ kJ} \dots \text{Ans.}$

#Change in Internal energy: $dU = m1 * (u2 - u1) = 195.283 \text{ kJ} \dots \text{Ans.}$



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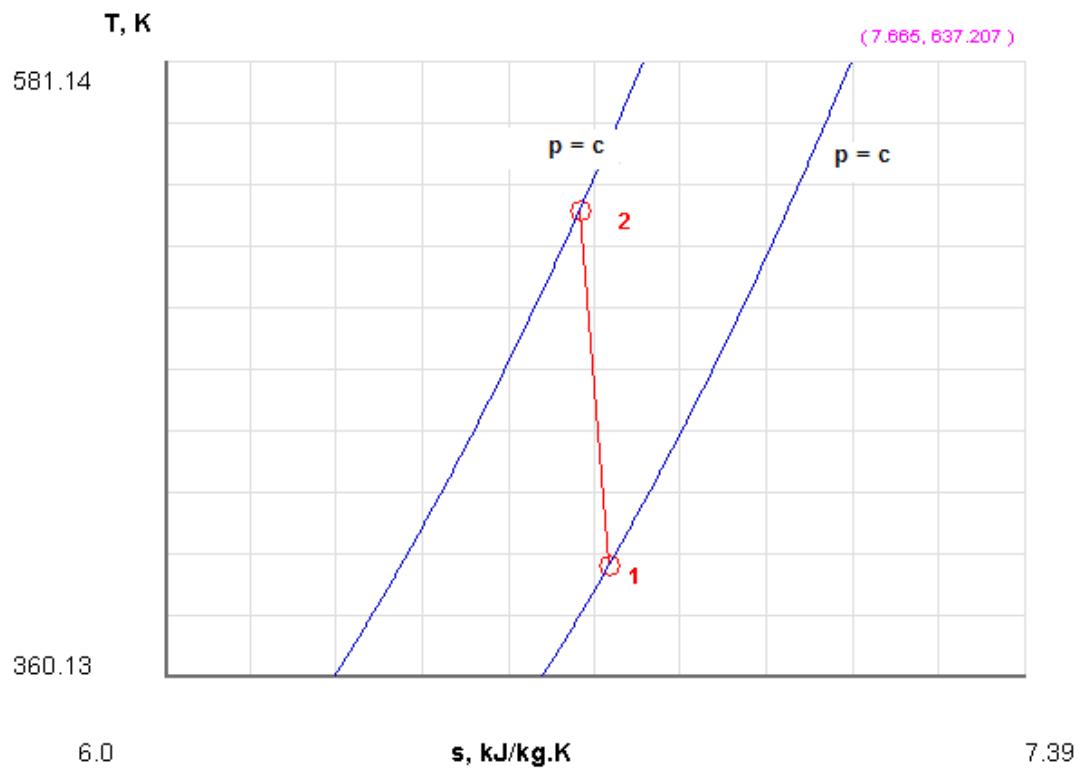
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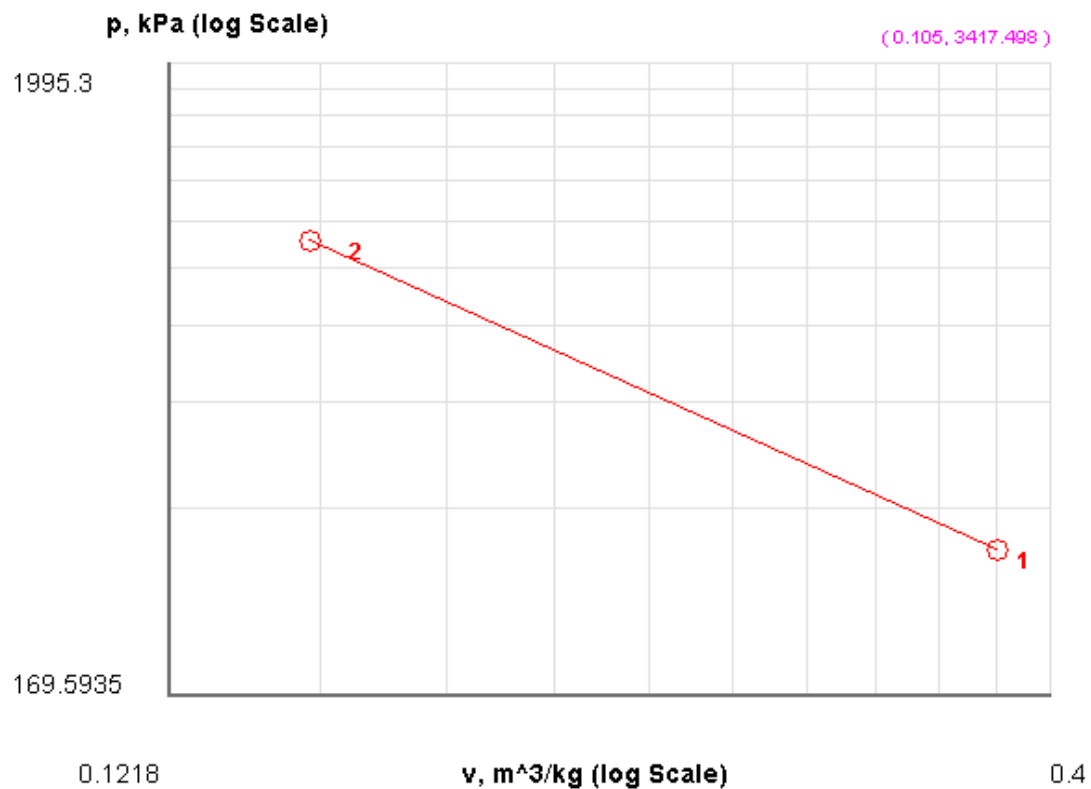
* Figures taken from London Business School's Masters in Management 2010 employment report



6. From the Plots widget, get **T-s diagram**, shown below:



And, the p-v diagram:



7. Also, get the TEST code etc from the I/O panel:

```
#~~~~~OUTPUT OF SUPER-CALCULATE

#

#      Daemon Path: States>System>IG-GenMixModel; v-10.ca08

#

#-----Start of TEST-code-----

States  {

    State-1: mixture, ;
    Given: { p1= 3.0 bar; T1= 127.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 2.0 kg; }

    State-2: mixture, ;
    Given: { p2= 10.0 bar; v2= "((p1*v1^1.3)/p2)^(1/1.3)" m^3/kg; Vel2= 0.0 m/s; z2= 0.0 m; m2=
    "m1" kg; }

    }

#-----End of TEST-code-----

#*****DETAILED OUTPUT: #

#

# Mixture composition:

#

# k      MM_k(kg/kmol) m_k(kg)      n_k(kmol) x_k(m_k/m) y_k(n_k/n)
#
# O2      32.0    0.26      0.00812    0.13      0.12
# N2      28.0    1.5      0.05357    0.75      0.79779
# CO2     44.01   0.24      0.00545    0.12      0.08121
# Total   29.78   2.0      0.06715

#
```

Evaluated States:

#

State-1: mixture, > ;

Given: $p_1 = 3.0$ bar; $T_1 = 127.0$ deg-C; $Vel_1 = 0.0$ m/s;

$z_1 = 0.0$ m; $m_1 = 2.0$ kg;

Calculated: $v_1 = 0.3723$ m³/kg; $u_1 = -1082.2665$ kJ/kg; $h_1 = -970.568$ kJ/kg;

$s_1 = 6.7187$ kJ/kg.K; $g_1 = -3659.0637$ kJ/kg; $e_1 = -1082.2665$ kJ/kg;

$j_1 = -970.568$ kJ/kg; **Vol1 = 0.7447 m³; MM1 = 29.7842 kg/kmol;**

$c_{p1} = 1.0231$ kJ/kg.K;

#

State-2: mixture, > ;

Given: $p_2 = 10.0$ bar; $v_2 = ((p_1 * v_1^{1.3}) / p_2)^{(1/1.3)}$ m³/kg; $Vel_2 = 0.0$ m/s;

$z_2 = 0.0$ m; $m_2 = "m_1"$ kg;

Calculated: $T_2 = 255.1579$ deg-C; $u_2 = -984.6251$ kJ/kg; $h_2 = -837.1525$ kJ/kg;

$s_2 = 6.6718$ kJ/kg.K; $g_2 = -4361.908$ kJ/kg; $e_2 = -984.6252$ kJ/kg;

$j_2 = -837.1525$ kJ/kg; **Vol2 = 0.295 m³; MM2 = 29.7842 kg/kmol;**

$c_{p2} = 1.0584$ kJ/kg.K;

#

#-----Property spreadsheet starts:

#

# State	p(kPa)	T(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 1	300.0	400.1	0.3723	-1082.27	-970.57	6.719
# 2	1000.0	528.3	0.1475	-984.63	-837.15	6.672

#

#*****CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)',
'= sqrt(4*A1/PI)', etc.) and press the Enter key)*****

#

Work done: W

$$=m_1 * (p_1 * v_1 - p_2 * v_2) / (1.3 - 1)$$

$$m_1 * (p_1 * v_1 - p_2 * v_2) / (1.3 - 1) = -238.4946396594271 \text{ kJ Ans.}$$

#Change in Enthalpy: dH :

$$=m1 * (h2 - h1)$$

$$m1 * (h2 - h1) = 266.8309326171875 \text{ kJ} \dots \text{Ans.}$$

#Change in Internal energy: dU :

$$=m1 * (u2 - u1)$$

$$m1 * (u2 - u1) = 195.28271484375 \text{ kJ}$$

=====

Prob.9.41. Natural gas as a mixture of 75% Methane and 25% Ethane by mass, is flowing to a compressor at 17 C and 100 kPa. The reversible adiabatic compressor brings the flow to 250 kPa. Find the exit temp and the needed work per kg flow. [Ref: 2]



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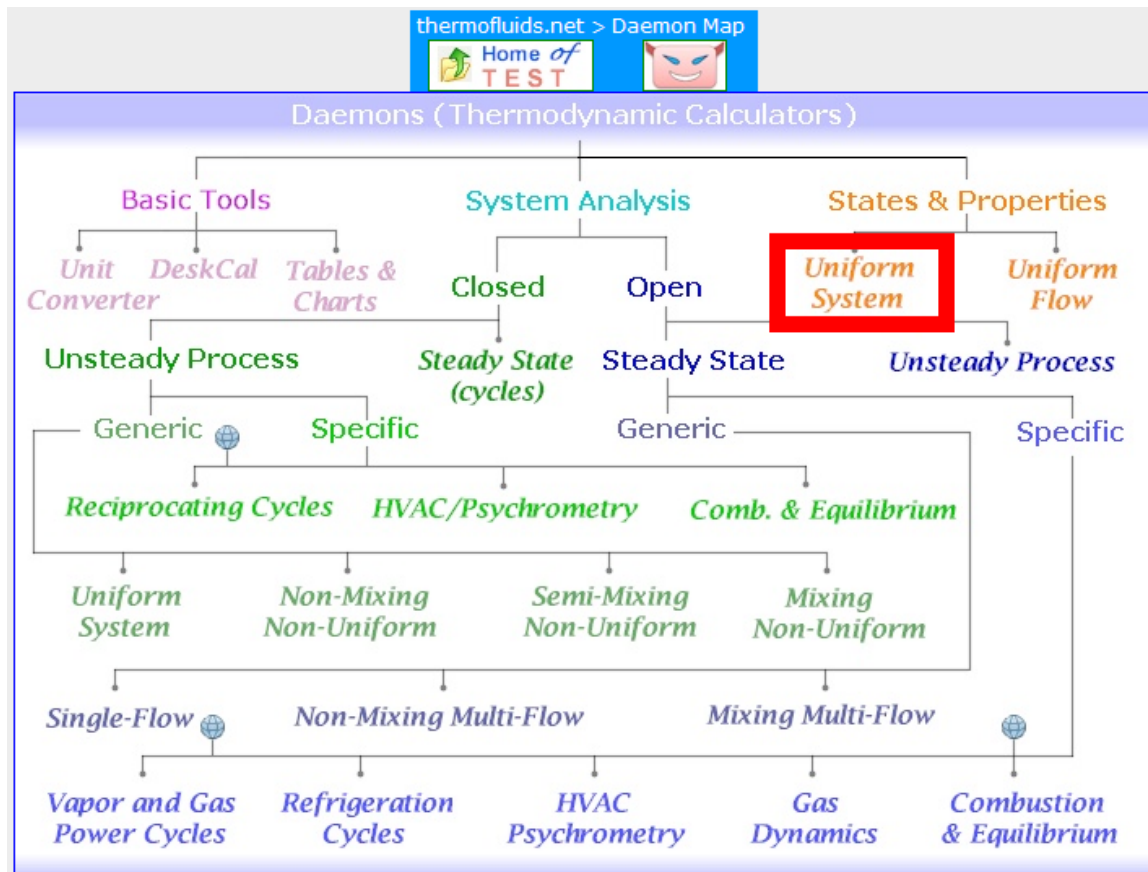


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TEST Solution:

Following are the steps:

1. Go to Daemons tree, select States & Properties – Uniform System:



2. For Material model, select General mixture – n- IG model as shown below. It can contain an unlimited number, n, of species.

Gases:	$c_p = \text{const.}$ PG+PG Model	 RG+RG Model	<p>Binary Mixture: The mixture of two gases, A and B, is expressed in terms of the mass or mole fraction of gas-A. Select one of the mixture models. Moist air is a special case of a binary mixture (PG+PG) of dry gas and water vapor.</p> <p>Examples: Evaluate properties of a flow of a mixture of two gases, O₂ and CO₂, given the mass or mole fraction of O₂ (gas-A). For specific examples, click on the help icon at the bottom margin of the daemon.</p>
	$p\nu = RT$ IG+IG Model	 MA (Moist Air) Model	
	$c_p = \text{const.}$ n-PG Model	 n-IG Model	

General Mixture: Mixture can contain an unlimited number, n, of species. Composition can be specified through mass, volume, mass fraction, or mole fraction.

Examples: Evaluate mixture and partial properties (including chemical potential) of a mixture of several gases. For specific examples, click on the help icon at the bottom margin of the daemon.

3. **Now, form the mixture:** To do this, follow Instructions given in the blue window:

i.e. to form the mixture, go down to the lower blue window, and select the gas from the widget, enter its % by mass or volume etc. as shown and click on Add/Modify. Then that gas gets entered in the blue window below. Do this for each component, and also enter **for State 1** (in the State panel) values for p_1 , T_1 and m_1 . Then, click on Calculate. Many properties of the mixture are calculated immediately:

h1 = -4214.667 kJ/kg [Specific enthalpy]

Mixed SI English Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< @State-1 > Calculate No-Plots Initialize

p_1	100.0	kPa	T_1	17.0	deg-C	v_1	1.32851	m ³ /kg	u_1	-4347.518	kJ/kg	h_1	-4214.667	kJ/kg
s_1	10.75587	kJ/kg.K	g_1	-7335.483	kJ/kg	Vel_1	0.0	m/s	z_1	0.0	m	e_1	-4347.518	kJ/kg
j_1	-4214.667	kJ/kg	m_1	1.0	kg	Vol_1	1.32851	m ³	MM_1	18.15803	kg/kmol	c_{p1}	2.14139	kJ/kg.K

Ethane(C2H6) 25.0 % by Mass Add/Modify Formation Enthalpy: No Yes

Composition and Partial Properties (partial properties calculated only after mixture pressure and temperature are entered or calculated.):

MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)	h_k(kJ/kg)	hbar_k(kJ/kmol)	p_k(kPa)	s0_k(kJ/kg.K)	s0bar_k(kJ/kmol.K)	s_k(kJ/kg.K)	sbar_k(kJ/kmol.K)	g_k(kJ/kg)
016.04	00.750	00.047	0.7500	0.8490	-0004685.6	-00075157.0	0084.904	11.55145	185.285	11.64310	186.755	-080
030.07	00.250	00.008	0.2500	0.1510	-0002802.1	-00084257.8	0015.096	07.57095	227.658	08.09735	243.487	-051

Total mass (kg): 01.000, Total mole (kmol): 00.055

Note from the above that Mixture vol. = 1.32851 m³, Mixture Mol. wt. = 18.15803 kg/kmol, Mixture c_p = 2.14139 kJ/kg.K.

4. For State 2, enter p_2 , $m_2 = m_1$, and $s_2 = s_1$ (since rev. adiabatic process is an isentropic process), $m_2 = m_1$. Hit Enter:

Move mouse over a variable to display its value with more precision.

Mixed SI English Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< @State-2 > Calculate No-Plots Initialize

p_2	250.0	kPa	T_2	77.64013	deg-C	v_2	0.64246	m ³ /kg	u_2	-4241.1143	kJ/kg	h_2	-4080.4985	kJ/kg
s_2	-7853.552	kJ/kg.K	g_2	-7853.552	kJ/kg	Vel_2	0.0	m/s	z_2	0.0	m	e_2	-4241.1143	kJ/kg
j_2	-4080.4985	kJ/kg	m_2	1.0	kg	Vol_2	0.64246	m ³	MM_2	18.15803	kg/kmol	c_{p2}	2.30294	kJ/kg.K

O2 1.0 % by Mass Add/Modify Formation Enthalpy: No Yes

Composition and Partial Properties (partial properties calculated only after mixture pressure and temperature are entered or calculated.):

MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)	h_k(kJ/kg)	hbar_k(kJ/kmol)	p_k(kPa)	s0_k(kJ/kg.K)	s0bar_k(kJ/kmol.K)	s_k(kJ/kg.K)	sbar_k(kJ/kmol.K)	g_k(kJ/kg)
016.04	00.750	00.047	0.7500	0.8490	-0004547.4	-00072940.1	0212.259	11.98357	192.216	11.60028	186.069	-086
030.07	00.250	00.008	0.2500	0.1510	-0002680.4	-00080598.6	0037.741	07.95110	239.090	08.22416	247.300	-055

Total mass (kg): 01.000, Total mole (kmol): 00.055

We see from the above that properties in State 2 are calculated.

5. Now, click on **SuperCalculate** and go to I/O panel. TEST code etc are available there. Also, we can use the I/O panel as a calculator to calculate the required quantities. Here, the advantage of using I/O panel is that you can transfer the quantities from the States panel just by entering the names of variables:

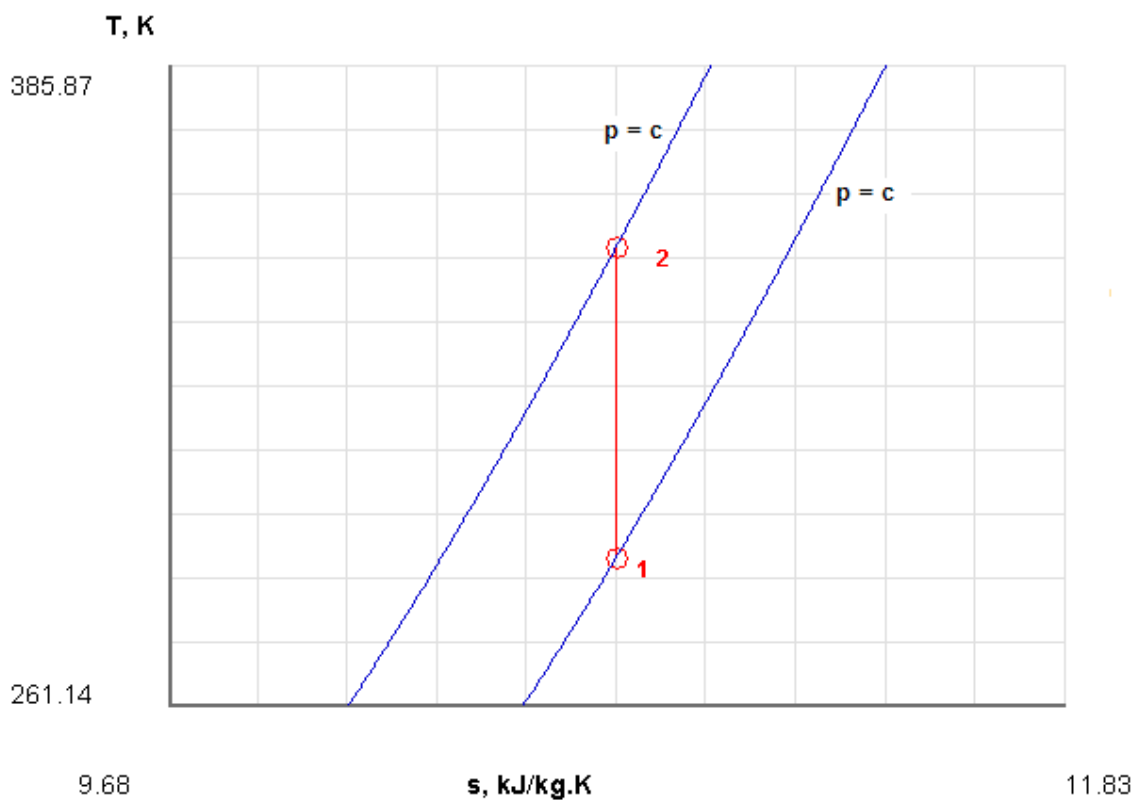
i.e. We get:

#Exit temp. $T_2 = 77.64\text{ C} = 350.790\text{ K} \dots \text{Ans.}$

#Work needed per kg flow, $W = m_1 * (h_2 - h_1) = 134.168\text{ kJ/kg} \dots \text{Ans.}$



6. From the Plots widget, get **T-s diagram**, shown below:



7. And, the TEST code etc from the I/O panel:

```
#~~~~~OUTPUT OF SUPER-CALCULATE

#

#   Daemon Path: States>System>IG-GenMixModel; v-10.ca08

#
```

#-----Start of TEST-code-----

States {

State-1: mixture, ;

Given: { p1= 100.0 kPa; T1= 17.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }

State-2: mixture, ;

Given: { p2= 250.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; }

}

#-----End of TEST-code-----

*****DETAILED OUTPUT:

#

Mixture composition:

#

# k	MM_k(kg/kmol)	m_k(kg)	n_k(kmol)	x_k(m_k/m)	y_k(n_k/n)
# Methane(CH4)	16.04	0.75	0.04676	0.75	0.84904
# Ethane(C2H6)	30.07	0.25	0.00831	0.25	0.15096
# Total	18.16	1.0	0.05507		

#

Evaluated States:

#

State-1: mixture, > ;

Given: p1= 100.0 kPa; T1= 17.0 deg-C; Vel1= 0.0 m/s;

z1= 0.0 m; m1= 1.0 kg;

Calculated: v1= 1.3285 m³/kg; u1= -4347.518 kJ/kg; h1= -4214.667 kJ/kg;

s1= 10.7559 kJ/kg.K; g1= -7335.483 kJ/kg; e1= -4347.518 kJ/kg;

j1= -4214.667 kJ/kg; Vol1= 1.3285 m³; MM1= 18.158 kg/kmol;

c_p1= 2.1414 kJ/kg.K;

#


```
# State-2: mixture, > ;
# Given: p2= 250.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s;
# z2= 0.0 m; m2= "m1" kg;
# Calculated: T2= 77.6401 deg-C; v2= 0.6425 m^3/kg; u2= -4241.1143 kJ/kg;
# h2= -4080.4985 kJ/kg; g2= -7853.552 kJ/kg; e2= -4241.1143 kJ/kg;
# j2= -4080.4985 kJ/kg; Vol2= 0.6425 m^3; MM2= 18.158 kg/kmol;
# c_p2= 2.3029 kJ/kg.K;
#
#-----Property spreadsheet starts:
```

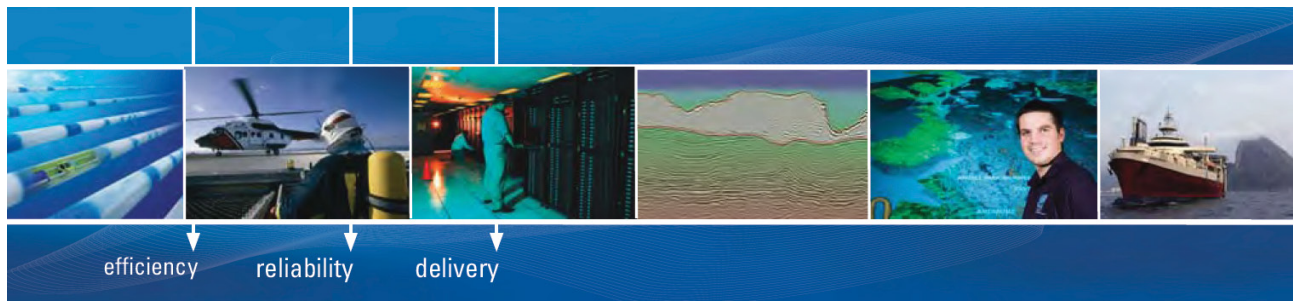
```
#
```

# State	p(kPa)	T(K)	v(m ³ /kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 1	100.0	290.2	1.3285	-4347.52	-4214.67	10.756
# 2	250.0	350.8	0.6425	-4241.11	-4080.5	10.756

```
#
```

```
*****CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)',
'= sqrt(4*A1/PI)', etc.) and press the Enter key)*****
```

```
#
```



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#Exit temp. T2:

$$T_2 = 350.7901306152344 \text{ K ... Ans.}$$

#Work needed per kg flow, W:

$$m_1 * (h_2 - h_1) = 134.16845703125 \text{ kJ/kg Ans.}$$

=====

9.14 REFERENCES:

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2. Sonntag et.al. *Fundamentals of Thermodynamics*. 5th ed. Singapore: John Wiley & Sons, 1999
3. <http://www.lon-capa.org/~mmp/applist/pvt/pvt.htm> (Java Applet for Ideal gas)
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(Van der Waals eqn calculator)
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7. <http://www.ecourses.ou.edu/>
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Appendix

EES Function to find out the compressibility Factor, Z when Tr and Pr are given:

Recall that we have the compressibility factor chart as shown below:

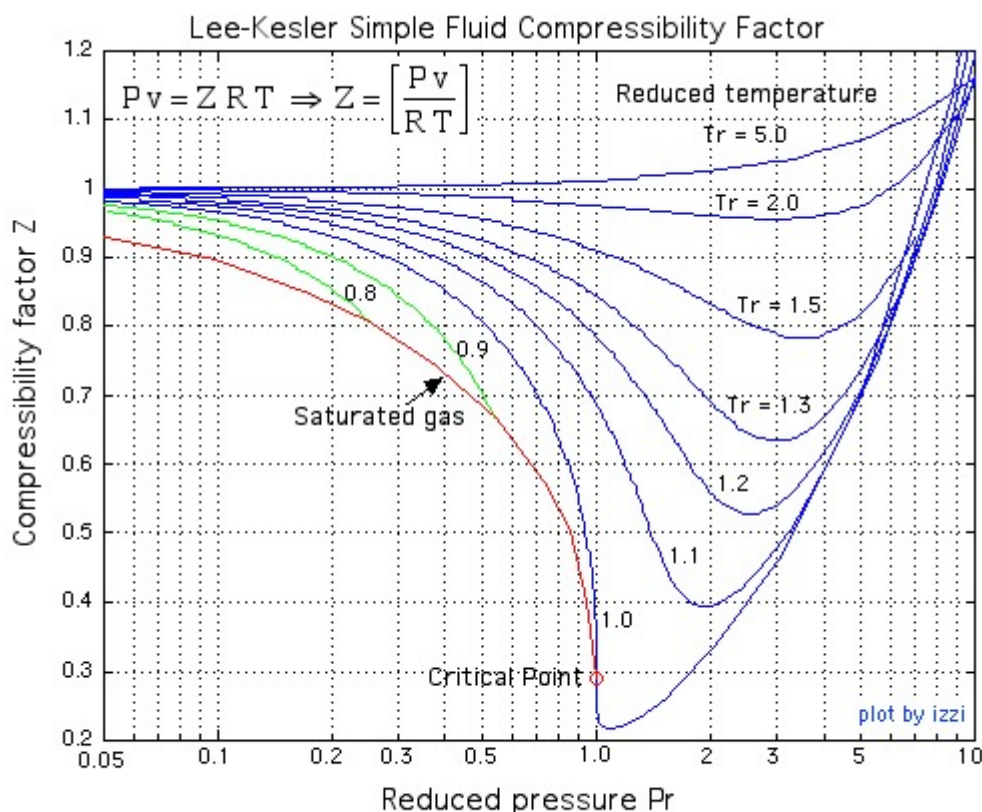


Fig. 9.6 Lee-Kesler compressibility chart [8]

Now, in computer calculations, it is not very convenient to refer to the above graph as and when required. Also, interpolation in this graph is difficult because the x-axis is in logarithmic scale.

Therefore, it is preferable to have an EES Function to calculate Z when Tr and Pr are given. It makes the calculations very easy and simple.

To write the EES Function, following are the steps:

1. Digitize each curve in the above plot using the 'free' software "Plot Digitizer" available from <http://plotdigitizer.sourceforge.net>. It is a Java based program, which is very easy to use.
2. Copy the x-y data produced in PlotDigitizer to EXCEL.
3. Use EES to re-cast the data such that x-axis (i.e. Pr) values are common for all the curves i.e. for Tr = 5, 2, 1.5,0.8, by linear interpolation.

4. Set up the final Table in EXCEL as shown below. Table is shown only partially, to conserve space.

	A	B	C	D	E	F	G	H	I	J	K	L
319			9.55	1.157	1.144	1.327	1.24	1.158	1.146	1.133		
320			9.6	1.158	1.146	1.337	1.244	1.161	1.148	1.138		
321			9.65	1.159	1.149	1.348	1.249	1.164	1.151	1.143		
322			9.7	1.159	1.151	1.359	1.253	1.167	1.153	1.147		
323			9.75	1.16	1.153	1.37	1.258	1.17	1.156	1.152		
324			9.8	1.161	1.155	1.381	1.262	1.172	1.158	1.157		
325			9.85	1.162	1.158	1.391	1.267	1.175	1.161	1.162		
326			9.9	1.166	1.16	1.402	1.271	1.178	1.163	1.167		
327			9.95	1.176	1.162	1.413	1.276	1.181	1.166	1.172		
328			10	1.185	1.164	1.424	1.278	1.183	1.168	1.177		

	A	B	C	D	E	F	G	H	I	J	K	L
319			9.55	1.157	1.144	1.327	1.24	1.158	1.146	1.133		
320			9.6	1.158	1.146	1.337	1.244	1.161	1.148	1.138		
321			9.65	1.159	1.149	1.348	1.249	1.164	1.151	1.143		
322			9.7	1.159	1.151	1.359	1.253	1.167	1.153	1.147		
323			9.75	1.16	1.153	1.37	1.258	1.17	1.156	1.152		
324			9.8	1.161	1.155	1.381	1.262	1.172	1.158	1.157		
325			9.85	1.162	1.158	1.391	1.267	1.175	1.161	1.162		
326			9.9	1.166	1.16	1.402	1.271	1.178	1.163	1.167		
327			9.95	1.176	1.162	1.413	1.276	1.181	1.166	1.172		
328			10	1.185	1.164	1.424	1.278	1.183	1.168	1.177		

- Now, copy this Table as a **Lookup Table** in to EES and name it as 'CompressibilityFactor'.
- Now, this Table is in a format suitable for 2D interpolation in EES, i.e. top horizontal row gives Tr values: 5 , 2, 1.5 0.8, and left vertical column gives Pr values: 0.05, 0.1, 0.1510. Rest of the numbers in the Table are corresponding Z values.
- Z value for given Tr and Pr is found out by 2D interpolation in EES using the built-in Function **interpolate2DM**.
- The simple EES Function to find Z when Tr and Pr are given is now written:

\$UnitSystem SI Pa C J

FUNCTION Compressibility_Factor_Z(Tr,Pr)

{ Compressibility_Factor_Z ... finds the compressibility factor, given Tr (=T/Tc) and Pr (=P/Pc)}

Compressibility_Factor_Z = Interpolate2DM('CompressibilityFactor',Tr,Pr)

END

“=====”

“Example:”

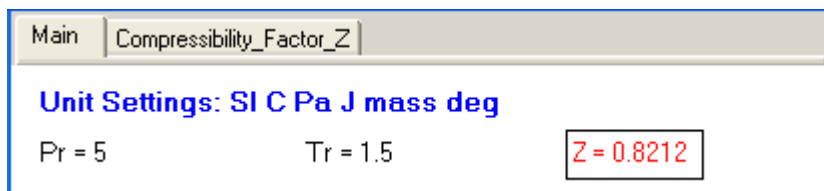
$T_r = 1.5$

$P_r = 5$

“Then, Z is found out by:”

$Z = \text{Compressibility_Factor_Z}(T_r, P_r)$

Result:



Use of the above Function is demonstrated with the following example:

Example: Calculate the density of Nitrogen at 260 bar and 15 C using the compressibility chart.

Following is the EES program:

“Data:”

$P = 260$ “bar”

$T = 15 + 273$ “K”

$R = 8314/28$ “J/kg.K ... Gas const. for N2”

$P_c = 33.94$ “bar...critical pressure for N2....from Table on page 18”

$T_c = 126.2$ “K...critical temp. for N2..from Table on page 18”

“Calculations:”

$P_r = P/P_c$ “...reduced pressure”

$T_r = T/T_c$ “....reduced temp.”

$Z = \text{Compressibility_Factor_Z}(T_r, P_r)$ “...finds compressibility factor, Z Using the EES Function written above”

“And, density, rho:”

“ $\rho = P/(Z * R * T)$... where rho is in kg/m^3 , P in Pa, R in J/kg.K and T in Kelvin”

“Therefore:”

$\rho = P * 10^5 / (Z * R * T)$ “....finds rho in kg/m^3 ”

Results:

Unit Settings: SI C Pa J mass deg

$P = 260$ [bar]

$P_r = 7.661$

$P_c = 33.94$ [bar]

$R = 296.9$ [J/kg-K]

$\rho = 285.8$ [kg/m^3]

$T = 288$ [K]

$T_r = 2.282$

$T_c = 126.2$ [K]

$Z = 1.064$

Thus:

Compressibility Factor, $Z = 1.064$ Ans.

Density of $\text{N}_2 = \rho = 285.8 \text{ kg/m}^3$... Ans.

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To continue...

As we mentioned in the Preface in Part-I, generally, the subject of Thermodynamics is taught over two semesters, under the titles **Basic Thermodynamics** and **Applied Thermodynamics**.

Now, in this book entitled **Basic Thermodynamics: Software Solutions**, presented in four parts, we have solved problems on the topics such as: Units, Pressure, Temperature, Properties of Pure substances, Zeroth Law, Heat and Work, First Law of Thermodynamics for a closed system and for flow processes, Second Law of Thermodynamics, Heat engines, Refrigerators and Heat Pumps, Entropy, Availability and Irreversibility, Real and Ideal gases and Gas mixtures etc.

In the next series of books entitled **Applied Thermodynamics: Software Solutions**, we shall solve problems on the following topics: Thermodynamic relations, Vapour power cycles, Gas power cycles, Refrigeration cycles, Psychrometrics, Reactive Systems and Compressible fluid flow.

At the beginning of each chapter, definitions, Statements and Formulas used are presented. Then, problems are solved using Mathcad, Engineering Equation Solver (EES) or The Expert System on Thermodynamics (TEST).