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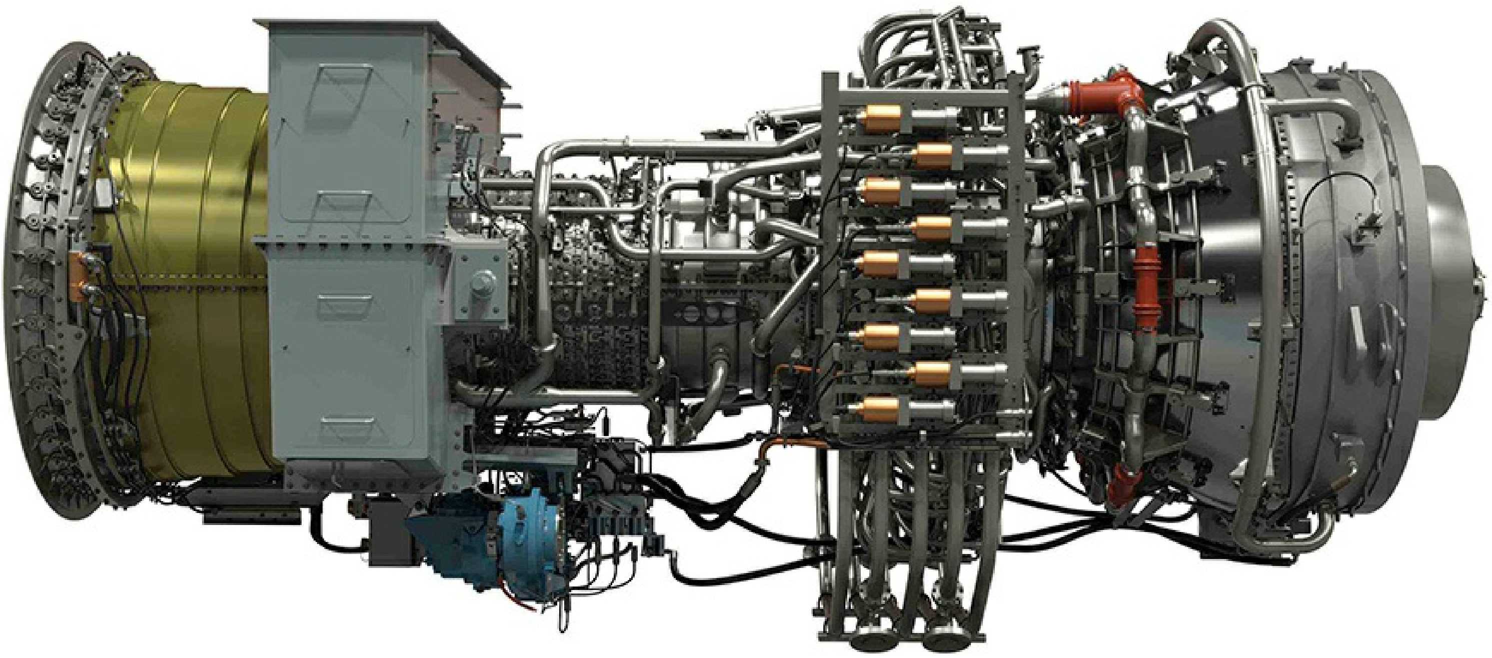
Basic Thermodynamics: Software Solutions – Part II

Dr. M. Thirumaleshwar



Dr. M. Thirumaleshwar

Basic Thermodynamics: Software Solutions – Part II

(Work, Heat, I Law applied to Closed systems and Flow processes)

Basic Thermodynamics: Software Solutions – Part II
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Contents

To see Part-I, download: Basic Thermodynamics: Software Solutions – Part I

4 Work, Heat and I Law of Thermodynamics applied to Closed systems

Learning objectives:

1. **Total energy of a system** is defined as the sum of internal energy, kinetic energy and potential energy. i.e. on a *unit mass basis*: $e = u + C^2/2 + g.z$ where C is the velocity, z is the elevation from a datum.
2. Energy crosses the boundary of a closed system either as Work or Heat, or as both.
3. Both Work and Heat are 'path functions', i.e. inexact differentials.
4. In Thermodynamics, Work is said to be done by a system if the sole effect things external to the system can be reduced to the raising of a weight.
5. 'Boundary work' for a simple compressible system is given by:

$$W_{12} = \int_{V1}^{V2} p \, dV$$

6. Similarly, other types of work, viz. electrical work, shaft work, paddle work, flow work, work in stretching a wire, work due to surface tension, magnetization work, free expansion etc. have to be considered, if need be.
7. 'Heat transfer' is energy transfer due to temperature difference only.
8. Conduction, Convection and Radiation are the main modes of heat transfer. Heat transfer may occur in one of these modes or, in some cases, one or more modes may be present.
9. **First Law is a statement of conservation of Energy.**
10. First Law for a system undergoing a cycle, and for processes in a closed system are considered.
11. Different processes for an ideal gas in a closed system (as in a piston-cylinder device) are of special interest.

4.1 Formulas used:

4.1.1 Work:

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

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

4.1.2 pdV- work or displacement work:

$$dW = p \cdot dV$$

$$W_{12} = \int_{V1}^{V2} p \, dV$$ ....Integration performed on a quasi-static path

4.1.3 pdV- work in various quasi-static processes:

(a). Constant pressure (isobaric) process:

$$W_{12} = p \cdot (V2 - V1)$$

(b). Constant volume (isochoric) process:

$$W_{12} = 0$$

(c). For a process in which pV = const....Isothermal process:

$$W_{12} = p1 \cdot V1 \cdot \ln\left(\frac{p1}{p2}\right)$$

(d). For a process in which pV^{γ} = const....reversible adiabatic or isentropic process:

$$W_{12} = \frac{p1 \cdot V1 - p2 \cdot V2}{\gamma - 1} = \frac{R \cdot (T1 - T2)}{\gamma - 1} = \frac{p1 \cdot V1}{n - 1} \cdot \left[1 - \left(\frac{p2}{p1}\right)^{\frac{\gamma - 1}{\gamma}}\right]$$

Also, for a perfect gas:

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

And for isentropic process, pv^{γ} = const., we have:

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

$$\frac{p2}{p1} = \left(\frac{v1}{v2}\right)^{\gamma}$$

$$\frac{T2}{T1} = \left(\frac{v1}{v2}\right)^{\gamma-1}$$

$$\frac{T2}{T1} = \left(\frac{p2}{p1}\right)^{\frac{\gamma-1}{\gamma}}$$

(e). For a process in which pV^n = const....polytropic process:

$$W_{12} = \frac{p1 \cdot V1 - p2 \cdot V2}{n-1} = \frac{p1 \cdot V1}{n-1} \cdot \left[1 - \left(\frac{p2}{p1}\right)^{\frac{n-1}{n}}\right]$$

i.e. $W_{12} = \dfrac{R \cdot (T1 - T2)}{n-1}$

Also: for a polytropic process:

$$\frac{p2}{p1} = \left(\frac{v1}{v2}\right)^{n}$$

$$\frac{T2}{T1} = \left(\frac{v1}{v2}\right)^{n-1}$$

$$\frac{T2}{T1} = \left(\frac{p2}{p1}\right)^{\frac{n-1}{n}}$$

For a perfect gas:

$$p \cdot v = R \cdot T \qquad du = cv \cdot dT$$

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

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

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

$$Q = (u2 - u1) + W = c_v \cdot (T2 - T1) + R \cdot (T1 - T2)$$

Simplifying, we get:

$$Q_{poly} = \frac{\gamma - n}{\gamma - 1} \cdot \frac{R \cdot (T1 - T2)}{n - 1}$$

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

Polytropic sp. heat:

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

Mean Effective Pressure (MEP, or p_m):

$$MEP = \frac{Area\_of\_Indicator\_diagram}{Stroke\_length} \cdot K$$ ...where k = Spring constant.

Indicated Power (IP):

$$IP = \frac{p_m \cdot A \cdot L \cdot N}{60}$$ kW...for a two stroke engine..where pm is in kPa, A in m^2, L in m, N in RPM.... this is IP for one cylinder

Note: Put N = N/2 for four stroke engine

Brake Power (BP):

$$BP = \frac{2 \cdot \pi \cdot N \cdot T}{60}$$ ...where N is RPM, T is Torque

Mech. efficiency:

$$\eta_{mech} = \frac{BP}{IP}$$

4.1.4 Other types of Work transfer:

1. Electrical Power:

$$W_{dot} = E \cdot I$$

2. Shaft Work:

$$W_{shaft} = T \cdot \omega$$ ...where T is Torque, ω is angular velocity

3. Paddle work or Stirring work:

$$W = \int_1^2 m \cdot g \, dZ = \int_1^2 T \, d\theta$$

4. Flow Work:

$$W_{flow} = p \cdot v$$ ...per unit mass

5. Work done in stretching a wire:

$$W = -\int_1^2 J \, dL$$ ..where J is the tension, dL is expansion of wire

6. Work done in changing the area of a surface film:

$$W = -\int_1^2 \sigma \, dA$$ ..where σ is the surface tension N/m)

7. Work done in magnetization of a paramagnetic solid:

$$W = -\int_1^2 H \, dI$$ ..where H is the field strength and I is the component of magnetization field in the direction of the field

8. Work done in Free expansion:

$$W_{free\_expn} = 0$$ ...since there is no resistance to the fluid at boundary

4.1.5 Heat Transfer, Q:

Q is positive while flowing *into* the system;

W is positive if work is done *by* the system.

Heat Transfer Q_{12}:

Heat transfer is a path function.

$$Q_{12} = \int_{1}^{2} T\,ds \qquad \text{...where T is in K, s is entropy}$$

Specific heat, c:

It is the amount of heat required to raise a unit mass of substance through a unit rise in temperature.

$$c = \frac{Q}{m \cdot \Delta t} \qquad \text{J/kg.K}$$

For a gas, for a constant pressure, reversible non-flow process:

$$dQ = m \cdot c_p \cdot dT$$

For a gas, for a constant volume, reversible non-flow process:

$$dQ = m \cdot c_v \cdot dT$$

4.1.6 First Law for a system undergoing a cycle:

$\Sigma W = J \cdot \Sigma Q$ **....for a cycle. J = 1 in S.I. Units.i.e. 1 N.m = 1 Joule.**

4.1.7 First Law for a closed system undergoing a change of state:

$$Q - W = \Delta E$$

or:

$$Q = \Delta E + W$$

4.1.8 First Law is a statement of conservation of Energy.

Energy is a property of the system; it is therefore, a 'point function'.

Considering only the kinetic, potential and internal energies, Total energy is:

$$E = E_k + E_p + U_{int}$$

4.1.9 For an Ideal gas:

Internal Energy U is a function of T only.

We write:

$$dQ = dE + dW$$

i.e. $dQ = dU + dW$

i.e. $dQ = dU + p \cdot dV$ ...when only pdV work is present

Enthalpy, h:

$$h = u + p \cdot v \quad \text{J/kg}$$

For a perfect gas:

$$h = c_v \cdot T + R \cdot T = (c_v + R) \cdot T = c_p \cdot T$$

4.1.10 Fist Law for non-flow processes or for Closed systems:

For reversible, const. volume process:

$$Q = (u2 - u1) + W \quad \text{...where} \quad W = \int p\, dv$$

....But, W = 0, since dV = 0

Therefore: $Q = u2 - u1 = c_v \cdot (T2 - T1)$ ...J/kg

For reversible, const. pressure process:

$$Q = (u2 - u1) + W \quad \text{...where} \quad W = \int p\, dv$$

....But, W = p.(v2-v1)

Therefore: $Q = h2 - h1 = c_p \cdot (T2 - T1)$ ...J/kg

For reversible, Isothermal process:

$$Q = (u2 - u1) + W \quad \text{...where} \quad W = \int p\, dv$$

Therefore: $Q = c_v \cdot (T2 - T1) + W = 0 + W$

i.e. $Q = p1 \cdot v1 \cdot \ln\left(\frac{v2}{v1}\right) = p1 \cdot v1 \cdot \ln\left(\frac{p1}{p2}\right)$ ...J/kg

For reversible, adiabatic process:

$$Q = (u2 - u1) + W \quad \text{...where} \quad W = \int p\, dv$$

But, Q = 0 for adiabatic process.

Therefore: $0 = (u2 - u1) + W$

i.e. $W = u1 - u2$ ....for any adiabatic process

And, for rev. adiab. process: $p \cdot v^{\gamma} = const$

And: $$W = \frac{p_1 \cdot v_1 - p_2 \cdot v_2}{\gamma - 1} = \frac{R \cdot (T1 - T2)}{\gamma - 1}$$

==

4.2 Now, let us work out a few problems with EES:

"**Prob.4.1.** A perfect gas is undergoing a process in which T is proportional to V^(-2/5). Calculate the work done by the gas in going from state 1 in which pressure is 100 bar and volume is 4 m^3 to the state 2 in which volume is 2 m^3. Also calculate the final pressure. [VTU-BTD-Dec-06–Jan-07]"

EES Solution:

"Data:"

P1=100E05[Pa]
V1=4[m^3]
V2=2[m^3]

"Calculations:"

"We have:
T = k1 * V^(-2/5); But, PV = RT for perfect gas.
i.e. P.V / R = k1 * V^(-2/5)
i.e. P.V^(7/5) = k where k = k1 * R, a const."
P1 * V1^(7/5) = P2 * V2^(7/5)
k = P1 * V1^(7/5)
Work=integral(k*V^(-7/5),V,V1,V2) "…using the built-in integral function of EES"

"Note: In the above, we calculate Work as Integral of P.dV. So, P is expressed as a function of V. V1 and V2 are limits of integration, i.e. from V1 to V2."

Now, hit F2 to calculate.

Results:

Unit Settings: SI K Pa J mass deg

k = 6.964E+07	P1 = 1.000E+07 [Pa]	P2 = 2.639E+07 [Pa]
V = 2 [m^3]	V1 = 4 [m^3]	V2 = 2 [m^3]
Work = -3.195E+07 [J]		

Thus:

Work = -3.195E07 W … negative sign indicates that work is done on the system….Ans.

Final pressure, P2 = 2.639E07 Pa = 263.9 bar … Ans.

Additionally, plot the variation of Work and P2 as the final volume varies from 0.5 m^3 to 3 m^3:

First, compute the Parametric Table:

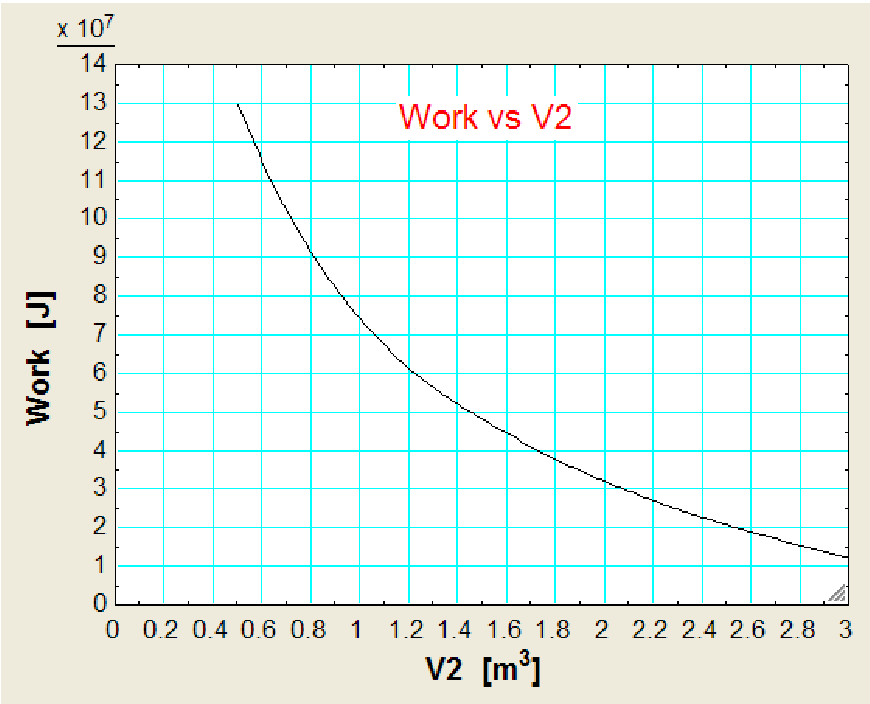
(Note that we have written the absolute value of Work done, i.e. without the negative sign).

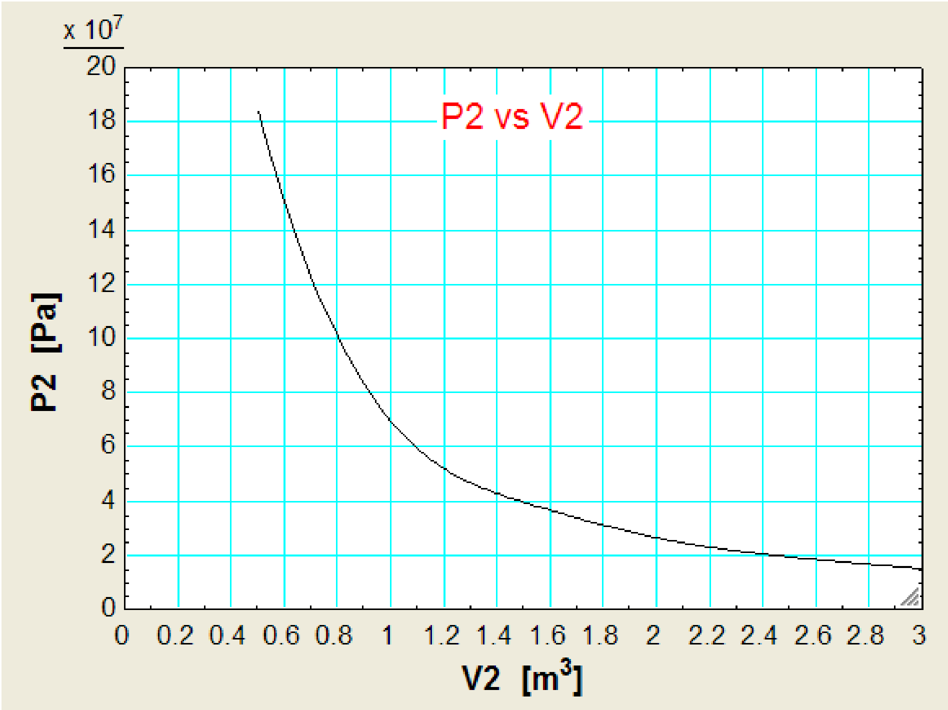
Parametric Table

Table 1

1..6	V2 [m3]	Work [J]	P2 [Pa]
Run 1	0.5	1.297E+08	1.838E+08
Run 2	1	7.411E+07	6.964E+07
Run 3	1.5	4.804E+07	3.948E+07
Run 4	2	3.195E+07	2.639E+07
Run 5	2.5	2.068E+07	1.931E+07
Run 6	3	1.220E+07	1.496E+07

Now, plot the results:




x 10^7
P2 vs V2
P2 [Pa]
V2 [m^3]
0
2
4
6
8
10
12
14
16
18
20
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3

==

"**Prob.4.2**. An engine cylinder has a piston of area 0.12 m^2 and contains gas at a pressure of 1.5 MPa. The gas expands according to a process which is represented by a straight line on a p-V diagram. The final pressure is 0.15 MPa. Calculate the work done by the gas if the piston stroke is 0.3 m. [VTU-BTD-July/Aug.2004-New-Scheme]"

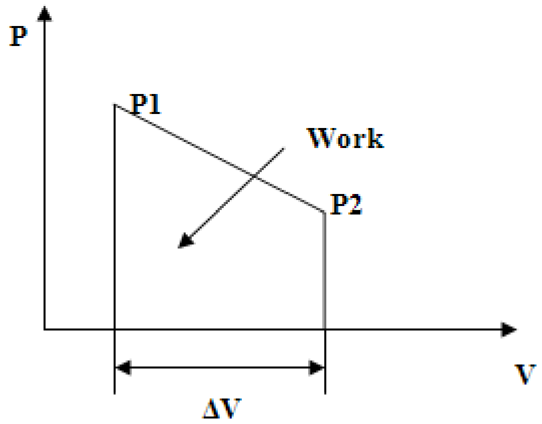


Fig.Prob.4.2

EES Solution:

"Data:"

P1 = 1.5E03 [kPa]

P2 = 0.15E03 [kPa]

A = 0.12 [m^2] "….piston area"

L = 0.3 [m] "…stroke"

"Calculations:"

DELTAV = A * L "[m^3]"

Work = P2 * DELTAV + (P1 – P2) * DELTAV/2 "[kJ]"

Solution:

Unit Settings: SI C kPa kJ mass deg

A = 0.12 [m^2]	ΔV = 0.036 [m^3]	L = 0.3 [m]	P1 = 1500 [kPa]
P2 = 150 [kPa]	Work = 29.7 [kJ]		

Thus:

Work done by the gas = 29.7 kJ….Ans.

(b) Plot the variation of Work as the final pressure P2 varies from 100 kPa to 1000 kPa:

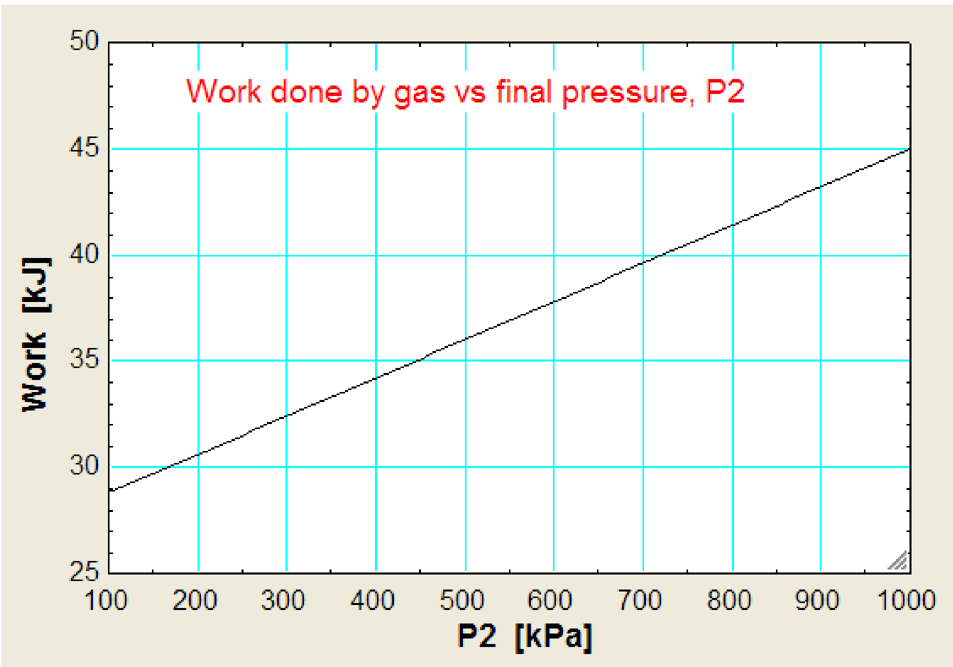
First, compute the Parametric Table:

Parametric Table

Table 1

1..10	P2 [kPa]	Work [kJ]
Run 1	100	28.8
Run 2	200	30.6
Run 3	300	32.4
Run 4	400	34.2
Run 5	500	36
Run 6	600	37.8
Run 7	700	39.6
Run 8	800	41.4
Run 9	900	43.2
Run 10	1000	45

Now, plot the results:



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"Prob.4.3. A spherical balloon of 1 m dia contains a gas at 200 kPa pressure. The gas inside the balloon is heated until the pressure reaches 500 kPa. During the process of heating, the pressure of gas inside the balloon is proportional to the cube of the diameter of the balloon. Determine the work done by the gas inside the balloon. [VTU-BTD-June-July-08]"

EES Solution:

"Data:"

P1=200[kPa]
D1=1[m^3]
k=200 "….since P1 = k * D1^3"
P2=500[kPa]

"Calculations:"

P2=k*D2^3 "…finds D2"
V1=(pi/6)*D1^3"[m^3]"
V2=(pi/6)*D2^3"[m^3]"
Work = integral(k*6 * V/pi,V,V1,V2) "[kJ]….Note the use of built-in integral function of EES"

"Note: In the above, we calculate Work as Integral of P.dV. So, P is expressed as a function of V. V1 and V2 are limits of integration, i.e. from V1 to V2."

Results:

Unit Settings: SI C kPa kJ mass deg

D1 = 1 [m^3]	D2 = 1.357 [m]	k = 200	P1 = 200 [kPa]
P2 = 500 [kPa]	V = 1.309	V1 = 0.5236 [m^3]	V2 = 1.309 [m^3]
Work = 274.9 [kJ]			

Thus:

Work done by the gas = 274.9 kJ …. Ans.

(b) Plot the variation of Work as the final pressure P2 varies from 300 kPa to 750 kPa:

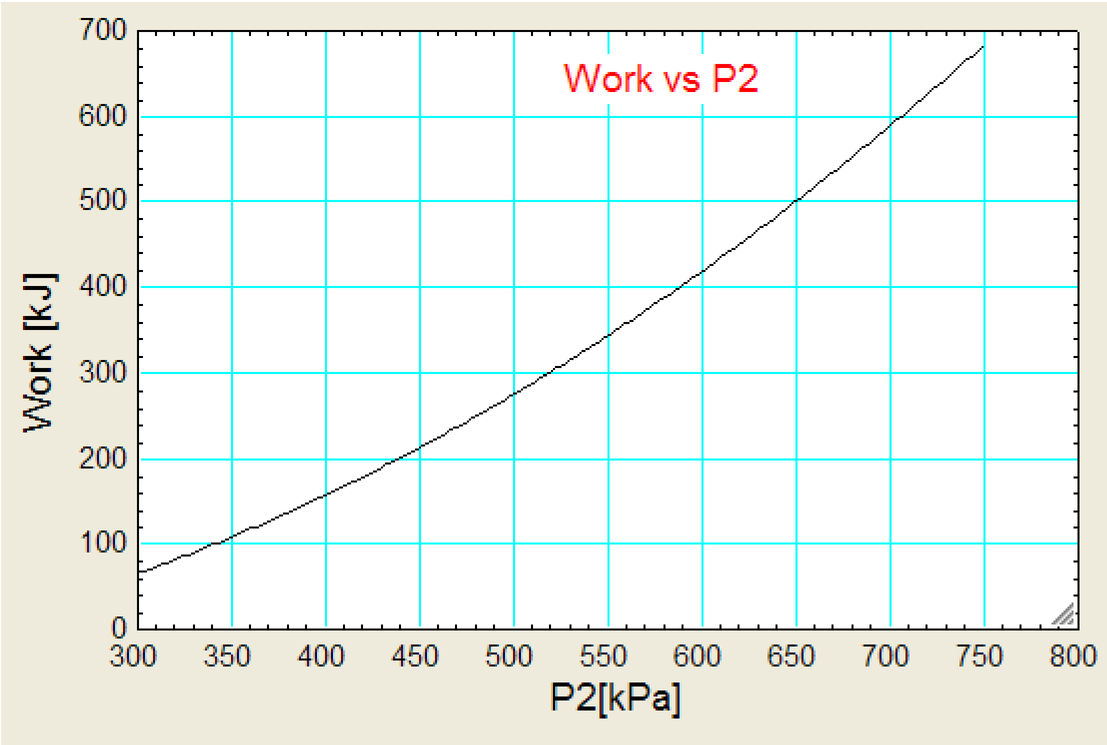
First, compute the Parametric Table:

Parametric Table

Table 1

1..10	P2 [kPa]	Work [kJ]
Run 1	300	65.45
Run 2	350	108
Run 3	400	157.1
Run 4	450	212.7
Run 5	500	274.9
Run 6	550	343.6
Run 7	600	418.9
Run 8	650	500.7
Run 9	700	589
Run 10	750	684

Now, plot the results:



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"**Prob.4.4.** A spherical balloon of 1 m dia contains a gas at 1.5 bar pressure. Due to heating, the pressure reaches 4.5 bar. During the process of heating, the pressure is proportional to the cube of the diameter of the balloon. Determine the work done by the gas inside the balloon. [VTU-BTD-Feb. 2002]"

EES Solution:

This is similar to the previous problem.

"Data:"

P1=150[kPa]

D1=1[m^3]

k=150 "….since P1 = k * D1^3"

P2=450[kPa]

"Calculations:"

P2=k*D2^3 "…finds D2"

V1=(pi/6)*D1^3"[m^3]"

V2=(pi/6)*D2^3"[m^3]"

Work = integral(k * 6 * V/pi,V,V1,V2) "[kJ]….Note the use of built-in integral function of EES"

"Note: In the above, we are calculating Work as Integral of P.dV. So, P is expressed as a function of V.

V1 and V2 are limits of integration, i.e. from V1 to V2."

Results:

Unit Settings: SI C kPa kJ mass deg

D1 = 1 [m^3]	D2 = 1.442 [m]	k = 150	P1 = 150 [kPa]
P2 = 450 [kPa]	V = 1.571	V1 = 0.5236 [m^3]	V2 = 1.571 [m^3]
Work = 314.2 [kJ]			

Thus: Work done by the gas = 314.2 kJ …. Ans.

===

"Prob.4.5. A spherical balloon of dia 0.5 m is initially at a pressure of 100 kPa. Due to heating, pressure increases to 400 kPa during which the inside pressure varies directly proportional to the square of the diameter of the balloon. Determine the displacement work during this process. [VTU-BTD-July-2007]"

EES Solution:

"Data:"

P1=100[kPa]
D1=0.5[m^3]
P1=k*D1^2 "…determines k"
P2=400[kPa]
P2=k*D2^2 "….determines D2"

"Calculations:"

V1=(pi/6)*D1^3"m3"
V2=(pi/6)*D2^3"m3"
Work = integral(k*(6*V/pi)^(2/3),V,V1,V2) "kJ…..using the built-in function integral of EES"

"Note: In the above, we are calculating Work as Integral of P.dV. So, P is expressed as a function of V.

V1 and V2 are limits of integration, i.e. from V1 to V2."

Results:

Unit Settings: SI C kPa kJ mass deg

D1 = 0.5 [m^3]	D2 = 1 [m]	k = 400	P1 = 100 [kPa]
P2 = 400 [kPa]	V = 0.5236 [m^3]	V1 = 0.06545 [m^3]	V2 = 0.5236 [m^3]
Work = 121.7 [kJ]			

Thus: Work done by the gas = 121.7 kJ …. Ans.

==

"**Prob.4.6.** A quasi-static process occurs such that P = (V^2 + 8/V), where P is the pressure in bar and V is the volume in m^3. Find the work done when volume changes from 1 m^3 to 3 m^3. [VTU-Jan.2004]'"

EES Solution:

"Data:"

p=(v^2+8/v) "bar"
v1=1"m^3"
v2=4"m^3"

"Calculation:"

W=10^5*(integral(p,v,v1,v2)) "J….uses the built-in integral function of EES"

Results:

Unit Settings: SI K kPa kJ molar deg

p = 18 [bar]   v = 4 [m^3]   v1 = 1 [m^3]   v2 = 4 [m^3]

W = 3.209E+06 [J]

Thus: Work done by the gas = 3.209E06 J …. Ans.

(b) In addition, plot Work against V2, as V2 changes from 1.5 m^3 to 5 m^3:

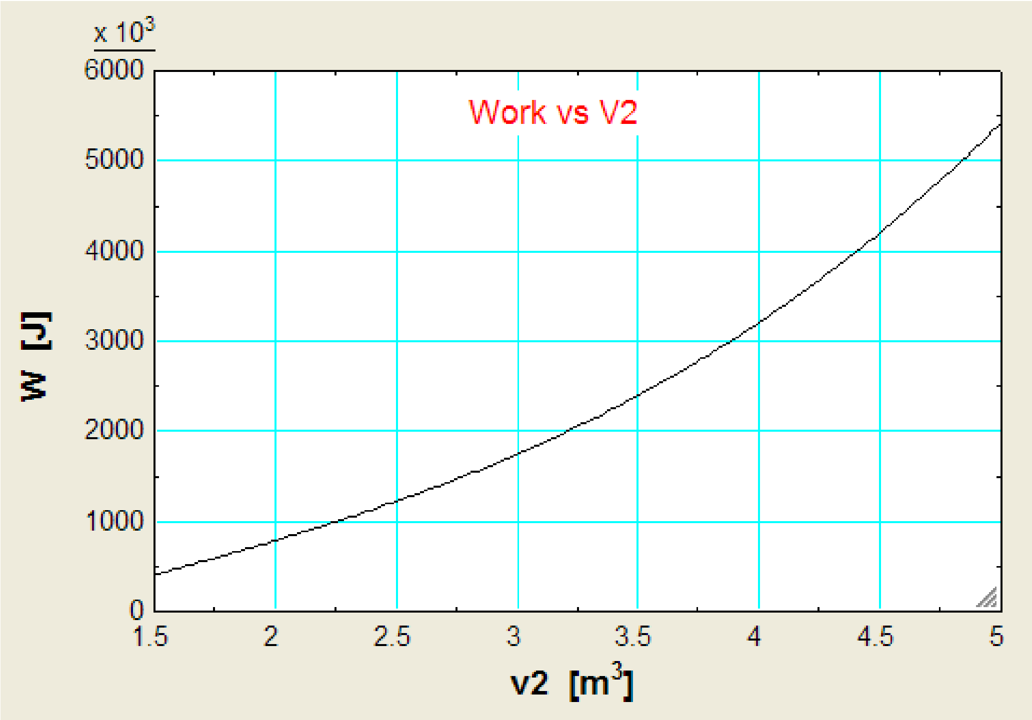
First, compute the Parametric Table:

Parametric Table

Table 1

1..8	v2 [m3]	W [J]
Run 1	1.5	403540
Run 2	2	787857
Run 3	2.5	1.221E+06
Run 4	3	1.746E+06
Run 5	3.5	2.398E+06
Run 6	4	3.209E+06
Run 7	4.5	4.207E+06
Run 8	5	5.421E+06

Now, plot the graph:



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"Prob.4.7. 1 kg of air at 15 C and 100 kN/m^2 is compressed isentropically to 600 kN/m^2. Determine the final temp and the work done. If the air is cooled to 15 C at constant pressure, calculate the heat transferred. Take gamma = 1.4, cp = 1.0213 kJ/kg.K, R = 0.287 kJ/kg.K. [VTU-Jan. 2005]"

EES Solution:

"Data:"

m = 1 "[kg]"
T1=15+273 "[K]"
p1=10^5 "[Pa]"
p2=6*10^5 "[Pa]"
gamma=1.4 "…ratio of sp. heats,(cp/cv) for air"
cp=1.0213*10^3"[J/kg.K]….sp. heat"
R=287 "[J/kg.K]….gas const."

"Calculations:"

T2/T1 = (p2/p1)^((gamma-1)/gamma)"…temp ratio for an isentropic process…. determines T2"
W_ad=R*(T1-T2)/(gamma-1) "Adiabatic work"
Q=m*cp*(T2-T1) "[J]….heat transferred, when cooled to T1 from T2, at const. pressure"

Results:

Unit Settings: SI K kPa kJ molar deg

cp = 1021 [J.kg-K]	γ = 1.4	m = 1 [kg]	p1 = 100000 [Pa]
p2 = 600000 [Pa]	Q = 196632 [J]	R = 287 [J/kg$_K$]	T1 = 288 [K]
T2 = 480.5 [K]	W_{ad} = -138141 [J]		

Thus:

Final temp T2 = 480.5 K …. Ans.

Work done = -138141 J …. Ans. negative sign indicating work done *on* the system

Heat transferred in const. pressure cooling, Q = 196632 J … Ans.

(b) In addition, as p2 varies from 100 kPa to 1000 kPa, plot the variation of T2, W and Q against p2:

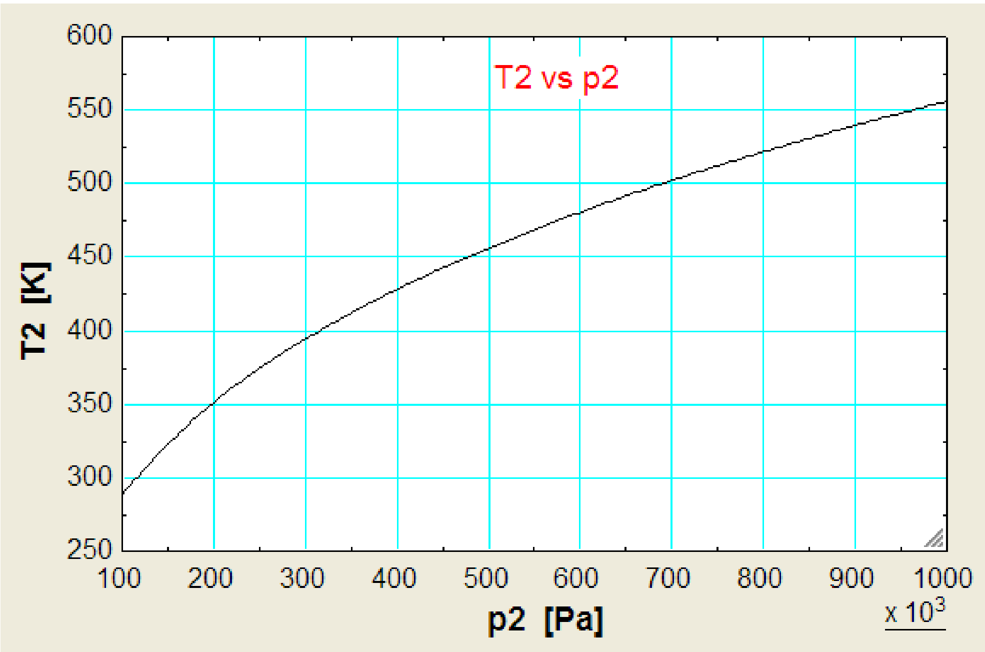
First, compute the Parametric Table:

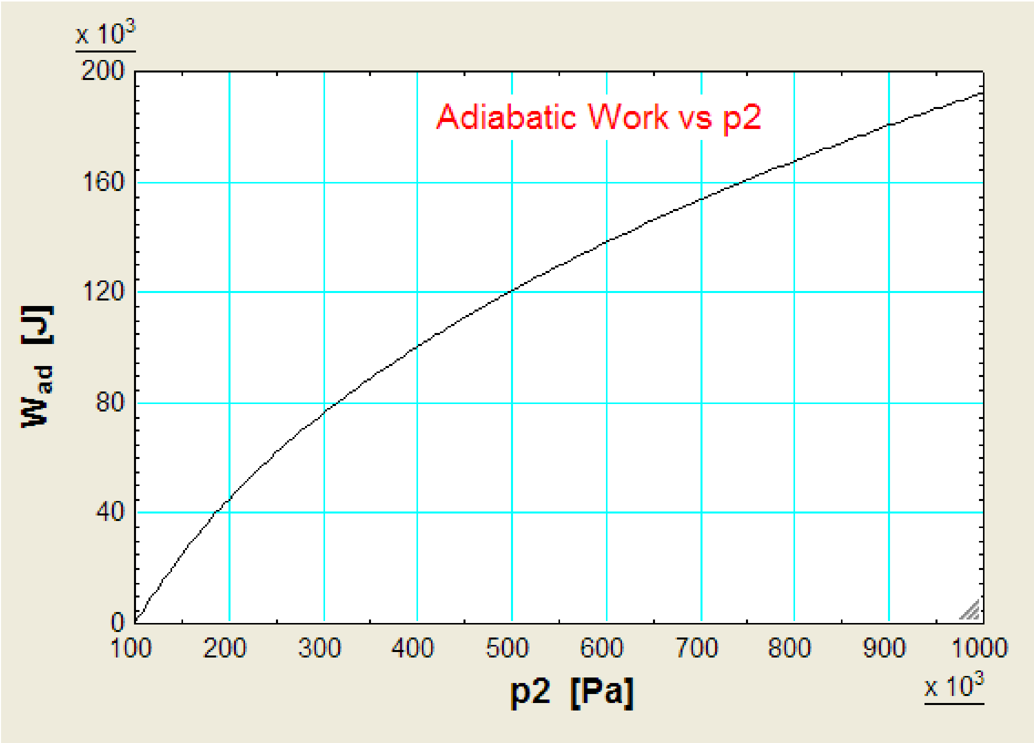
Table 1

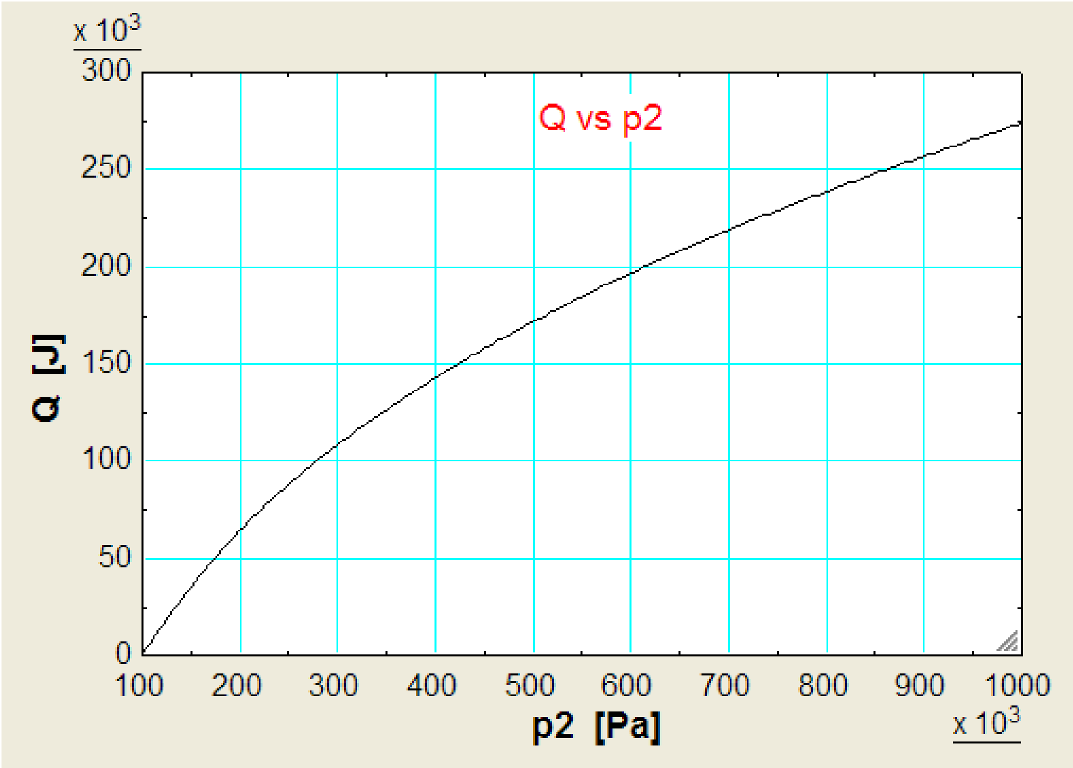
1..10	p2 [Pa]	T2 [K]	W_{ad} [J]	Q [J]
Run 1	100000	288	0	0
Run 2	200000	351.1	45257	64419
Run 3	300000	394.2	76196	108459
Run 4	400000	428	100426	142948
Run 5	500000	456.1	120640	171721
Run 6	600000	480.5	138141	196632
Run 7	700000	502.2	153666	218730
Run 8	800000	521.7	167677	238675
Run 9	900000	539.6	180488	256910
Run 10	1000000	556	192319	273750

Note that in the above Table, we have taken the absolute value of Work, with the understanding that it is the work done on the gas during compression.

Now, plot the results:




x 10^3
200
160
120
80
40
0
Wad [J]
Adiabatic Work vs p2
100
200
300
400
500
600
700
800
900
1000
p2 [Pa]
x 10^3



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"Prob.4.8. 5 kg of Nitrogen at 100 C is heated in a reversible, non-flow, constant volume process till the pressure becomes three times the initial pressure. Determine: (i) final temp (ii) change in internal energy (iii) change in enthalpy, and (iv) heat transfer. Take R = 0.297 kJ/kg.K, cv = 0.7435 kJ/kg.K. [VTU-Jan. 2004]"

EES Solution:

"Data:"

m = 5 "kg"
PressureRatio = 3 "pr. ratio= p2/p1"
T1=100+273 "K"
cv=743.5 "J/kg.K"
R=297 "J/kg.K"

"Calculations:"

T2 = PressureRatio * T1"..finds T2… since p1/T1 = p2/T2 at const. volume"
cp – cv = R "..for Ideal gas…finds cp"
DELTAU=m * cv * (T2-T1) "J… change in internal energy"
DELTAH=m * cp * (T2-T1) "J… change in enthalpy"
W = 0 "..since it is a const. volume process"
Q=DELTAU +W "J.. from I law for a closed system"

Results:

Unit Settings: SI K kPa kJ molar deg

cp = 1041 [J/kg-K]	cv = 743.5 [J/kg-K]	ΔH = 3.881E+06 [J]
ΔU = 2.773E+06 [J]	m = 5 [kg]	PressureRatio = 3
Q = 2.773E+06 [J]	R = 297 [J/kg-K]	T1 = 373 [K]
T2 = 1119 [K]	W = 0 [J]	

Thus:

Final temp, T2 = 1119 K, Change in Int. energy, DELTAU = 2.773E06 J,

Change in enthalpy, DELTAH = 3.881E06 J, Heat transfer, Q = 2.773E06 J …. Ans.

==

"**Prob.4.9.** 1 kg of air contained in a closed system at 100 kPa and 300 K is compressed isothermally till the volume halves. During the process, it is also stirred with a Torque of 1 N.m at 400 RPM for 1 hour. Calculate the net work done on the system. Assume R = 0.285 kJ/kg.K. [VTU-July 2003]"

EES Solution:

"Data:"

m=1 "kg"
p1=100*10^3 "Pa"
T1=300 "K"
p1=0.5*p2 "…since p1.V1 = p2.V2 at constant T"
N=400*60 "Revolutions in one hour"
T=1 "N.m…. torque"
R=285 "J/kg.K"

"Calculations:"

W_iso = R * T1 * ln(p1/p2) "J.... isothermal work on the system"
W1=-2 * pi * N * T "J.... stirring work on the system"
W_net=W_iso+W1 "J.... net work on the system"

Results:

Unit Settings: SI K kPa kJ molar deg

m = 1 [kg]	N = 24000 [rev.]	p1 = 100000 [Pa]	p2 = 200000 [Pa]
R = 285 [J/kg-K]	T = 1 [N.m]	T1 = 300 [K]	$W1$ = -150796 [J]
W_{iso} = -59264 [J]	W_{net} = -210061 [J]		

Thus:

Net work done on the system = -210061 J.....Ans. Negative sign indicating that work is done *on* the system.

==

"Prob.4.10. 1.5 kg of a gas undergoes a quasi-static process, in which the pressure and sp. vol. are related by the equation: p = a – b.v, where a and b are constants. The initial and final pressures are 1000 kPa and 200 kPa respectively. The corresponding volumes are 0.2 m^3 and 1.2 m^3. The specific internal energy of the gas is given by the relation: u = 1.5 p v – 35, where u is in kJ/kg, p is in kPa, and v is in m^3/kg. Find the magnitude and direction of heat transfer and the max. internal energy of the gas during the process. [VTU-Jan. 2005]"

EES Solution:

"Data:"

m=1.5 "kg"
"u=1.5 * p * v – 35 ….. internal energy"
p1=1000 "kPa … initial pressure"
v1=0.2/m "m3/kg . initial sp. volume"
p2=200 "kPa … final pressure"
v2=1.2/m "m3/kg … final sp. volume"

"Calculations:"

"To find a and b:"

P1 = a – b * v1"…initial pressure"
P2 = a – b * v2 "….final pressure"

"To find W, Q and DELTAU:"

DELTAU = U2-U1 "J ….. change in internal energy"
p = a – b * v "….. reln. between p and v, by data"
W = m * 10^3 * integral(p,v,v1,v2)"J….. using the built-in function 'integral' of EES"
Q = W + (U2 – U1) "J … by I Law for a closed system"
U1 = m * (1.5 * p1 * v1 – 35) * 10^3 "J….. internal energy at state 1"
U2 = m * (1.5 * p2 * v2 – 35) * 10^3 "J … internal energy at state 2"

Results:

Unit Settings: SI K kPa kJ molar deg

a = 1160	b = 1200	ΔU = 60000 [J/kg]	m = 1.5 [kg]
p = 200 [kPa]	p1 = 1000 [kPa]	p2 = 200 [kPa]	Q = 660000 [J]
U1 = 247500 [J]	U2 = 307500 [J]	v = 0.8 [m^3]	v1 = 0.1333 [m^3]
v2 = 0.8 [m^3]	W = 600000 [J]		

Thus:

Q = 660000 J …. Ans. It is positive, indicating that heat is *transferred to* the system.

U2 = max. int. energy = 307500 J …. Ans.

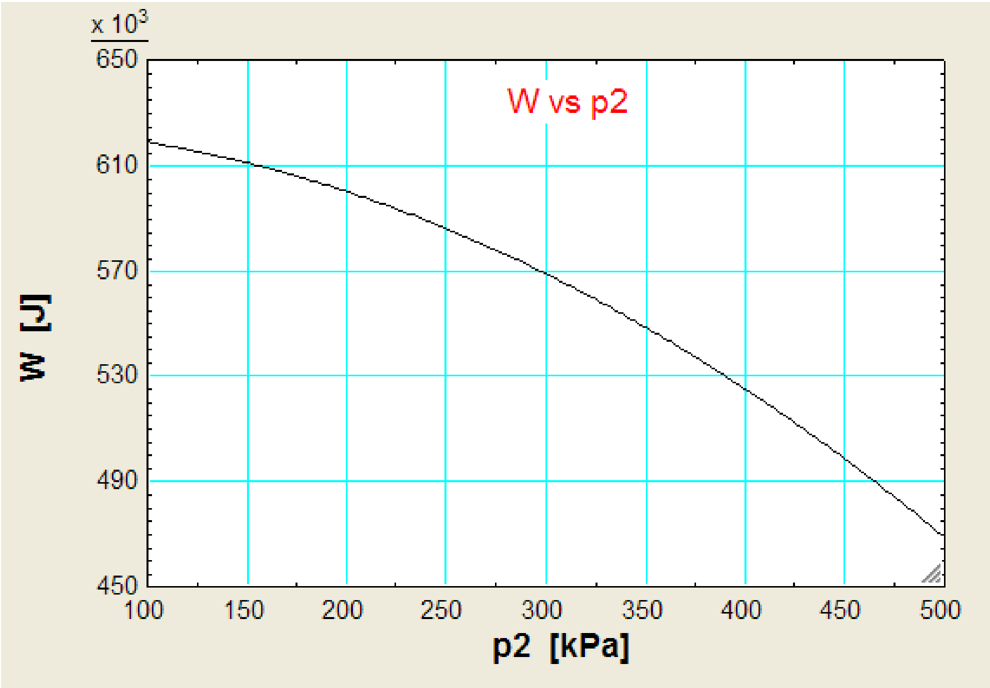
(b) Plot Q, W and DELTAU as final pressure p2 varies from 500 to 100 kPa:

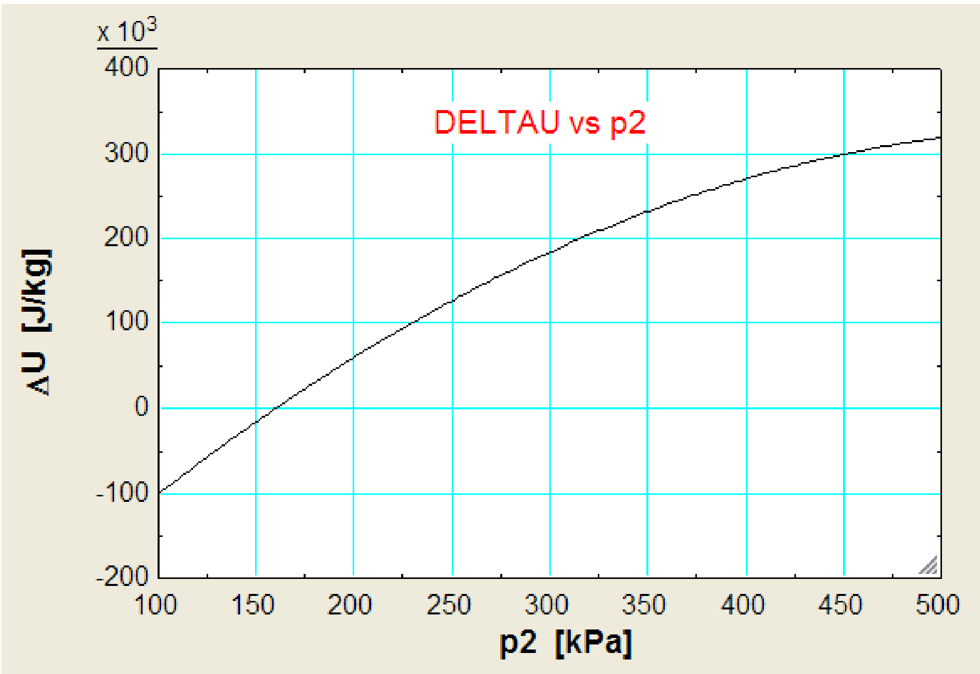
First, compute the Parametric Table:

Table 1

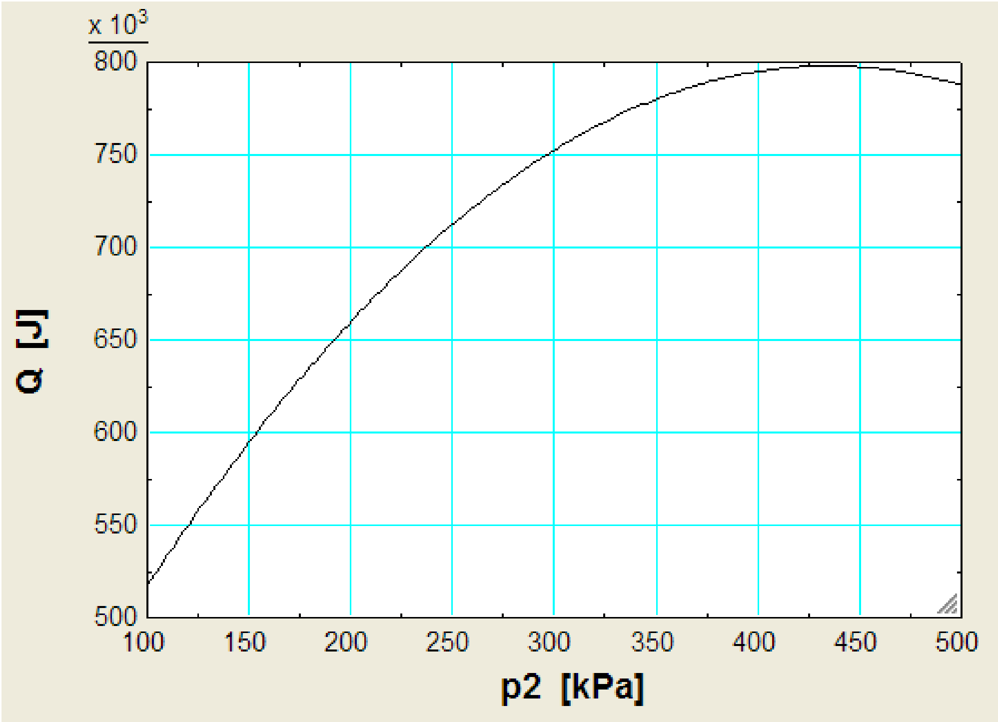
1..9	p2 [kPa]	W [J]	ΔU [J/kg]	Q [J]
Run 1	500	468750	318750	787500
Run 2	450	498438	299063	797500
Run 3	400	525000	270000	795000
Run 4	350	548438	231563	780000
Run 5	300	568750	183750	752500
Run 6	250	585938	126563	712500
Run 7	200	600000	60000	660000
Run 8	150	610938	-15938	595000
Run 9	100	618750	-101250	517500

Next, plot the results:





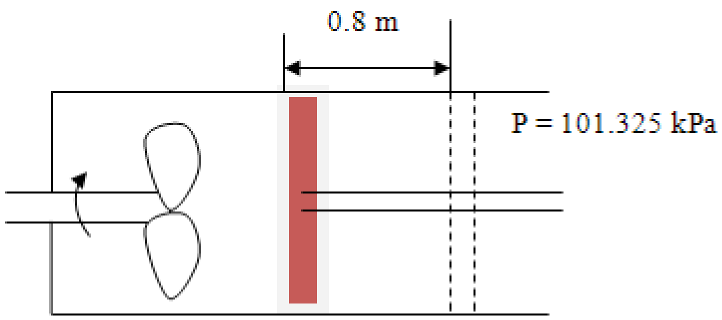
Note that after p2 = approx. 160 kPa, DELTAU becomes negative.



Note that after p2 = approx. 425 kPa, Q decreases.

===

"Prob.4.11. A piston-cylinder mechanism containing a fluid has a stirring device as shown. The piston is frictionless and held against the fluid by atm. pressure of 101.325 kPa. The stirring device is turned 10000 revolutions with an average torque against the fluid, of 1.275 N.m. The piston is 0.6 m dia and it moves by 0.8 m. Calculate the net work transfer. [VTU-July 2002]"



EES Solution:

"Data:"

N=10000 "revolutions"
T=1.275[J]
d = 0.6[m]
L=0.8[m]
p=101.325E03[Pa]

"Calculations:"

W1=-2 * pi * N * T "J … stirring work done on the system"
W2=F * L "J…boundary work done by the system"
F=p * A "N…force exerted on the piston by atm."
A=(pi/4) * (d)^2 "m^2 …. area of piston"
W_tot = W1+W2 "J….net work"

Results:

Unit Settings: SI K kPa kJ molar deg

A = 0.2827 [m^2]	d = 0.6 [m]	F = 28649 [N]	L = 0.8 [m]
N = 10000 [Rev.]	p = 101325 [Pa]	T = 1.275 [J]	W1 = -80111 [J]
W2 = 22919 [J]	W_{tot} = -57191 [J]		

Thus: Net work done = -57191 J, negative sign indicating work done *on* the system.

==

"Prob.4.12. A closed system undergoes a cycle composed of 4 processes 1-2, 2-3, 3-4 and 4-1. The energy transfers are as tabulated:

Process	Q(kJ/min.)	W (kJ/min.)	ΔU (kJ/min.)
1–2	400	150	-
2–3	200	-	300
3–4	-200	-	-
4–1	0	75	-

(i) complete the Table (ii) determine the rate of work in kW [VTU-Jan. 2004]"

EES Solution:

"Data:"

"Process 1–2:"

Q_12=W_12+DELTAU_12 "kJ/min"
Q_12=400 "kJ/min"
W_12=150 "kJ/min"

"Process 2–3:"

Q_23=W_23+DELTAU_23 "kJ/min"
Q_23=200 "kJ/min"
DELTAU_23=300 "kJ/min"

"Process 3–4:"

Q_34=W_34+DELTAU_34 "kJ/min"
Q_34=-200 "kJ/min"

"Process 4–1:"

Q_41=W_41+DELTAU_41 "kJ/min"
Q_41=0 "kJ/min"
W_41=75 "kJ/min"

Q_12+Q_23+Q_34+Q_41=W_12+W_23+W_34+W_41 "…First Law for the whole cycle"

"Net Heat and Work in cycle:"

Q_net = (W_12 + W_23 + W_34 + W_41) / 60 "[kJ/s]"
W_net = (W_12+W_23+W_34+W_41) / 60 "[kJ/s]"

Results:

Unit Settings: SI K kPa kJ molar deg

$\Delta U_{12} = 250$ [kJ/min] $\quad \Delta U_{23} = 300$ [kJ/min] $\quad \Delta U_{34} = -475$ [kJ/min]

$\Delta U_{41} = -75$ [kJ/min] $\quad Q_{12} = 400$ [kJ/min] $\quad Q_{23} = 200$ [kJ/min]

$Q_{34} = -200$ [kJ/min] $\quad Q_{41} = 0$ [kJ/min] $\quad Q_{net} = 6.667$ [kW]

$W_{12} = 150$ [kJ/min] $\quad W_{23} = -100$ [kJ/min] $\quad W_{34} = 275$ [kJ/min]

$W_{41} = 75$ [kJ/min] $\quad W_{net} = 6.667$ [kW]

Thus:

Following is the completed Table:

Process	Q(kJ/min.)	W (kJ/min.)	ΔU (kJ/min.)
1-2	400	150	**250**
2-3	200	**-100**	300
3-4	-200	**275**	**-475**
4-1	0	75	**-75**

And, W_net = 6.667 kW …. Ans.

===

"**Prob.4.13.** During a reversible, constant pressure process in a closed system with p = 105 kPa, properties of the system change from V1 = 0.25 m^3, t1 = 10 C to V2 = 0.45 m^3, t2 = 240 C. Specific heat at const. pressure, cp is given by: cp = (0.4 + 18 / (t + 40)) kJ/kg.C. Assuming the mass of the system as 1 kg, determine: (i) heat transfer (ii) work transfer (iii) change in internal energy, and (iv) change in enthalpy. [VTU-Jan. 2003]"

EES Solution:

"Data:"

p=105 * 10^3 "Pa"
V1=0.25 "m3"
V2=0.45 "m3"
t1=10 "C"
t2=240 "C"
Cp=(0.4+18/(t+40)) * 10^3 "J/kg.C"

"Calculations:"

Q=integral(Cp,t,t1,t2) "J….finds heat transfer"
W = p * (V2-V1) "J….. finds work transfer"
Q = W + DELTAU "….by I Law for a closed system"
DELTAH = Q "J…change in enthalpy for const. pressure process"

Results:

Unit Settings: SI K kPa kJ molar deg

Cp = 464.3 [J/kg-C]	ΔH = 123011 [J/kg]	ΔU = 102011 [J/kg]	p = 105000 [Pa]
Q = 123011 [J/kg]	t = 240 [C]	t1 = 10 [C]	t2 = 240 [C]
V1 = 0.25 [m^3]	V2 = 0.45 [m^3]	W = 21000 [J/kg]	

Thus:

Q = 123011 J/kg, W = 21000 J/kg, ΔU = 102011 J/kg, ΔH = 123011 J/kg ….. Ans.

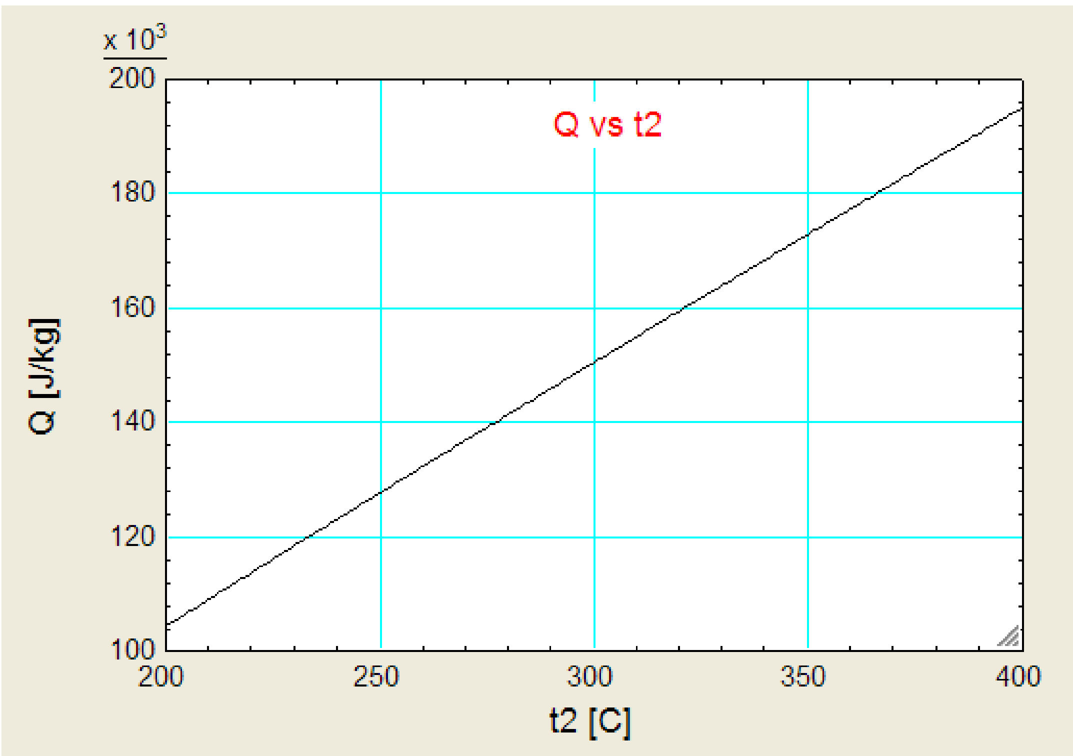
(b) As t2 varies from 200 C to 400 C, plot the variation of Q:

First, compute the Parametric Table:

Table 1

1..11	t2 [C]	Q [J/kg]
Run 1	200	104236
Run 2	220	113677
Run 3	240	123011
Run 4	260	132253
Run 5	280	141414
Run 6	300	150506
Run 7	320	159535
Run 8	340	168508
Run 9	360	177431
Run 10	380	186309
Run 11	400	195147

Now, plot the results:



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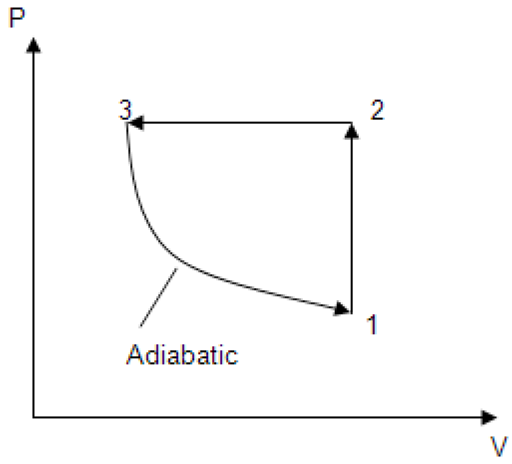
"**Prob.4.14.** A system receives 200 kJ of heat at constant volume. Then, it rejects 70 kJ of heat at constant pressure and work done on the system being 50 kJ. If the system is restored to the initial state by an adiabatic process, how much work will be done during the adiabatic process? Calculate the change in internal energy for the above mentioned processes and draw the p-V diagram. [VTU-Feb. 2002]"

EES Solution:

"Let:
process 1–2 : constant vol. process,
process 2–3: constant pr. process,
process 3–1: adiabatic process."



"Process 1–2:"

Q_12 = 200"kJ…. heat transfer, by data"
W_12 = 0 "kJ … for const. vol. process"
Q_12 = W_12 + DELTAU_12 "…by First Law for the process"

"Process 2–3:"

Q_23 = -70"kJ…. heat rejected, by data"
W_23 = -50 "kJ… work done on the system, by data"
Q_23 = W_23 + DELTAU_23 "…by First Law for the process"

"Process 3–1:"

Q_31 = 0 "kJ….. since adiabatic, by data"
Q_31 = W_31 + DELTAU_31 "…by First Law for the process"
DELTAU_12 + DELTAU_23 + DELTAU_31 = 0 "….since it is a closed cylce"

Results:

Unit Settings: SI K kPa kJ molar deg

ΔU_{12} = 200 [kJ]	ΔU_{23} = -20 [kJ]	ΔU_{31} = -180 [kJ]	Q_{12} = 200 [kJ]
Q_{23} = -70 [kJ]	Q_{31} = 0 [kJ]	W_{12} = 0 [kJ]	W_{23} = -50 [kJ]
W_{31} = 180 [kJ]			

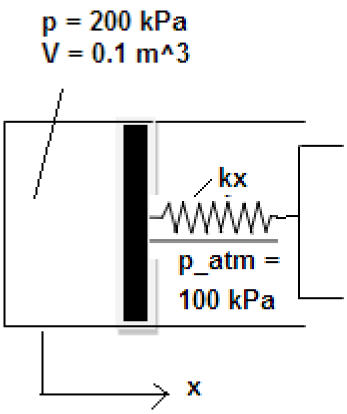
Thus:

Work done in adiabatic process, W_31 = 180 kJ … Ans.

Change in internal energies: ΔU_{12} = 200 kJ, ΔU_{23} = -20 kJ, ΔU_{31} = -180 kJ …. Ans.

===

"**Prob. 4.15.** Consider the system shown in fig. Initial conditions of the gas are: V1 = 0.1 m^3, p1 = 200 kPa. Ambient pressure: 100 kPa and the spring exerts a force which is proportional to the displacement from its equilibrium position. The gas is heated until the volume is doubled, at which point p2 = 600 kPa. Determine the work done by the gas. [VTU-Aug. 2001]"



EES Solution:

"Data:"

p1=200 "kPa"
V1 = 0.1 "m3"
V2 = 2*V1 "m3"
p2=600 "kPa"

"Calculations:"

W_tot=((p1+p2)/2) * (V2-V1) "kJ"

Results:

Unit Settings: SI K kPa kJ molar deg

p1 = 200 [kPa]   p2 = 600 [kPa]   V1 = 0.1 [m^3]   V2 = 0.2 [m^3]

W_{tot} = 40 [kJ]

Thus:

Work done by the gas = 40 kJ …. Ans.

==

"**Prob.4.16.** A fluid is heated reversibly at a constant pressure of 1.03 bar until it has a specific volume of 0.1m^3/kg. It is then compressed reversibly according to the law pv = constant to a pressure of 4.2 bar, then allowed to expand reversibly according to the law: pv^1.2 = constant to the initial conditions. The work done in the constant pressure process is 820 J and the mass of the fluid present is 0.2kg. Calculate the net work done on or by the fluid in the process and sketch cycle on a p-v diagram."

EES Solution:

Data:

p1 = 1.03E05 "Pa"

p2 = p1"….const. pr."

v2 = 0.1"m^3…. sp. volume"

w_12 = 820"J"

p3 = 4.2E05 "Pa"

mass = 0.2"kg"

"Calculations:"

p2 * (v2-v1) = w_12 "gives v1"

p3 * v3 = p2 * v2 "gives v3"

w_23 = (p2 * v2) * ln(v3/v2)"J…work done in isothermal process 2–3"

w_31 = (p3 * v3 – p1* v1)/(1.2 – 1)"J… work done in polytropic process 3–1"

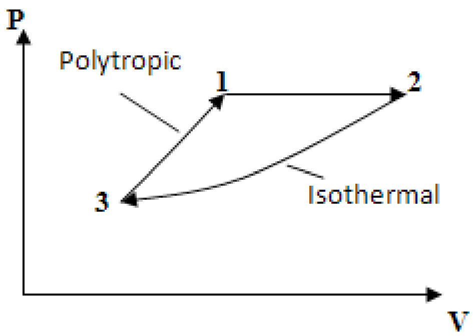
w_net = w_12 + w_23 + w_31"J…net work done in the cycle, per kg"

Work_net = w_net * mass"J…net work done in the cycle for mass = 0.2 kg"

Results:

Unit Settings: SI C kPa kJ mass deg

mass = 0.2 [kg]	p1 = 103000 [Pa]	p2 = 103000 [pA]
p3 = 420000 [Pa]	v1 = 0.09204 [m^3]	v2 = 0.1 [m^3]
v3 = 0.02452 [m^3]	$Work_{net}$ = -1911 [J]	w_{12} = 820 [J]
w_{23} = -14477 [J]	w_{31} = 4100 [J]	w_{net} = -9557 [J]



Thus:

Net work done = -1911 J .. negative sign indicating work done *on* the system….Ans.

===

"**Prob.4.17.** A fluid system undergoes a non flow frictionless process from V1 = 6 m^3 and V2 = 2 m^3. The pressure and volume relation during the process is given by following relation, P in N/m2 where V is in m^3. Determine the magnitude and direction of work transfer during the process.[VTU-Sept. 2009]"

EES Solution:

"Data:"

P= (15/V) + 2 "…relation between P and V"
V1 = 6 "m^3"
V2 = 2 "m^3"

"Calculation:"

W = integral (P, V, V1, V2) "J….work done …using the built-in integral function of EES"

Results:

Unit Settings: SI C kPa kJ mass deg

P = 9.5 [Pa]   V = 2 [m^3]   V1 = 6 [m^3]   V2 = 2 [m^3]   W = -24.48 [J]

Thus:

Work done = -24.48 J….negative sign indicating work done *on* the system…..Ans.

===

4.3 Now, let us solve a few problems with TEST:

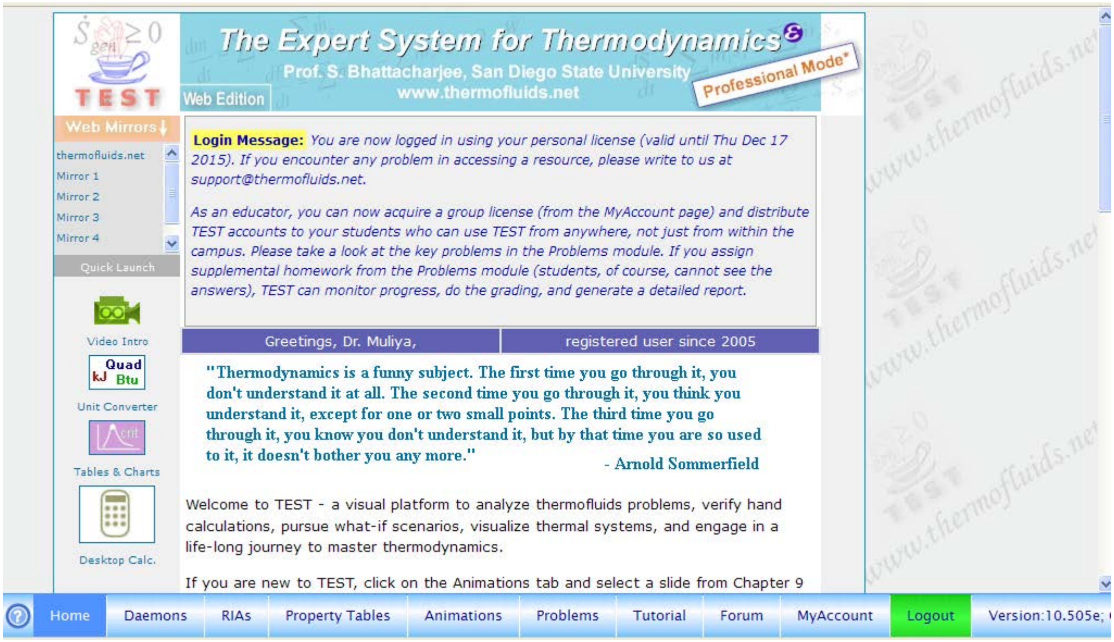
Prob. 4.18. Nitrogen at an initial state of 300 K, 150 kPa, and 0.2 m^3 is compressed slowly in an isothermal process to a final pressure of 800 kPa. Determine the work done during the process. [Ref.1]

TEST Solution:

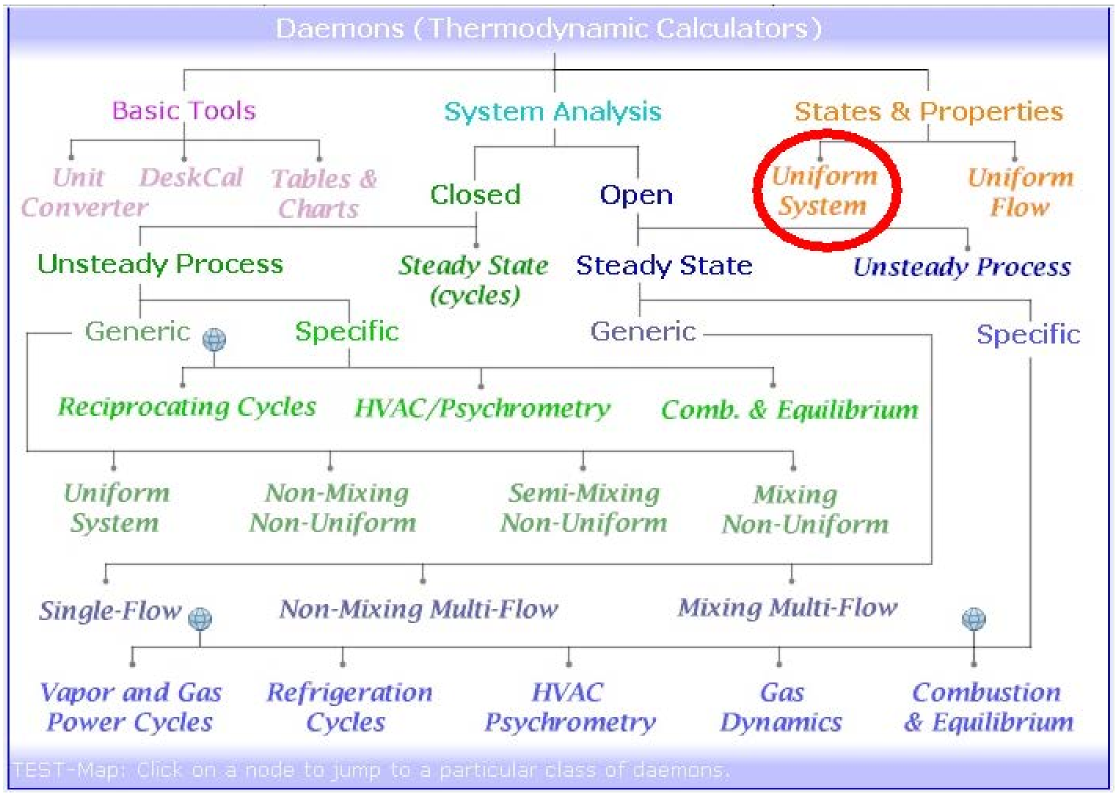
Let us solve this problem with The Expert System for Thermodynamics (TEST):

Following are the steps:

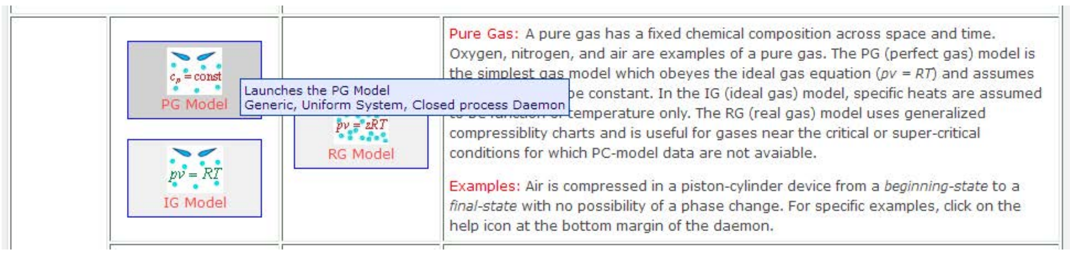
1. Start TEST after logging in to www.thermofluids.net. We get the following Greeting screen:



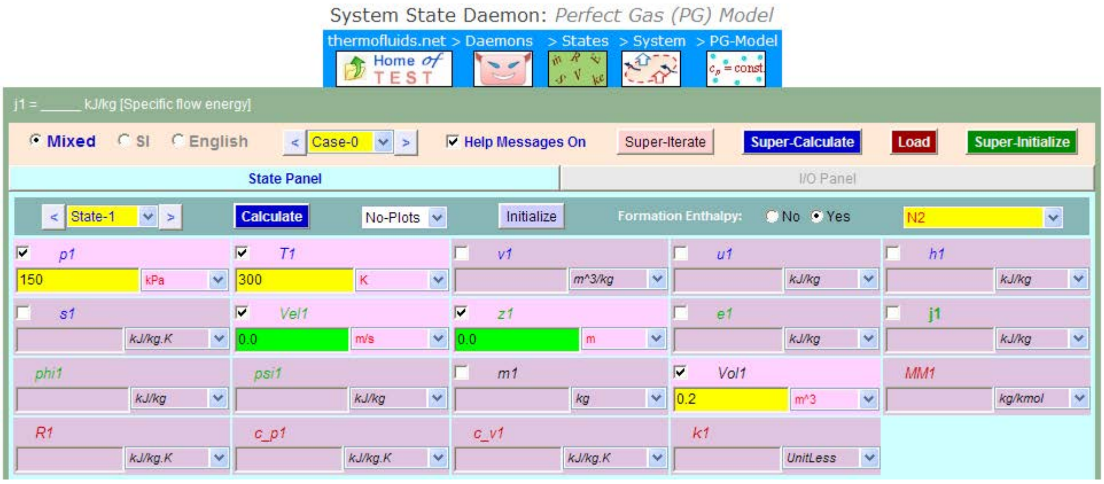
2. Click on Daemons at the menu bar at the bottom to get the following Daemons Map:



3. We can choose the States and Properties – Uniform system to get the states 1 and 2, and then calculate the work for Isothermal process, OR: go to System Analysis – Closed – Generic – Uniform system to make the direct analysis of the process. Choosing the States & Properties – Uniform System, we get:

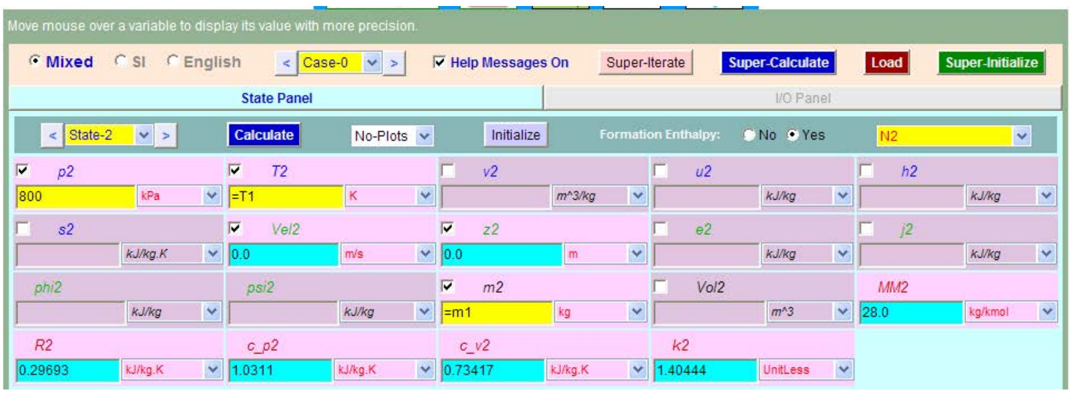


4. We choose for the Material model: the PG Model, i.e. cp = const. Clicking on it, we get the following screen. Now, choose State 1, Enter p1, T1, Vol1 in proper units as given in data:

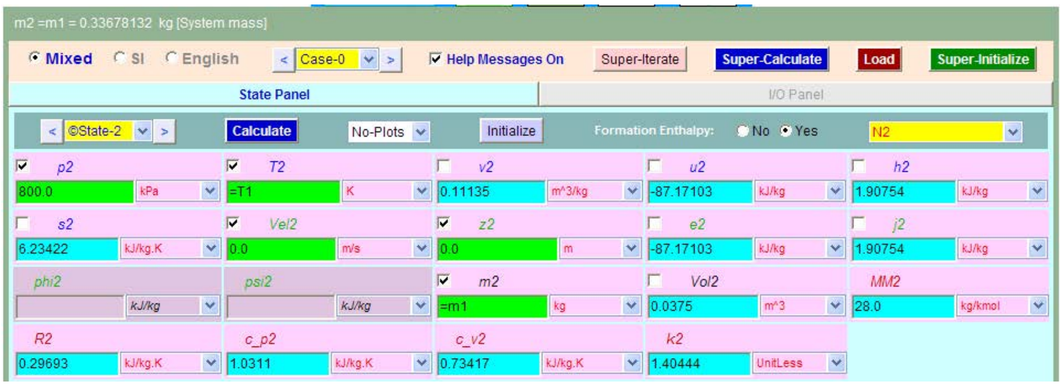


5. Click on Calculate and state 1 is calculated:

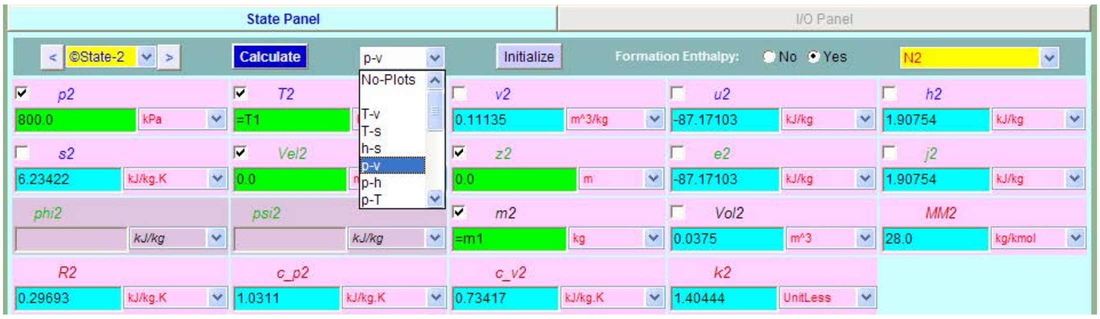
6. Similarly, choose State 2, enter p2, T2 and m2. Note that we wrote T2 = T1, m2 = m1.



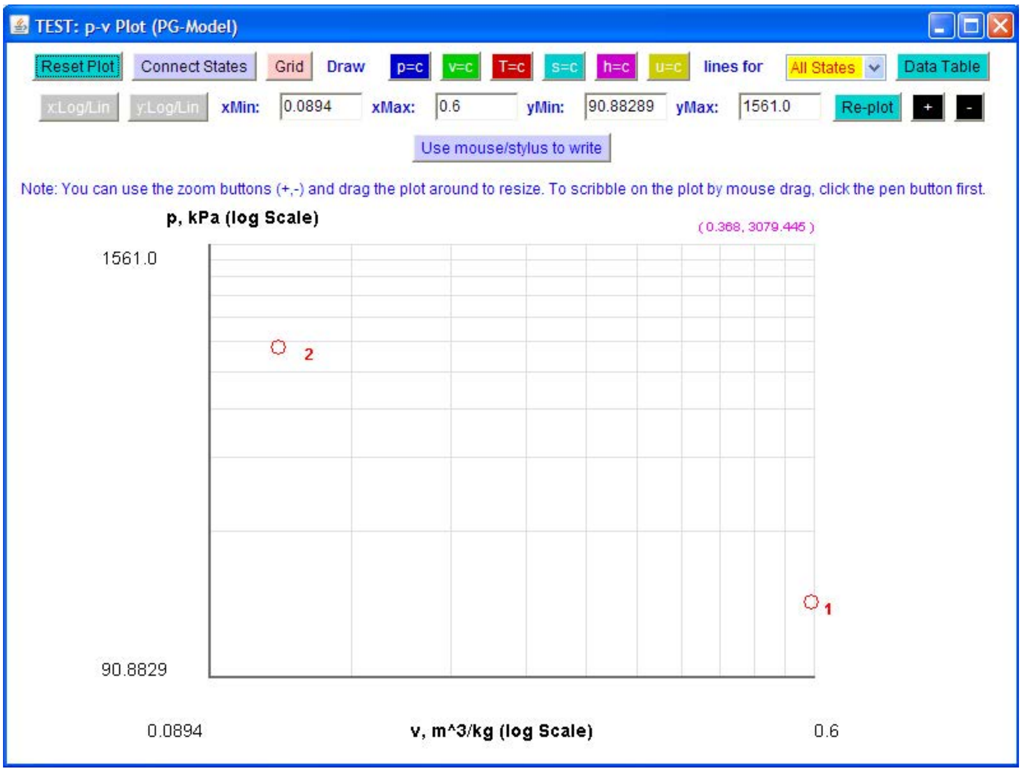
7. Click on Calculate. State2 is calculated:



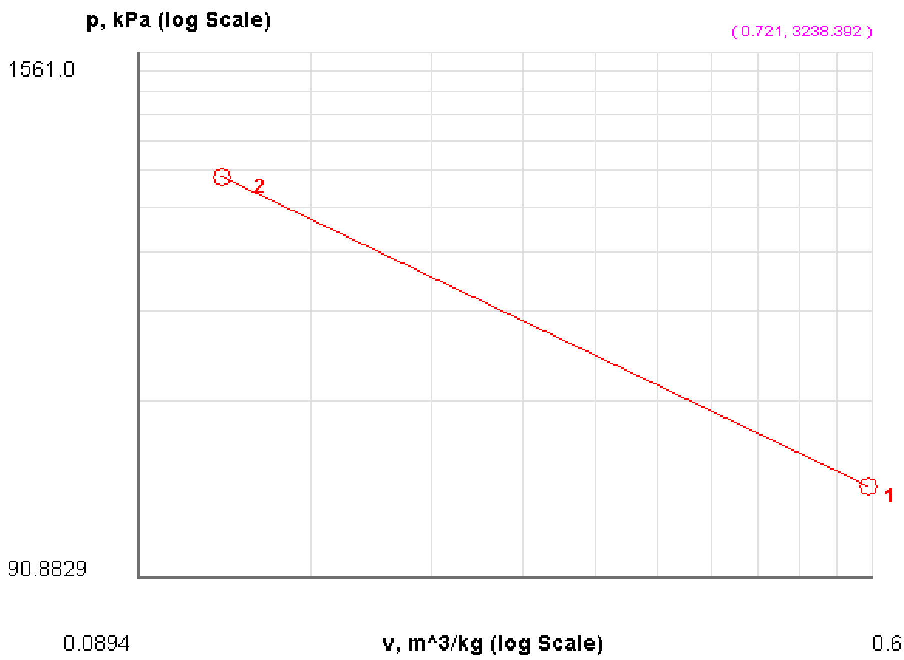
8. Draw the p-V diagram: Select Plots-p-V diagram:



And, immediately, following plot with the two states marked, is presented:



You can format it further, connect the states, draw different lines such as p = c, v = c, T = c etc. (see the top line in the above screen shot), and change the axes limits too if required. In the following T = c is executed:



9. Now, that States 1 and 2 are fully known, we can calculate Isothermal work by going to the I/O panel: **Click on Super Calculate** and go to I/O panel:

Clicking on I/O panel, we get:

#*******ANALYST: Dr. Muliya; TEST License: Professional*******
Solution logged at: Dec 11, 2013 9:26:29 PM
#--------------------Start of TEST-code ---
States {
State-1: N2;
Given: { p1= 150.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.2 m^3; }
State-2: N2;
Given: { p2= 800.0 kPa; T2= "T1" K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; }
}
#----------------------End of TEST-code ---

Evaluated States:

State-1: N2 > PG-Model;
Given: p1= 150.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s;
z1= 0.0 m; Vol1= 0.2 m^3;
Calculated: v1= 0.5939 m^3/kg; u1= -87.171 kJ/kg; h1= 1.9075 kJ/kg;
s1= 6.7313 kJ/kg.K; e1= -87.171 kJ/kg; j1= 1.9075 kJ/kg;
m1= 0.3368 kg; MM1= 28.0 kg/kmol; R1= 0.2969 kJ/kg.K;
c_p1= 1.0311 kJ/kg.K; c_v1= 0.7342 kJ/kg.K; k1= 1.4044 UnitLess;
State-2: N2 > PG-Model;
Given: p2= 800.0 kPa; T2= "T1" K; Vel2= 0.0 m/s;
z2= 0.0 m; m2= "m1" kg;
Calculated: v2= 0.1114 m^3/kg; u2= -87.171 kJ/kg; h2= 1.9075 kJ/kg;
s2= 6.2342 kJ/kg.K; e2= -87.171 kJ/kg; j2= 1.9075 kJ/kg;
Vol2= 0.0375 m^3; MM2= 28.0 kg/kmol; R2= 0.2969 kJ/kg.K;
c_p2= 1.0311 kJ/kg.K; c_v2= 0.7342 kJ/kg.K; k2= 1.4044 UnitLess;
#

#-------- Property spreadsheet starts: The following property table can be copied onto a spreadsheet (such as Excel) for further analysis or plots. ---------------

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	150.0	300.0	0.5939	-87.17	1.91	6.731
#	2	800.0	300.0	0.1113	-87.17	1.91	6.234

#

#--------Property spreadsheet ends---

#

#******CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)', '= sqrt(4*A1/PI)', etc.) and press the Enter key)*********

#

#Isothermal Work done: W = p1*Vol1 * ln (Vol2/Vol1)

=p1*Vol1 * ln (Vol2/Vol1)

p1*Vol1 * ln (Vol2/Vol1) = -50.21929300715014 kJ = -50.22 kJ …. Ans.

 # Alternatively:

=m1*R1*T1*ln(vol2/vol1)

m1*R1*T1*ln(vol2/vol1) = -50.21929300715015…. same as above.

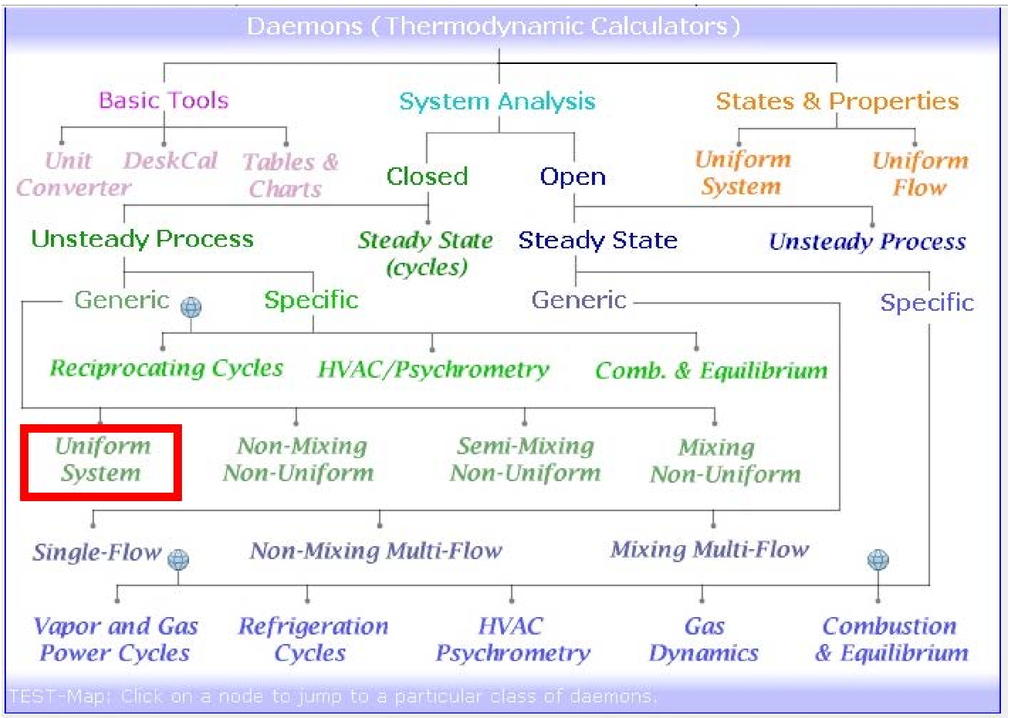
==

Alternatively:

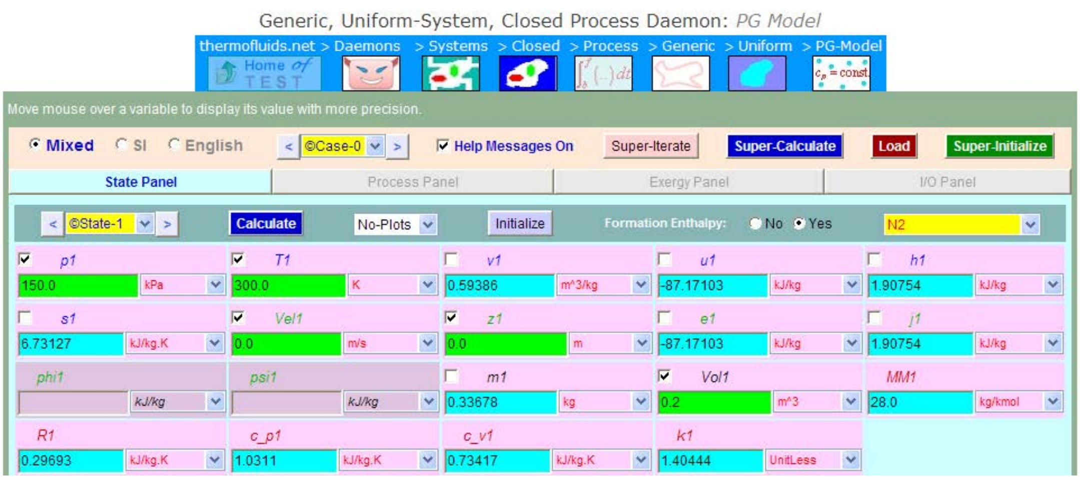
Use the System Analysis – Closed – Generic – Uniform System Daemon for the ***Process analysis.***

This is direct method, and is preferable since in addition to work and heat, it calculates exergy and 'lost work' too.

1. Select the appropriate daemon for process analysis as shown below:

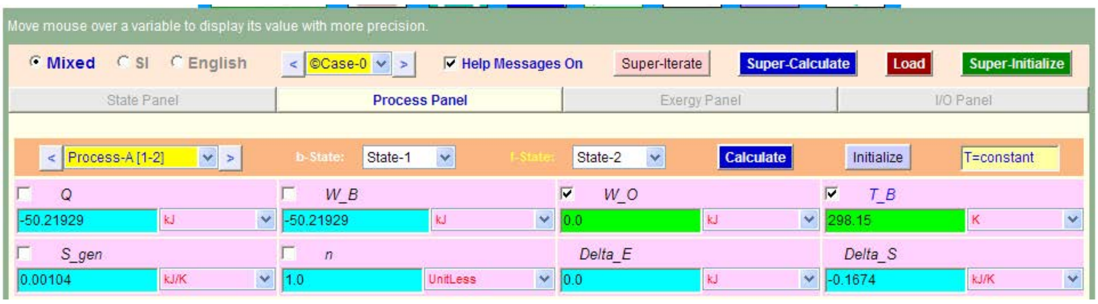


2. Clicking on Uniform System, and choosing the Perfect Gas Model with cp = const. gives following window. Fill up the known parameters viz, p1, T1, Vol1 for State 1, and click on Calculate. We get:



3. Fill up known parameters for State 2, click on Calculate:

4. Go to Process Panel. T_B is already checked there; also check W_O (i.e. other work) as zero. Click on Calculate and get the following results:

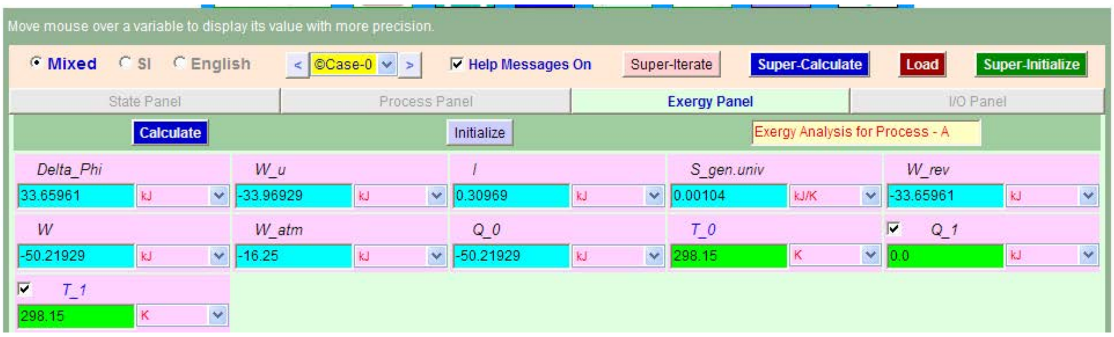


Note that we get: W_B = Boundary work for this Isothermal process as **-50.22 kJ;**

Also, the Heat rejected Q = W_B = -50.22 kJ for Isothermal process, as it should be.

5. To make exergy analysis, we should first choose 'dead state'. This is State '0', take it as p0 = 100 kPa, T_0 = 25 C. Go to States Panel and fill up these parameters for State 0, and click on Calculate:

6. Now, go to Exergy Panel:



Observe that I = T0 * ΔS = 0.30969 is the 'lost work'.

7. Click **on SuperCalculate** to generate the TEST Code and to get a record of all calculations, and go to I/O Panel to get TEST code etc:

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

Daemon Path: Systems>Closed>Process>Generic>Uniform>PG-Model; v-10.bb05

#-------------------Start of TEST-code ---

```
States      {
            State-0: N2;
            Given: { p0= 100.0 kPa; T0= 25.0 deg-C; Vel0= 0.0 m/s; z0= 0.0 m; }

            State-1: N2;
            Given: { p1= 150.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.2 m^3; }

            State-2: N2;
            Given: { p2= 800.0 kPa; T2= "T1" K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "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 -----------------------------------------------------------------------
```

#******DETAILED OUTPUT: All the computed properties and variables are displayed on this block.*************

 # Evaluated States:

```
#
#      State-0: N2 > PG-Model;
#            Given: p0= 100.0 kPa; T0= 25.0 deg-C; Vel0= 0.0 m/s;
#                  z0= 0.0 m;
#            Calculated: v0= 0.8853 m^3/kg; u0= -88.5292 kJ/kg; h0= 0.0 kJ/kg;
#                  s0= 6.8453 kJ/kg.K; e0= -88.5292 kJ/kg; j0= 0.0 kJ/kg;
#                  phi0= 0.0 kJ/kg; psi0= 0.0 kJ/kg; MM0= 28.0 kg/kmol;
#                  R0= 0.2969 kJ/kg.K; c_p0= 1.0311 kJ/kg.K; c_v0= 0.7342 kJ/kg.K;
#                  k0= 1.4044 UnitLess;
#      State-1: N2 > PG-Model;
#            Given: p1= 150.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s;
#                  z1= 0.0 m; Vol1= 0.2 m^3;
#            Calculated: v1= 0.5939 m^3/kg; u1= -87.171 kJ/kg; h1= 1.9075 kJ/kg;
#                  s1= 6.7313 kJ/kg.K; e1= -87.171 kJ/kg; j1= 1.9075 kJ/kg;
#                  phi1= 6.2086 kJ/kg; psi1= 35.9014 kJ/kg; m1= 0.3368 kg;
#                  MM1= 28.0 kg/kmol; R1= 0.2969 kJ/kg.K; c_p1= 1.0311 kJ/kg.K;
```

```
#                       c_v1= 0.7342 kJ/kg.K; k1= 1.4044 UnitLess;
#       State-2: N2 > PG-Model;
#               Given: p2= 800.0 kPa; T2= "T1" K; Vel2= 0.0 m/s;
#                       z2= 0.0 m; m2= "m1" kg;
#               Calculated: v2= 0.1114 m^3/kg; u2= -87.171 kJ/kg; h2= 1.9075 kJ/kg;
#                       s2= 6.2342 kJ/kg.K; e2= -87.171 kJ/kg; j2= 1.9075 kJ/kg;
#                       phi2= 106.1536 kJ/kg; psi2= 184.0973 kJ/kg; Vol2= 0.0375 m^3;
#                       MM2= 28.0 kg/kmol; R2= 0.2969 kJ/kg.K; c_p2= 1.0311 kJ/kg.K;
#                       c_v2= 0.7342 kJ/kg.K; k2= 1.4044 UnitLess;
```

#--------Property spreadsheet starts: The following property table can be copied onto a spreadsheet (such as Excel) for further analysis or plots. ---------------

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	0	100.0	298.2	0.8853	-88.53	0.0	6.845
#	1	150.0	300.0	0.5939	-87.17	1.91	6.731
#	2	800.0	300.0	0.1113	-87.17	1.91	6.234
#							

#--------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= -50.21929 kJ; W_B= -50.21929 kJ; S_gen= 0.0010386907 kJ/K; n= 1.0 UnitLess;
Delta_E= -0.0 kJ; Delta_S= -0.16739765 kJ/K;

 # Exergy Analysis Results:

```
# Exergy Analysis for Process – A (Dead state: State-0)
#               Given: Q= -50.21929 kJ; T_0= 298.15 K; Q_1= 0.0 kJ;
#                       T_1= 298.15 K;
#               Calculated: Delta_Phi= 33.65961 kJ; W_u= -33.96929 kJ; I= 0.30969 kJ;
#                       S_gen.univ= 0.00104 kJ/K; W_rev= -33.65961 kJ; W= -50.21929 kJ;
#                       W_atm= -16.25 kJ; Q_0= -50.21929 kJ;
```

==

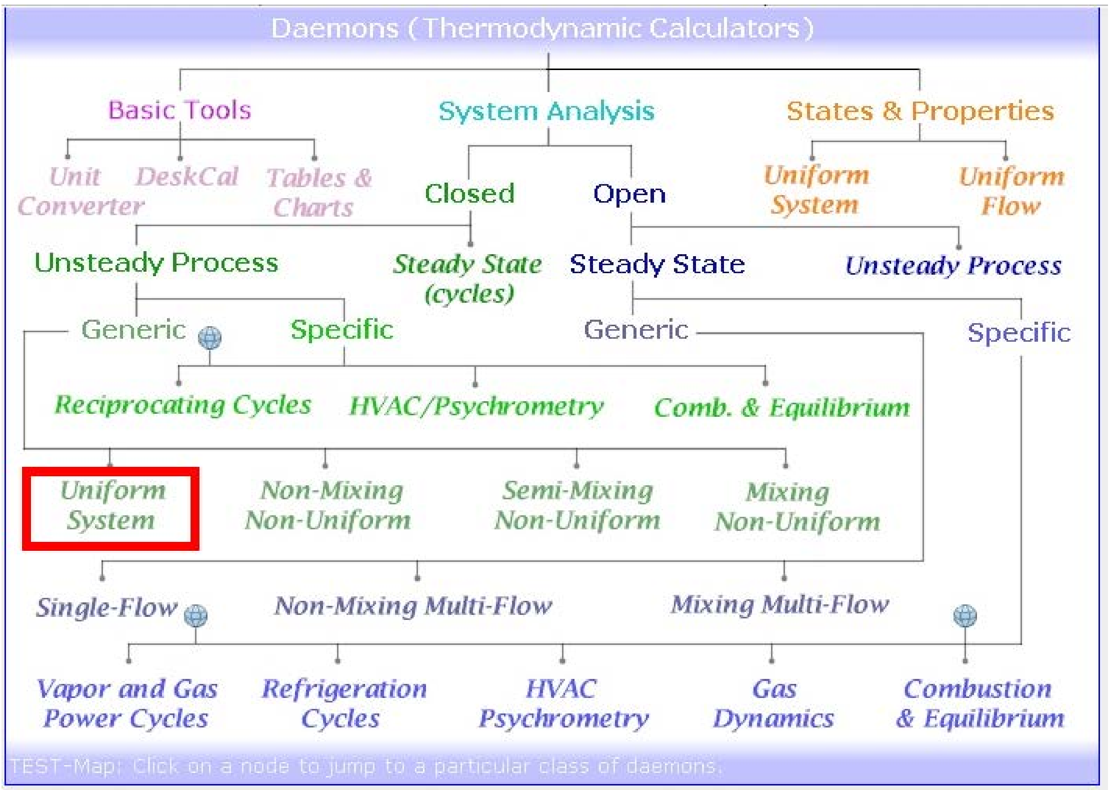
Prob.4.19. A mass of 1.2 kg of Air at 150 kPa and 12 C is contained in a gas-tight friction-less piston-cylinder device. The air is now compressed to a final pressure of 600 kPa. During the process heat is transferred from air such that the temp inside the cylinder remains constant. Calculate the work done during this process. [Ref. 1].

TEST Solution:

Use the System Analysis – Closed – Generic – Uniform System Daemon for the *Process analysis.*

Following are the steps:

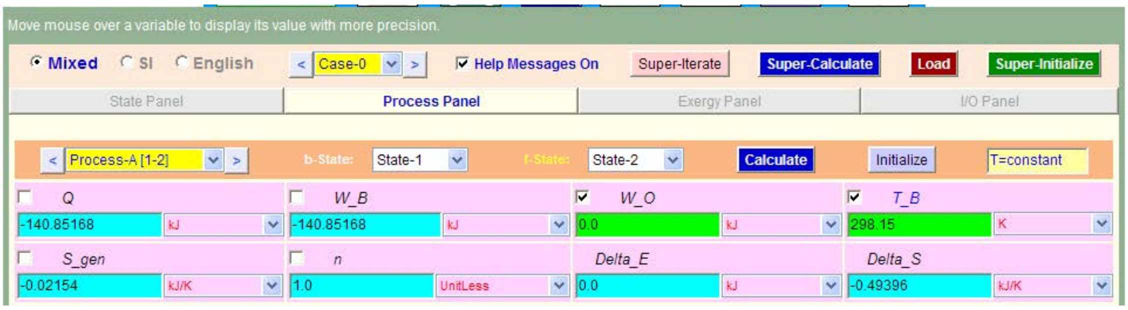
1. Select the appropriate daemon for process analysis as shown below:



2. Clicking on Uniform System, and choosing the Perfect Gas Model with cp = const. gives following window. Select the gas as N2, Fill up the known parameters viz, p1, T1, Vol1 for State 1, and click on Calculate. We get:

3. Select State 2, enter the known parameters, i.e. p2, T2, m2. Click on Calculate:

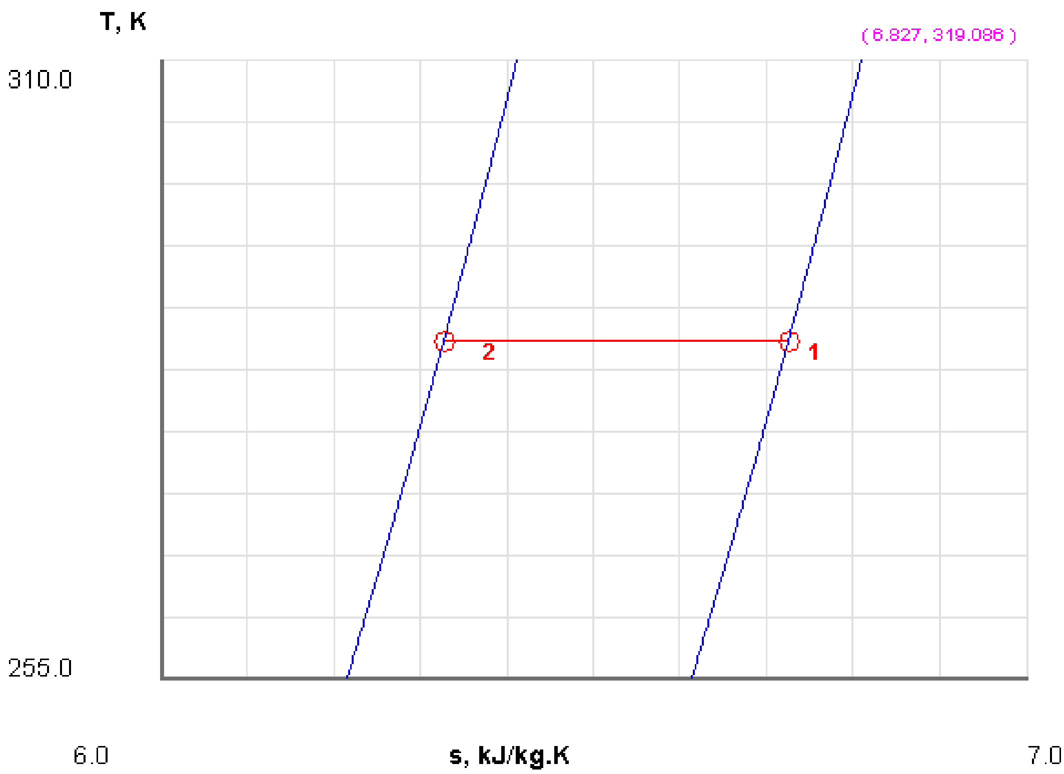
4. Go to Process Panel, enter W_O (i.e. works other than boundary works) as zero, click on Calculate:



Note that for this Isothermal process, Boundary work, **W_O is calculated as -140.85 kJ.** (Ans.)

Negative work indicates **work done *on* the system**. Obviously, heat transfer Q is equal to W_B and is negative, i.e. heat is leaving the system in this Isothermal process.

5. Plot below shows the States 1 and 2 on a T-s diagram:



6. Click on **SuperCalculate** to produce the TEST code, (with which we can regenerate these calculations later by loading this TEST code in the I/O Panel and clicking SuperCalculate). Now, go to I/O panel to view the TEST code and other calculated States. Only part of the I/O output is shown below:

```
#~~~~~~~~~~~~~~~~~~~~~~ OUTPUT OF SUPER-CALCULATE: (

#       Daemon Path: Systems>Closed>Process>Generic>Uniform>PG-Model; v-10.bb05

#-------------------Start of TEST-code ---------------------------------------------------------------------

 States  {
            State-1: N2;
            Given: { p1= 150.0 kPa; T1= 12.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.2 kg; }
            State-2: N2;
            Given: { p2= 600.0 kPa; T2= "T1" deg-C; Vel2= 0.0 m/s; z2= 0.0 m; m2= "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 ---------------------------------------------------------------------
#--------Property spreadsheet starts:. ---------------

#     State   p(kPa)     T(K)   v(m^3/kg)    u(kJ/kg)     h(kJ/kg)     s(kJ/kg)
#       1     150.0      285.2   0.5645       -98.07       -13.4        6.679
#       2     600.0      285.2   0.1411       -98.07       -13.4        6.267

=====================================================================================
```

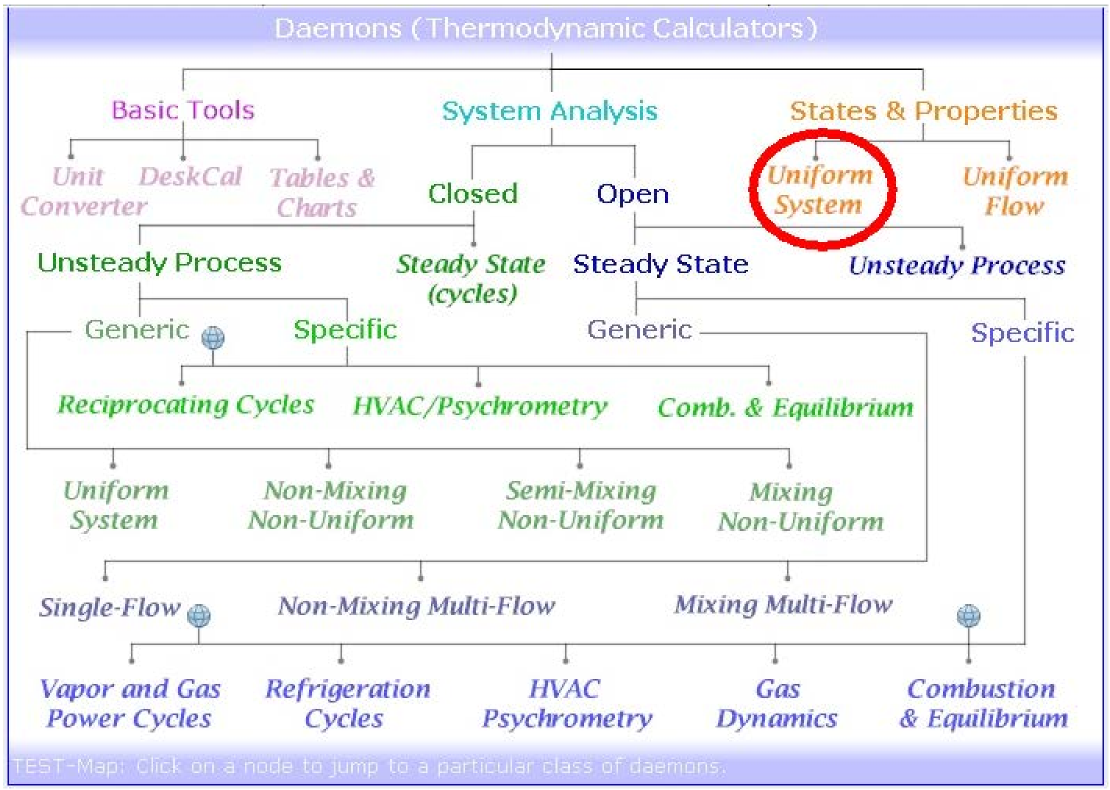
Prob. 4.20. A vessel having a volume of 5 m^3 contains 0.05 m^3 of sat. liquid water and 4.95 m^3 of sat. water vapour at 0.1 MPa. Heat is transferred until the vessel is filled with sat. vapour. Determine the heat transfer for this process. [Ref:2]

TEST Solution:

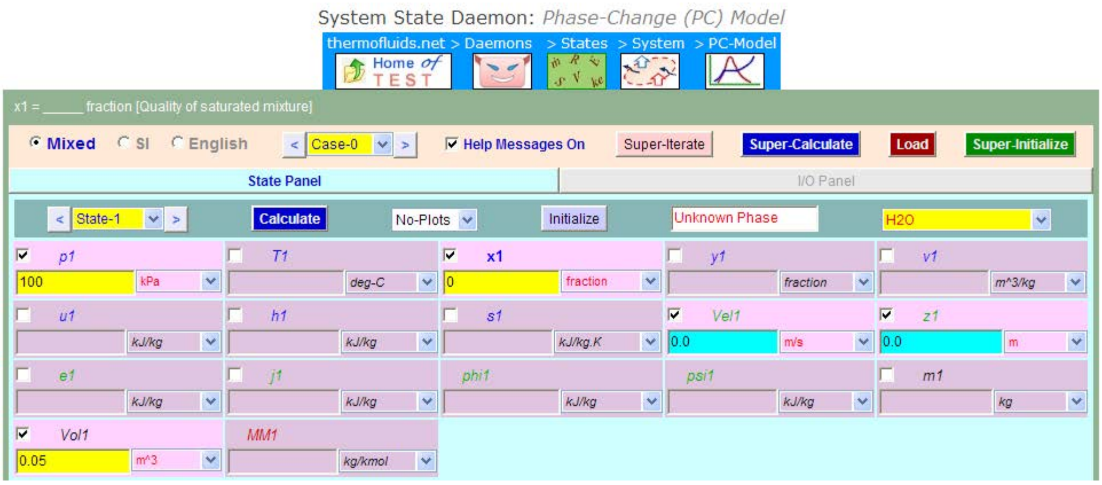
We shall use the States & Properties – Uniform System, with PC (i.e. Phase Change) Material model for Water, and then calculate the heat transferred in the I/O panel, using it as a calculator:

Following are the steps:

1. Select the System State daemon:



2. Choose the PC model for Material model. Following daemon presents itself. We shall call the sat. liq. As State 1, sat. vapour as State 2, and the combined liq + vapour as State 3. So, Fill up the known parameters p1, x1 and Vol1for State 1:



Note that in the above dryness fraction x1 is zero since it is sat. liq. state. Now, click on Calculate and we get:

Observe that m1, T1 etc are immediately calculated for Sat. water at 100 kPa.

3. Now, enter known parameters, i.e. p2, x2 and Vol2 for State 2:

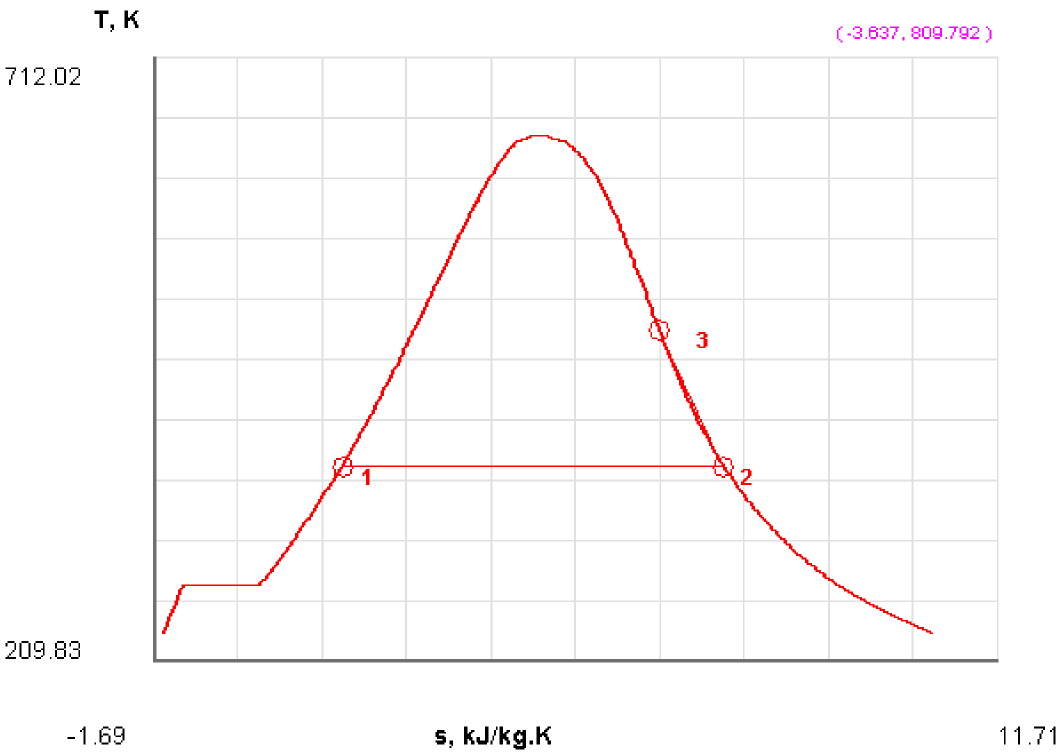
Here, x2 = 1 since we are dealing with sat. vapour. Click on Calculate, and we get:

Note that m2, u2, h2 etc. are immediately calculated for sat. water vap at 100 kPa.

4. Now, enter State 3. This is when the entire tank is filled with sat. water vap. i.e. x3 = 1, and of course, Vol3 = Vol1 + Vol2, and total mass m3 = m1+m2. Enter these parameters for State 3:

5. Click on Calculate and we get:

6. Get the T-s plot where States 1, 2 and 3 are shown:



7. Click on SuperCalculate to produce the TEST code and other calculated results. Go to I/O panel to see them. Part of the output is shown below:

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

#         Daemon Path: States>System>PC-Model; v-10.bb06

#--------------------Start of TEST-code -----------------------------------------------------------------------

States    {
          State-1: H2O;
          Given: { p1= 100.0 kPa; x1= 0.0 fraction; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.05 m^3; }
          State-2: H2O;
          Given: { p2= 100.0 kPa; x2= 1.0 fraction; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= 4.95 m^3; }
          State-3: H2O;
          Given: { x3= 1.0 fraction; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1+m2" kg; Vol3= "vol1+vol2" m^3; }
          }

#---------------------End of TEST-code ------------------------------------------------------------------
```

#--------Property spreadsheet :

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	100.0	372.8	0.0	0.001	417.34	417.44	1.303
# 02	100.0	372.8	1.0	1.694	2506.06	2675.46	7.359
# 03	2026.13	486.2	1.0	0.0983	2600.47	2799.74	6.336

#

#******CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)', '= sqrt(4*A1/PI)', etc.) and press the Enter key)*********

 # Calculate the heat transferred in the I/O panel, using it as a calculator:

Q = [(m3 * u3) – (m1 * u1 + m2 * u2)] …..heat transferred, since it is at constant volume
m1*u1 + m2*u2 = 27329.407721629643 kJ
m3*u3 = 132261.66395801632 kJ
#Therefore:

Q = m3*u3 – (m1*u1 + m2*u2) = 104932.25623638667 kJ = 104932.26 kJ …. Ans.

In addition, note that the masses of sat. liq. and vapour are:
m1 = 47.938637362598115 = 47.94 kg …. Mass of sat. liq.
m2 = 2.922078117838602 kg = 2.92 kg …. Mass of sat. vap.

And, total mass m3 is:

m3 = 50.86071548043672 = 50.86 kg …. Total mass

===

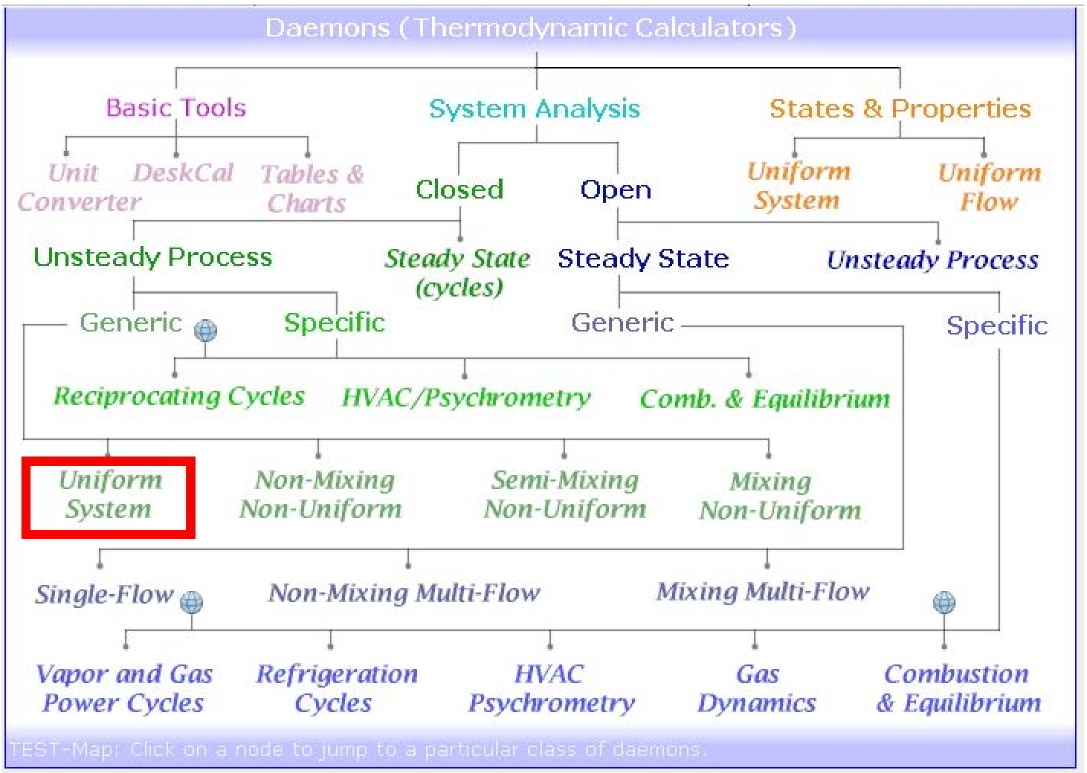
Prob.4.21. A cylinder fitted with a piston has a volume of 0.1 m^3 and contains 0.5 kg of steam at 0.4 MPa. Heat is transferred to the steam until the temp is 300 C, while the pressure remains constant. Determine the heat transfer and work for this process. [Ref: 2]

TEST Solution:

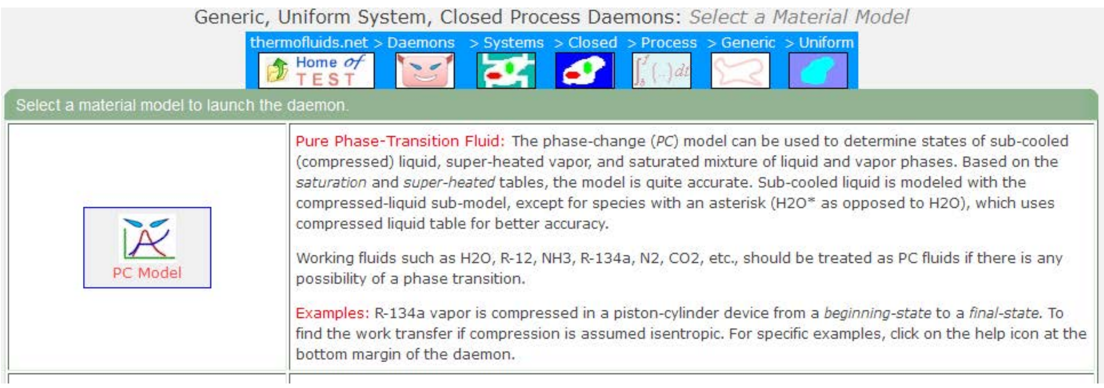
We use the System Analysis – Closed – Generic – Uniform System Daemon for the *Process analysis*.

Following are the steps:

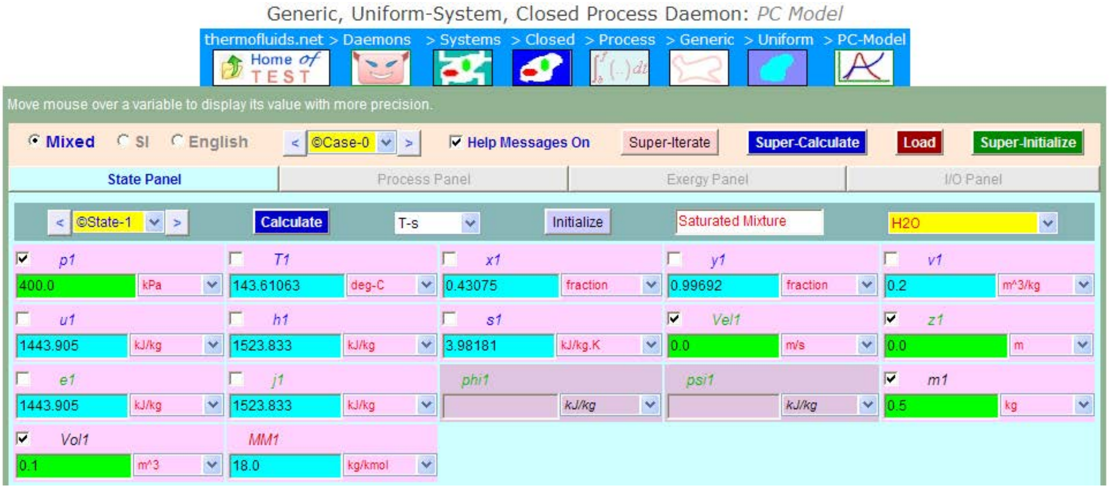
1. Select the appropriate daemon for process analysis as shown below:



2. Clicking on Uniform System, choose the PhaseChange (PC) Model for Material Model since we are dealing with Steam/Water.

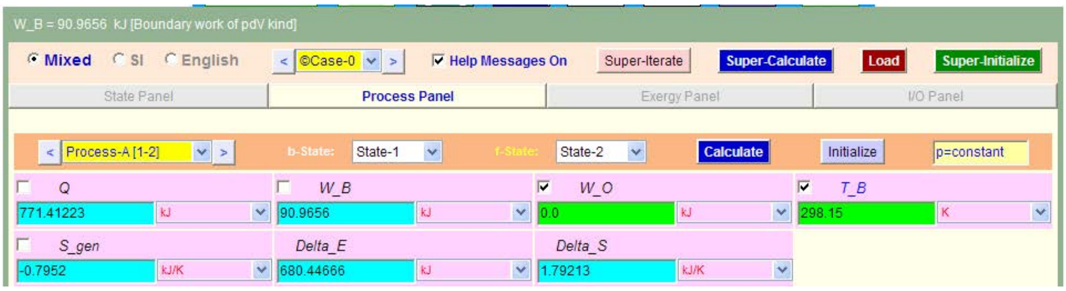


3. Fill up the known parameters viz, p1, m1, Vol1 for State 1. Click on Calculate. We get:



4. Select State 2, enter known parameters, i.e. p2, T2, m2, and click on Calculate:

5. Go to Process Panel, enter b-state and f-state, enter W_O = 0 (i.e. works other than pdV work), and click on Calculate. We get:

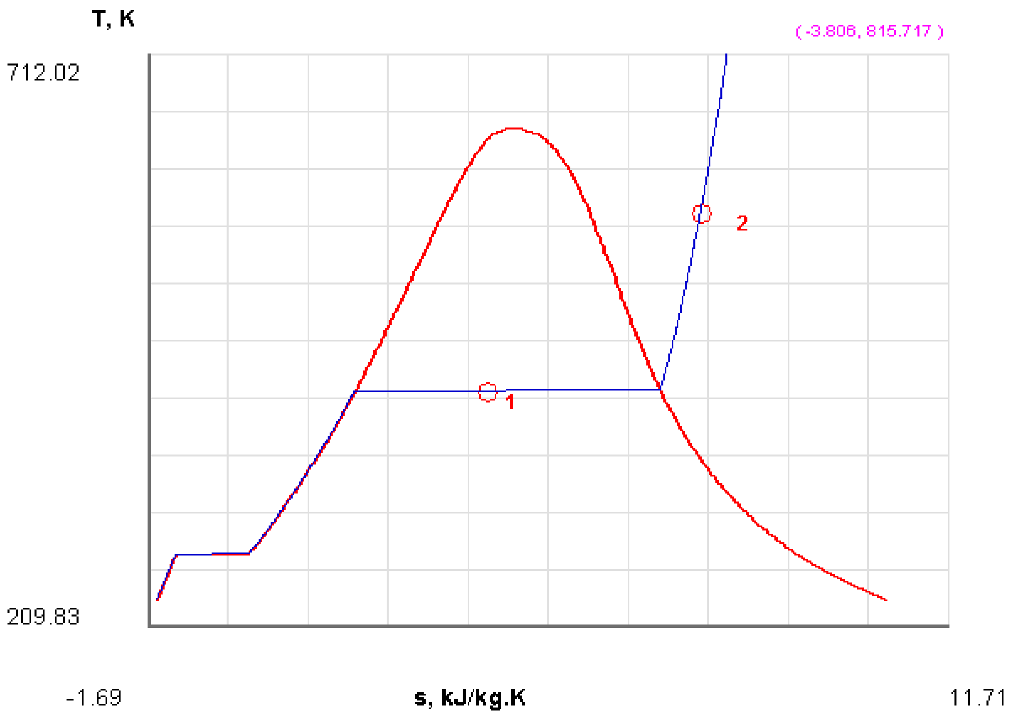


Thus: Boundary work, W_B = 90.9656 kJ and the heat transferred Q = 771.41 kJ….Ans.

Note that Work is positive, i.e. **work done *by* the system**.

Heat transfer q is positive, i.e. **Heat transferred *into* the system**.

6. On a T-s diagram, the State points are shown as follows:



7. Click on **SuperCalculate** to produce the TEST code, calculated State properties etc. Go to I/O panel to see the code. Part of I/O output is shown below:

```
#
#        Daemon Path: Systems>Closed>Process>Generic>Uniform>PC-Model; v-10.bb06
#
#--------------------Start of TEST-code -----------------------------------------------------------

States {
        State-1: H2O;
        Given: { p1= 400.0 kPa; Vel1= 0.0 m/s; z1= 0.0 m; m1= 0.5 kg; Vol1= 0.1 m^3; }
        State-2: H2O;
        Given: { p2= "p1" kPa; T2= 300.0 deg-C; Vel2= 0.0 m/s; z2= 0.0 m; m2= "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 -----------------------------------------------------------

# 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= 771.41223 kJ; W_B= 90.9656 kJ; S_gen= -0.7952037 kJ/K;
# Delta_E= 680.44666 kJ; Delta_S= 1.7921257 kJ/K;
```

==

Prob.4.22. Air at 1.02 bar, 22 C, initially occupying a cylinder volume of 0.015 m3, is compressed reversibly and adiabatically to a pressure of 6.8 bar. Calculate: (i) Final volume (ii) Final temp, and (iii) Work done. [Ref: 4]

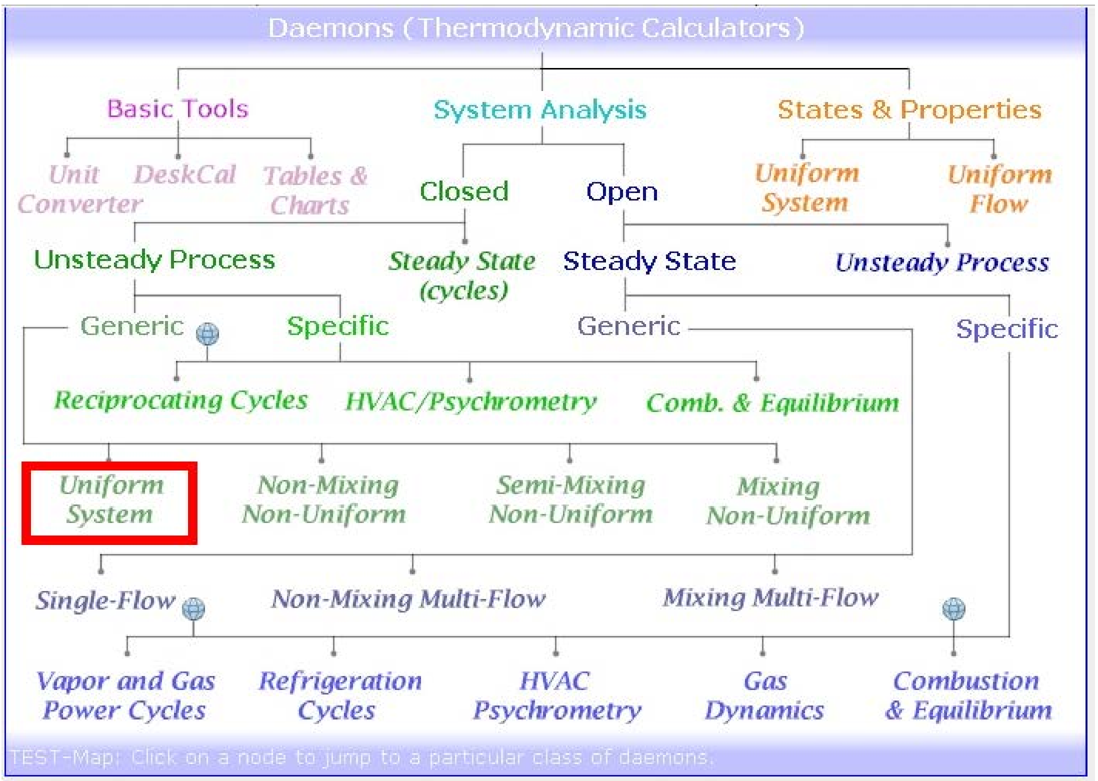
(b) In addition: If State 2 is reached by a polytropic process (n = 1.3) instead of by isentropic process, find out the values of Work and Heat transfers and their direction.

TEST Solution:

We use the System Analysis – Closed – Generic – Uniform System Daemon for the *Process analysis.*

Following are the steps:

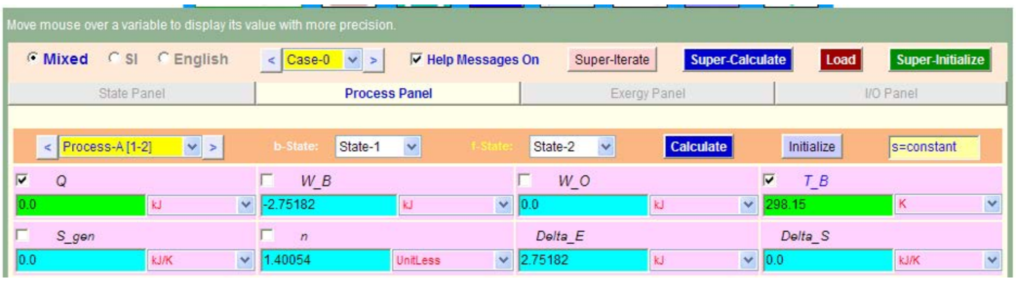
1. Select the appropriate daemon for process analysis as shown below:



2. Clicking on Uniform System, choose the Permanent Gas (PG) Model for Material Model since we are dealing with Air. Enter parameters p1, T1 and Vol1for State 1, click on Calculate. We get:

3. Select State 2, enter p2, m2 = m1, and s2 = s1 since it is an isentropic (i.e. reversible, adiabatic) process. Click on Calculate. We get:

4. Now, go to Process Panel, enter b_state = State 1, f-state = State 2, and Q = 0 since it is adiabatic process; click on Calculate. We get:

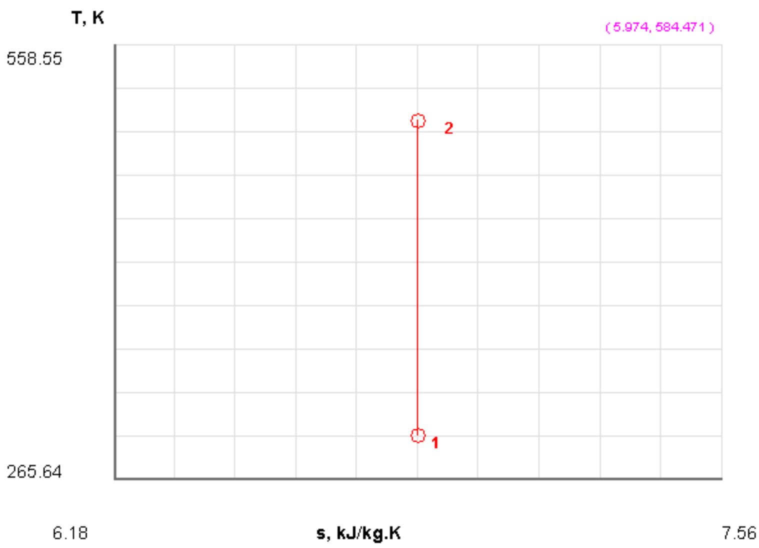


Thus:

Final volume, Vol2 = 0.00387 m^3, Final temp, T2 = 234.62 C…. Ans.

W_B = boundary work = -2.752 kJ …. Ans. Negative sign means that work is done *on* the system.

1. Plot the States 1 and 2 on the T-s diagram:

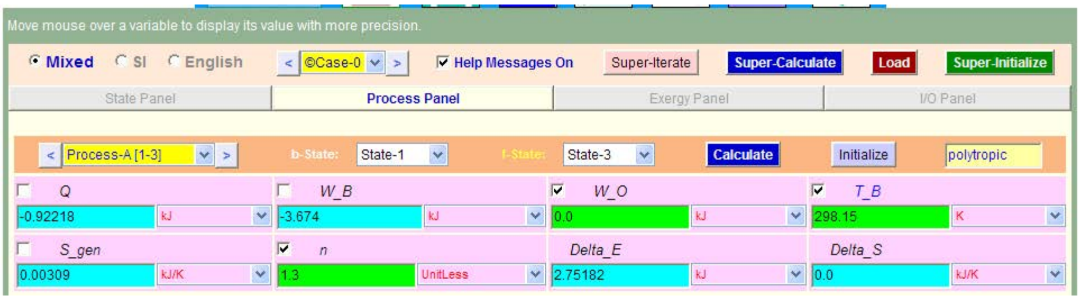


(b) If State 2 is reached by a polytropic process (n = 1.3), what are the values of Q and W_B?

Let the state after the polytropic process be designated as State 3. Note that State 2 and State 3 are identical:

1. Select State 3 and enter p3, T3 and m1. These are essentially the same as for State 2. Click on Calculate. We get:

2. Now, go to Process Panel. Enter b-state = State 1, f-state = State 3, n = 1.3 and Other Works, W_O = 0. Click on Calculate. We get:



Note that Q = -0.922 kJ, W_B = -3.674 kJ….. Ans. Negative sign means: Q leaving the system, W_B done on the system.

3. Click on **SuperCalculate** to generate TEST code and get all calculated results. See them on the I/O panel. Part of the output is given below:

```
#          Daemon Path: Systems>Closed>Process>Generic>Uniform>PG-Model; v-10.bb05

#--------------------Start of TEST-code -----------------------------------------------------------------------

 States   {
              State-1: Air;
              Given: { p1= 102.0 kPa; T1= 22.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.015 m^3; }
              State-2: Air;
              Given: { p2= 680.0 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; T3= "T2" K; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1" kg; }
              }

 Analysis {
              Process-A: b-State = State-1; f-State = State-3;
              Given: { W_O= 0.0 kJ; T_B= 298.15 K; n= 1.3 UnitLess; }
              }

#---------------------End of TEST-code ----------------------------------------------------------------------

#
```

#DETAILED OUTPUT:
Evaluated States:
State-1: Air > PG-Model;
Given: p1= 102.0 kPa; T1= 22.0 deg-C; Vel1= 0.0 m/s;
z1= 0.0 m; Vol1= 0.015 m^3;
Calculated: v1= 0.8304 m^3/kg; u1= -87.7146 kJ/kg; h1= -3.0105 kJ/kg;
s1= 6.8709 kJ/kg.K; e1= -87.7146 kJ/kg; j1= -3.0105 kJ/kg;
m1= 0.0181 kg; MM1= 28.97 kg/kmol; R1= 0.287 kJ/kg.K;
c_p1= 1.0035 kJ/kg.K; c_v1= 0.7165 kJ/kg.K; k1= 1.4005 UnitLess;
State-2: Air > PG-Model;
Given: p2= 680.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s;
z2= 0.0 m; m2= "m1" kg;
Calculated: T2= 507.7737 K; v2= 0.2143 m^3/kg; u2= 64.6319 kJ/kg;
h2= 210.3562 kJ/kg; e2= 64.6319 kJ/kg; j2= 210.3562 kJ/kg;
Vol2= 0.0039 m^3; MM2= 28.97 kg/kmol; R2= 0.287 kJ/kg.K;
c_p2= 1.0035 kJ/kg.K; c_v2= 0.7165 kJ/kg.K; k2= 1.4005 UnitLess;
State-3: Air > PG-Model;
Given: p3= "p2" kPa; T3= "T2" K; Vel3= 0.0 m/s;
z3= 0.0 m; m3= "m1" kg;
Calculated: v3= 0.2143 m^3/kg; u3= 64.6319 kJ/kg; h3= 210.3562 kJ/kg;
s3= 6.8709 kJ/kg.K; e3= 64.6319 kJ/kg; j3= 210.3562 kJ/kg;
Vol3= 0.0039 m^3; MM3= 28.97 kg/kmol; R3= 0.287 kJ/kg.K;
c_p3= 1.0035 kJ/kg.K; c_v3= 0.7165 kJ/kg.K; k3= 1.4005 UnitLess;
#

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	102.0	295.2	0.8304	-87.71	-3.01	6.871
#	2	680.0	507.8	0.2143	64.63	210.36	6.871
#	3	680.0	507.8	0.2143	64.63	210.36	6.871

#

#--------Property spreadsheet ends---

 # Mass, Energy, and Entropy Analysis Results:
Process-A: b-State = State-1; f-State = State-3;
Given: W_O= 0.0 kJ; T_B= 298.15 K; n= 1.3 UnitLess;
Calculated: Q= -0.92218256 kJ; W_B= -3.6739995 kJ; S_gen= 0.0030930154 kJ/K; Delta_E= 2.751817 kJ;
Delta_S= -0.0 kJ/K;

==

"**Prob.4.23.** 5 kg of Nitrogen at 100 C is heated in a reversible, non-flow, constant volume process till the pressure becomes three times the initial pressure. Determine: (i) final temp (ii) change in internal energy (iii) change in enthalpy, and (iv) heat transfer. Take R = 0.297 kJ/kg.K, cv = 0.7435 kJ/kg.K. [VTU-Jan. 2004]"

Note that this is the same as Prob. 4.8 which was solved with EES.

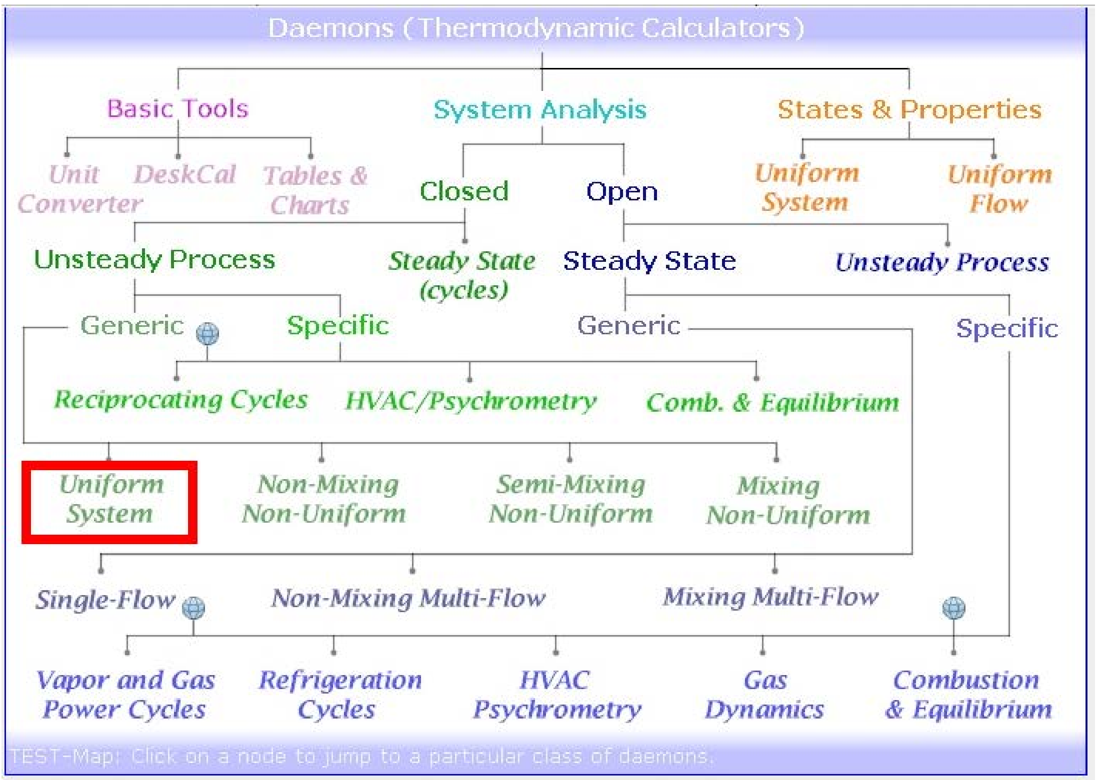
Now, let us solve it with TEST:

TEST Solution:

We use the System Analysis – Closed – Generic – Uniform System Daemon for the *Process analysis.*

Following are the steps:

1. Select the appropriate daemon for process analysis as shown below:

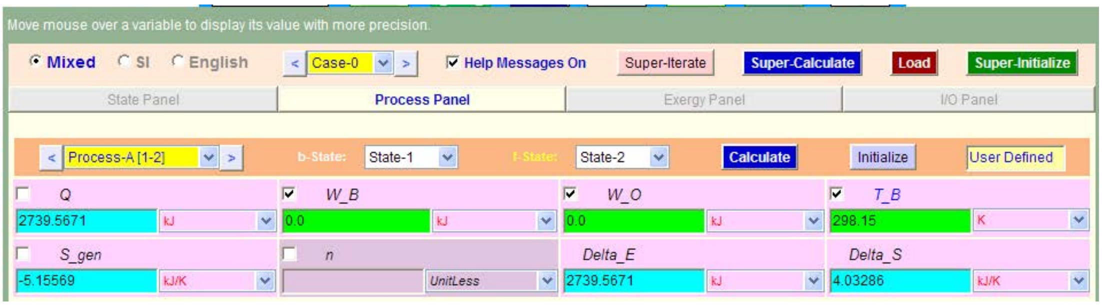


2. Clicking on Uniform System, choose the Permanent Gas (PG) Model for Material Model since we are dealing with Air. Enter parameters m1, T1 and Vol1 (= 1 m^3….assumed) for State 1, click on Calculate. We get:

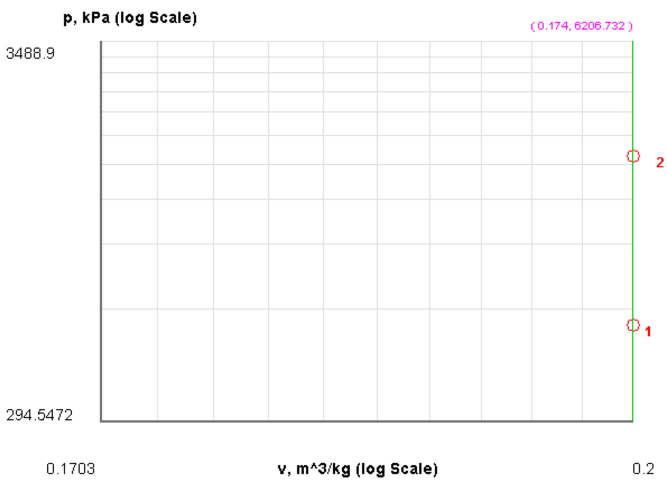
Note that, in calculations, we will be using the built-in properties for R, cp and cv, as seen in the above screenshot.

3. Select State 2, enter p2 = 3 * p1, Vol2 = Vol1, m2 = m1. Click on Calculate. We get:

4. Go to Process Panel, enter W_B = 0 since it is const. vol. process, W_O = o, since there is no other work interaction. Click on Calculate. We get:



5. States 1 and 2 are shown in the p-V diagram:



Thus:

Final temp, T2 = 846.3 C = 1119.4 K …. Ans.,

Heat transfer, Q = 2739.57 kJ …. Ans. Work is done *by* the system.

6. Click on **SuperCalculate** to get TEST code and calculated results. Also, calculate the change in internal energy and enthalpy in the I/O panel. Go to I/O panel. Part of the output is::

```
#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

#        Daemon Path: Systems>Closed>Process>Generic>Uniform>PG-Model; v-10.bb05

#-------------------Start of TEST-code ---------------------------------------------------------------------

States   {
         State-1: N2;
         Given: { T1= 100.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 5.0 kg; Vol1= 1.0 m^3; }
         State-2: N2;
         Given: { p2= "3*p1" kPa; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; Vol2= "Vol1" m^3; }
         }
```

Analysis {

Process-A: b-State = State-1; f-State = State-2;

Given: { W_B= 0.0 kJ; 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	553.99	**373.2**	0.2	-33.47	77.33	6.568
#	2	1661.98	**1119.4**	0.2	514.45	846.84	7.375

#--------Property spreadsheet ends--

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1; f-State = State-2;

Given: W_B= 0.0 kJ; W_O= 0.0 kJ; T_B= 298.15 K;

Calculated: **Q= 2739.57 kJ;** S_gen= -5.155695 kJ/K; Delta_E= 2739.5671 kJ; Delta_S= 4.0328584 kJ/K;

#******CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)', '= sqrt(4*A1/PI)', etc.) and press the Enter key)*********

 # Change in Internal Energy: ΔU = m1 * (u2 – u1)

i.e. ΔU = m1 * (u2 – u1) = 2739.5670715475585 = **2739.57 kJ… Ans.**

 # Change in Enthalpy: ΔH = m1 * (h2 – h1)

i.e. ΔH = m1 * (h2 – h1) = 3847.5560358332727 = **3847.56 kJ …. Ans.**

==

Compare the above results with those obtained with EES:

Unit Settings: SI K kPa kJ molar deg

cp = 1041 [J/kg-K]	cv = 743.5 [J/kg-K]	ΔH = 3.881E+06 [J]
ΔU = 2.773E+06 [J]	m = 5 [kg]	PressureRatio = 3
Q = 2.773E+06 [J]	R = 297 [J/kg-K]	T1 = 373 [K]
T2 = 1119 [K]	W = 0 [J]	

It is observed that results match very well.

==

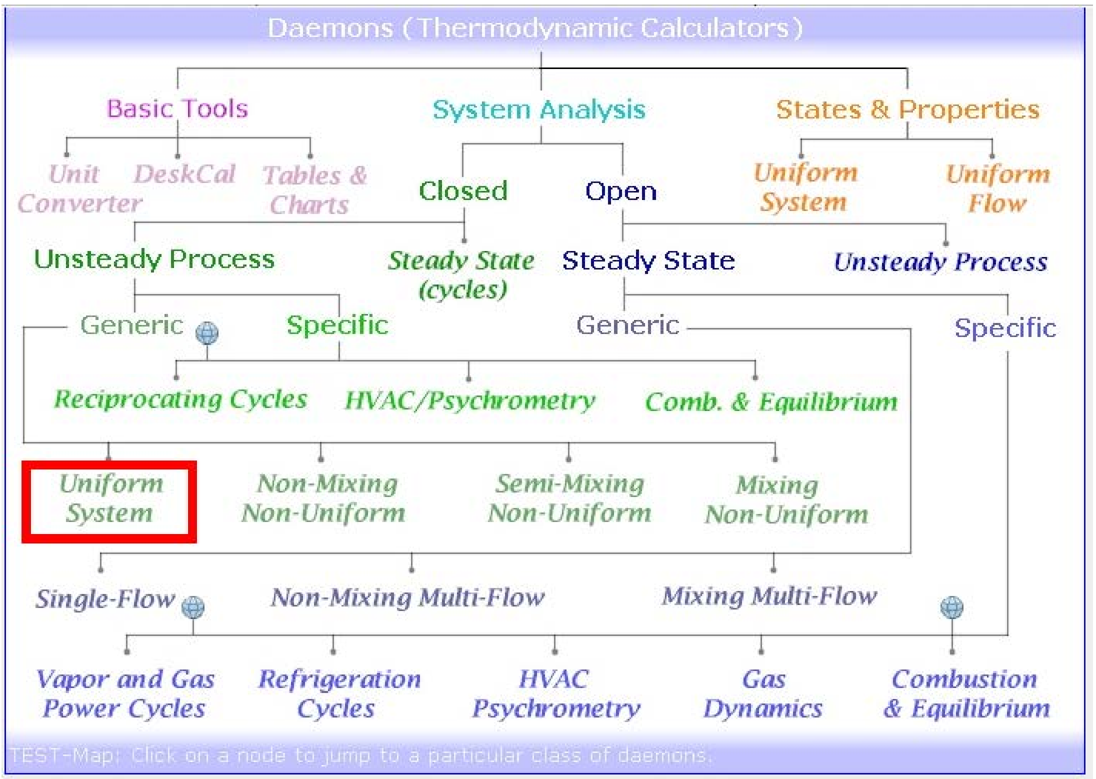
Prob.4.24.A piston-cylinder device contains 0.8 kg of Nitrogen initially at 100 kPa and 27 C. The nitrogen is now compressed slowly in a polytropic process (P.V^1.3 = const.) until the volume is reduced by one-half. Determine the work done and the heat transfer.[Ref: 1]

TEST Solution:

We use: System Analysis – Closed – Generic – Uniform System Daemon for the *Process analysis.*

Following are the steps:

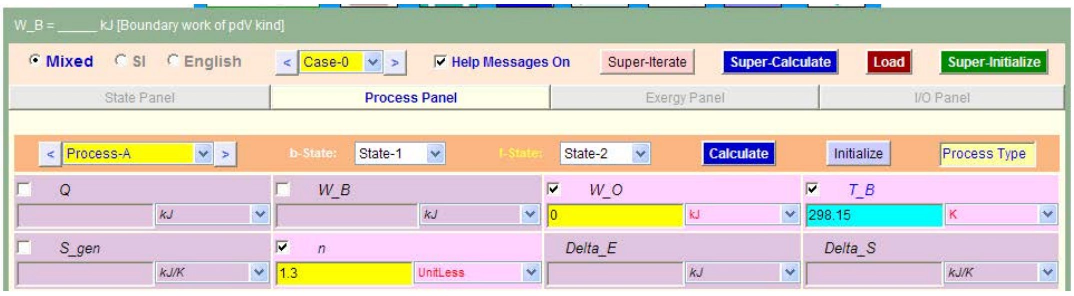
1. Select the appropriate daemon for process analysis as shown below:



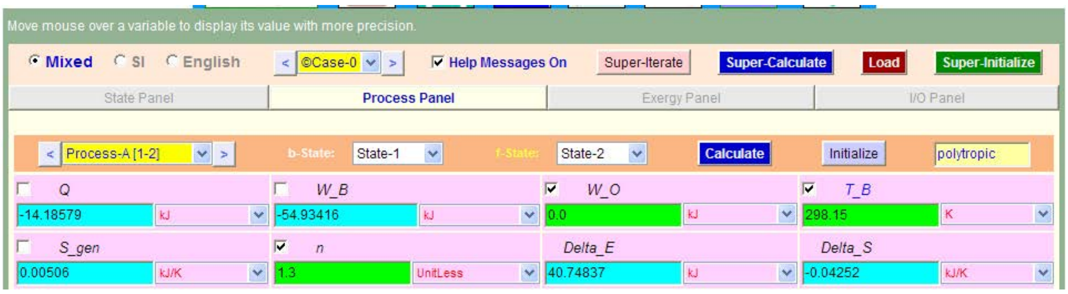
2. Clicking on Uniform System, choose the Permanent Gas (PG) Model for Material Model since we are dealing with N2. Enter parameters p1, T1, m1 for State 1, click on Calculate. We get:

3. Enter known quantities for State 2. We have: m2 = m1 and Vol2 = 0.5 * Vol1. Click on Calculate, but the entered data is not sufficient to make all calculations:

4. Let us proceed to the Process Panel and enter n = 1.3 (i.e, polytropic index), Other Works, W_O = 0. Click on Calculate. We get:



5. Since iteration has to be done with reference to other states, we have to click on **SuperCalculate** to complete the calculations. Then, we get:



Thus:

Work done, W_B = -54.93 kJ…. Ans. (Negative sign means work done on the system)

Heat transfer, Q = -14.19 kJ …..Ans. (Negative sign means heat rejected by the system).

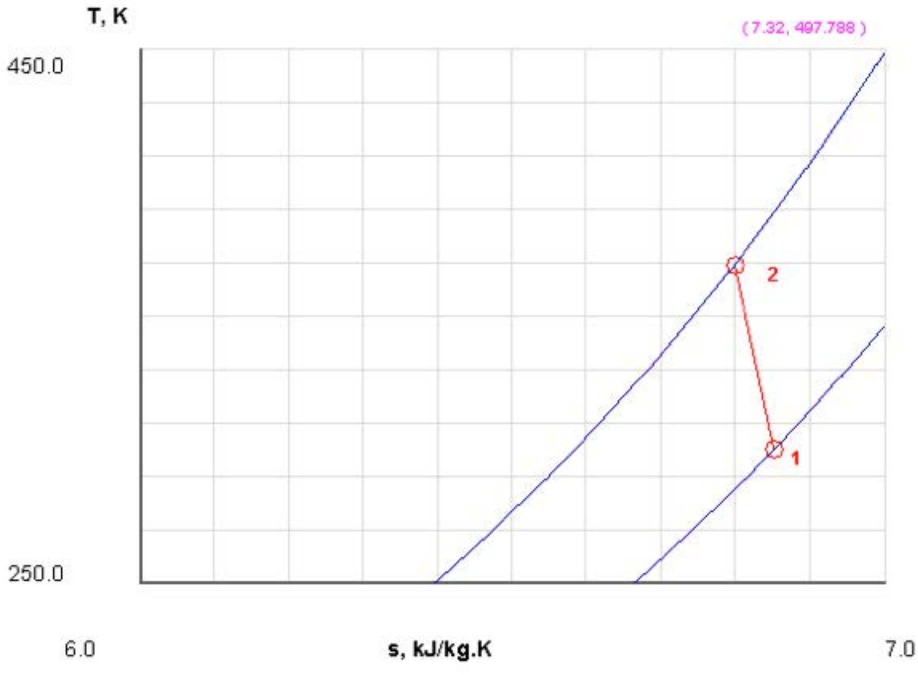
6. Now, go back to State Panel and examine State 2:

We see that values of p2 and T2 are now posted for State 2.

Thus:

P2 = 246.23 kPa, T2 = 96.38 C …. Ans.

7. T-s diagram showing States 1 and 2 is easily obtained:



8. Go to I/O panel to see the TEST Code and the calculated values:

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE (starts from your inputs)

#        Daemon Path: Systems>Closed>Process>Generic>Uniform>PG-Model; v-10.bb05

#-------------------Start of TEST-code ------------------------------------------------------------------

 States   {
            State-1: N2;
            Given: { p1= 100.0 kPa; T1= 27.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 0.8 kg; }
            State-2: N2;
            Given: { Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; Vol2= "0.5*Vol1" m^3; }
            }
 Analysis {
            Process-A: b-State = State-1; f-State = State-2;
            Given: { W_O= 0.0 kJ; T_B= 298.15 K; n= 1.3 UnitLess; }
            }
#--------------------End of TEST-code ---------------------------------------------------------------------

#
```

#--------Property spreadsheet starts: The following property table can be copied onto a spreadsheet (such as Excel) for further analysis or plots. ---------------

#

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	**100.0**	**300.2**	0.8912	-87.06	2.06	6.852
#	2	**246.23**	**369.5**	0.4456	-36.13	73.6	6.799

#--------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; n= 1.3 UnitLess;

Calculated: **Q= -14.185789 kJ; W_B= -54.93416 kJ**;

S_gen= 0.0050608176 kJ/K; Delta_E= 40.748367 kJ;

Delta_S= -0.042518552 kJ/K;

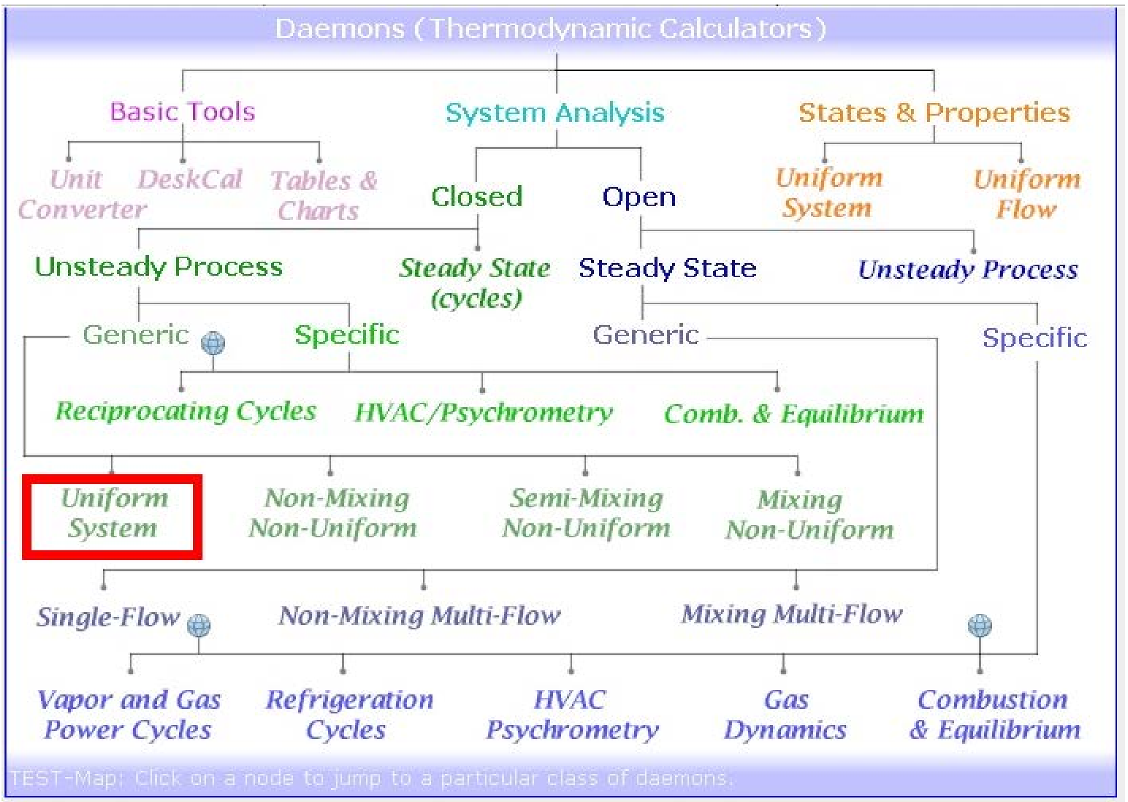
==

Prob.4.25. 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 pv^n = const. Find: (i) the value of index n (ii) the mass of air (iii) work transfer (iv) heat transferred during the process, and (v) change in entropy. [VTU-BTD-July 2007]

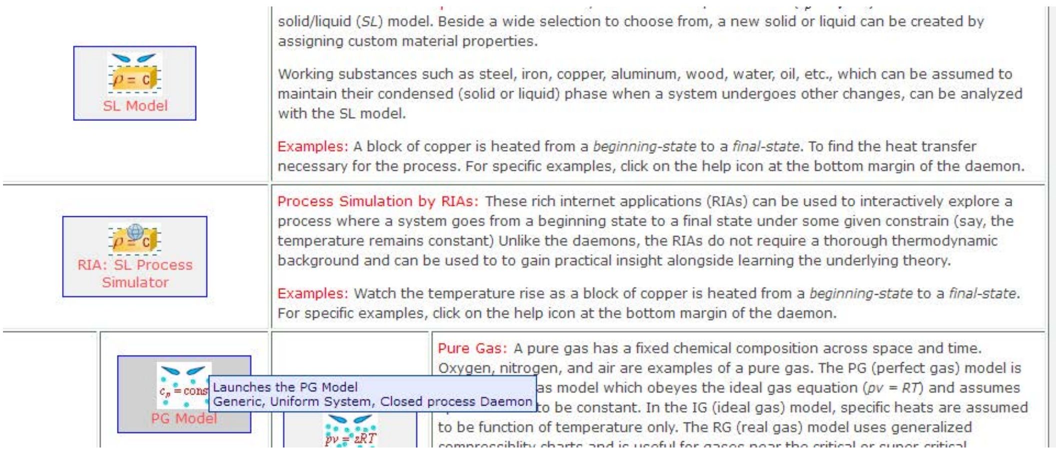
TEST Solution:

Following are the steps:

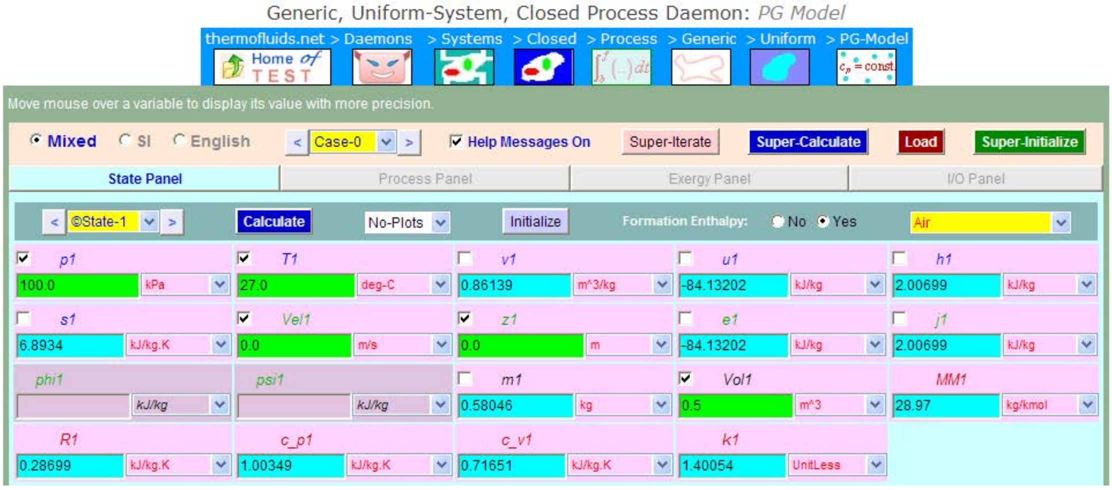
1. Select System Analysis-Generic-Uniform System:



2. For Material Model, select 'Perfect Gas' (PG) Model:

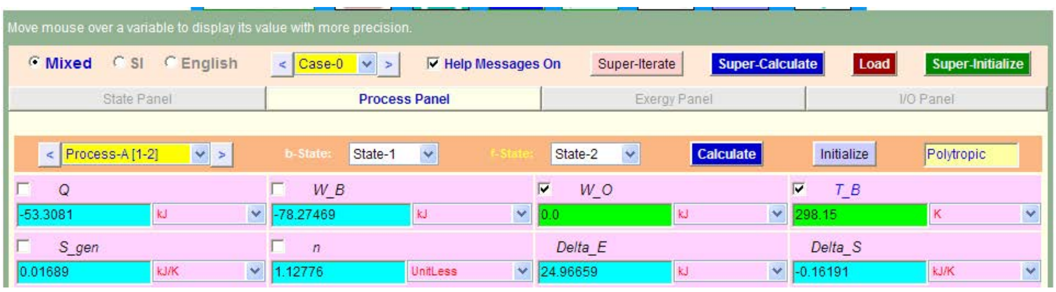


3. State 1: Enter p1, T1, Vol1. Hit Enter (or click Calculate).



4. State 2: Enter p2, Vol2, and m2 = m1. Hit Enter (or click Calculate).

5. Go to Process Panel. Enter b-state and f-state. Click W_O and enter W_O= 0. Click on Calculate:



6. **Now, click on SuperCalculate. Go to States Panel and see:**

And State 2:

Thus:

Index, n = 1.12776

Mass of air = m1 = m2 =0.58046 kg

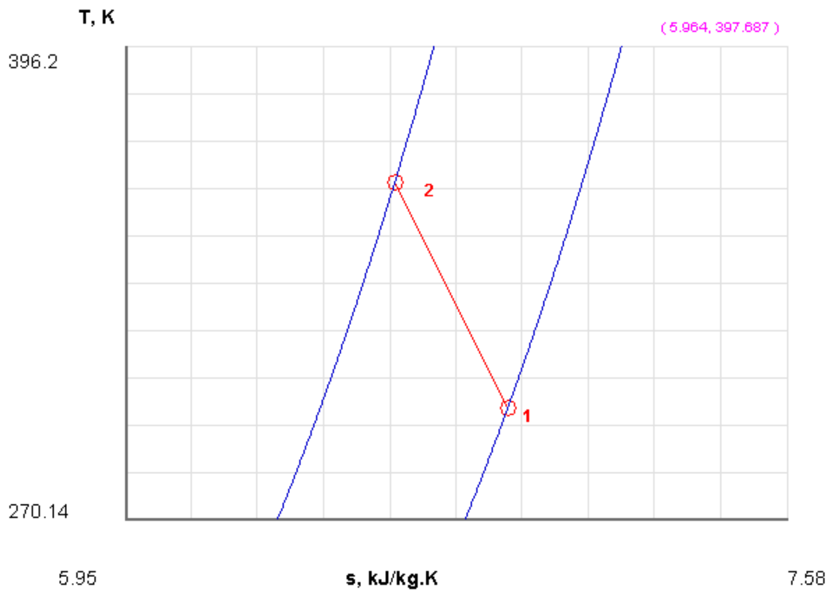
Work transfer = W_B = -78.27 kJ (Work done on the system, therefore negative)

Heat transfer = -53.3081 kJ

Entropy change = (s2 – s1) = -0.2789284256081599 = -0.2789 kJ/kg.K

Total change in entropy of system = Delta_S = -0.16191 kJ/K …. Ans.

T_s diagram:



And the I/O panel shows:

```
#          Daemon Path: Systems>Closed>Process>Generic>Uniform>PG-Model; v-10.bb05

#--------------------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 ---------------------------------------------------------------------

#     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      -84.13     2.01       6.893
#     2       500.0       360.2   0.2067      -41.12     62.25      6.614

#--------Property spreadsheet ends--------------------------------------------------------------------
```

 # Mass, Energy, and Entropy Analysis Results:

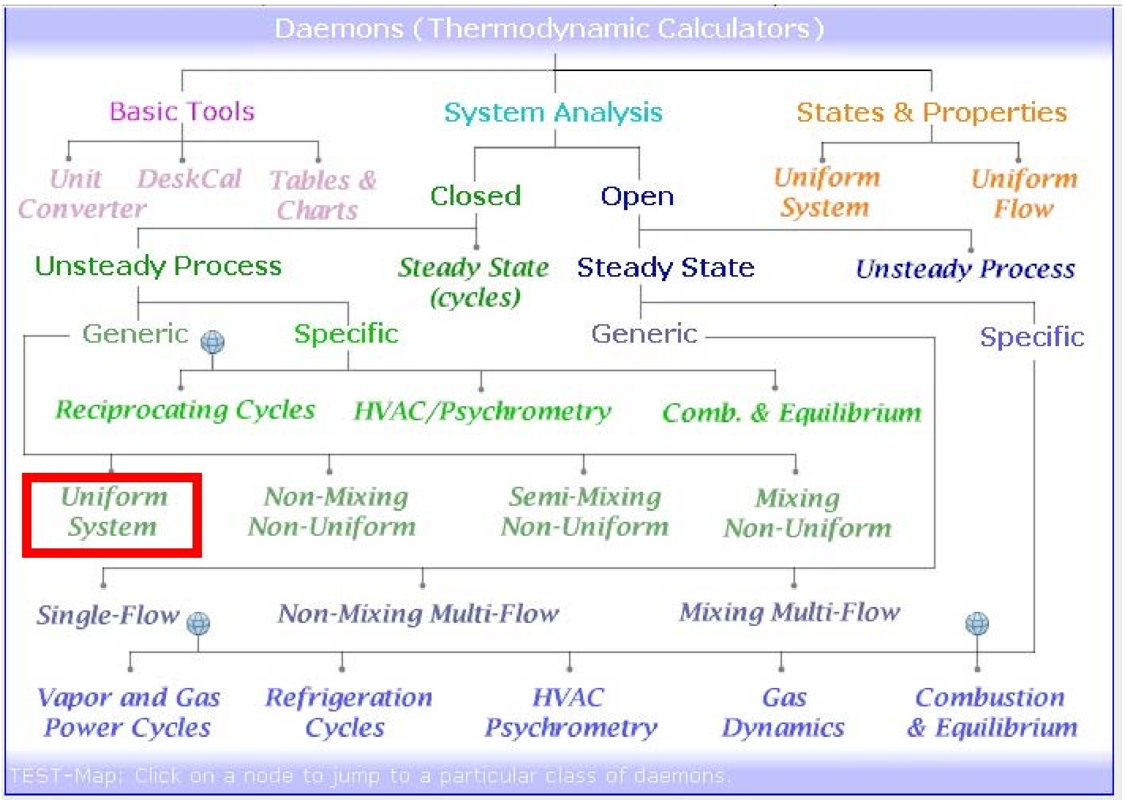
```
#          Process-A: b-State = State-1; f-State = State-2;
#                   Given: W_O= 0.0 kJ; T_B= 298.15 K;
#                   Calculated: Q= -53.3081 kJ; W_B= -78.27469 kJ; S_gen= 0.016890267 kJ/K;
                    n= 1.1277552 UnitLess;
#                            Delta_E= 24.966587 kJ; Delta_S= -0.16190599 kJ/K;

=================================================================================
```

Prob.4.26. Determine the amount of heat which should be supplied to 2 kg of water at 25 C to convert it in to steam at 5 bar and 0.9 dry. [VTU-BTD-Dec. 2007–Jan.2008]

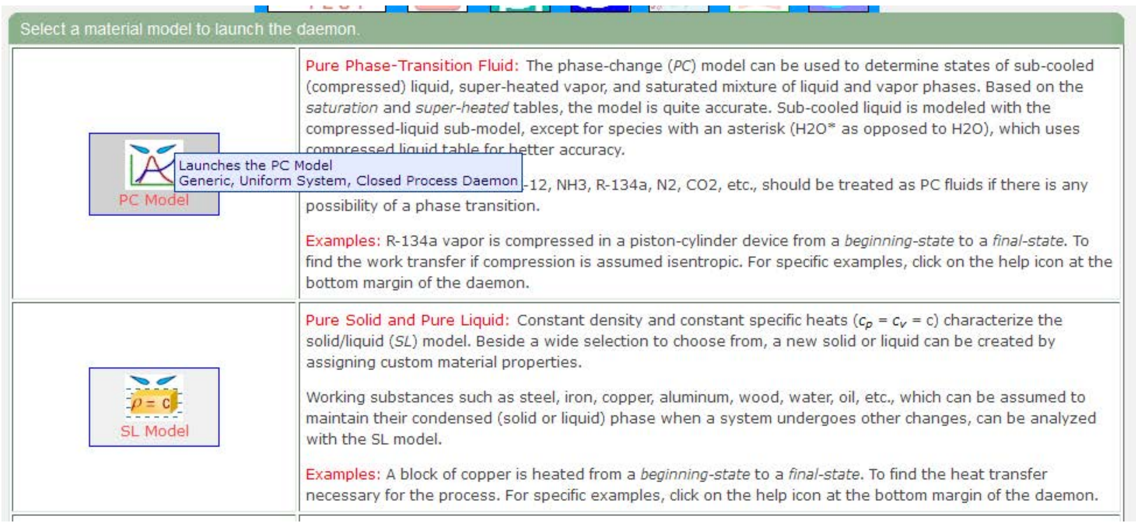
TEST Solution:

Following are the steps:

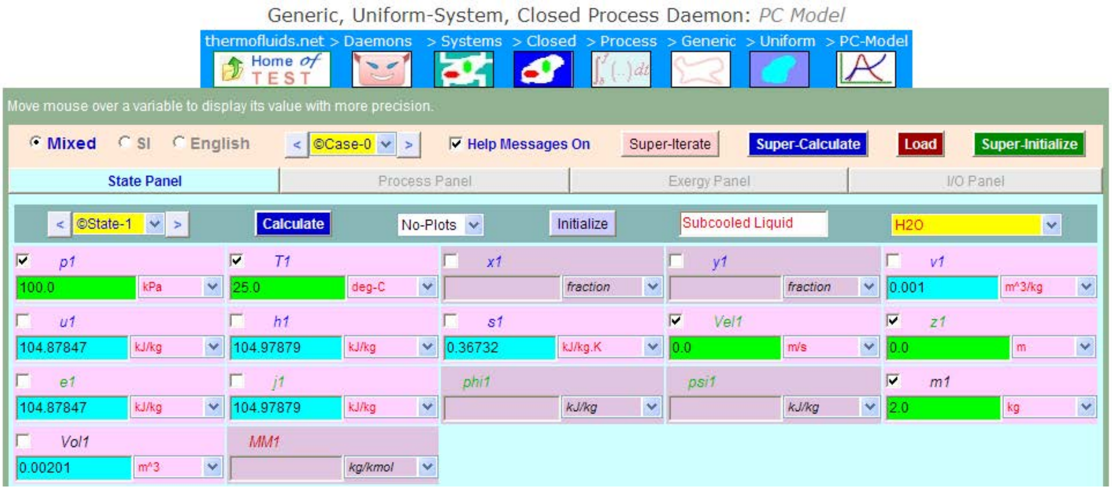
1. Select System analysis – Generic – Uniform System from the Daemon tree:



2. Select Phase Change (PC) for Material model, since we are dealing with Water:

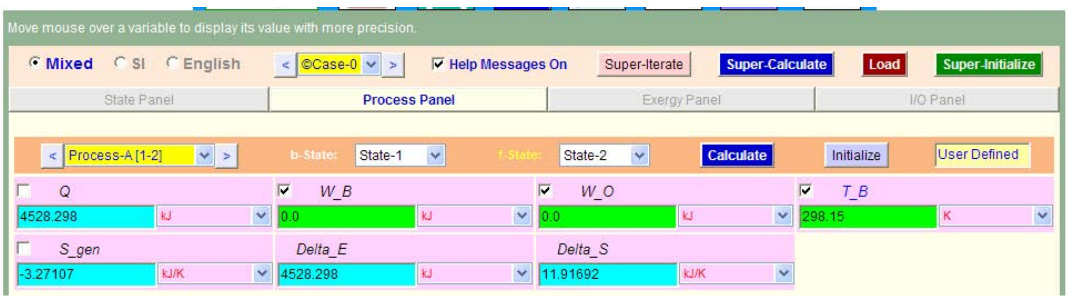


3. Enter parameters p1, T1, m1 for State 1; click on Calculate. We get:



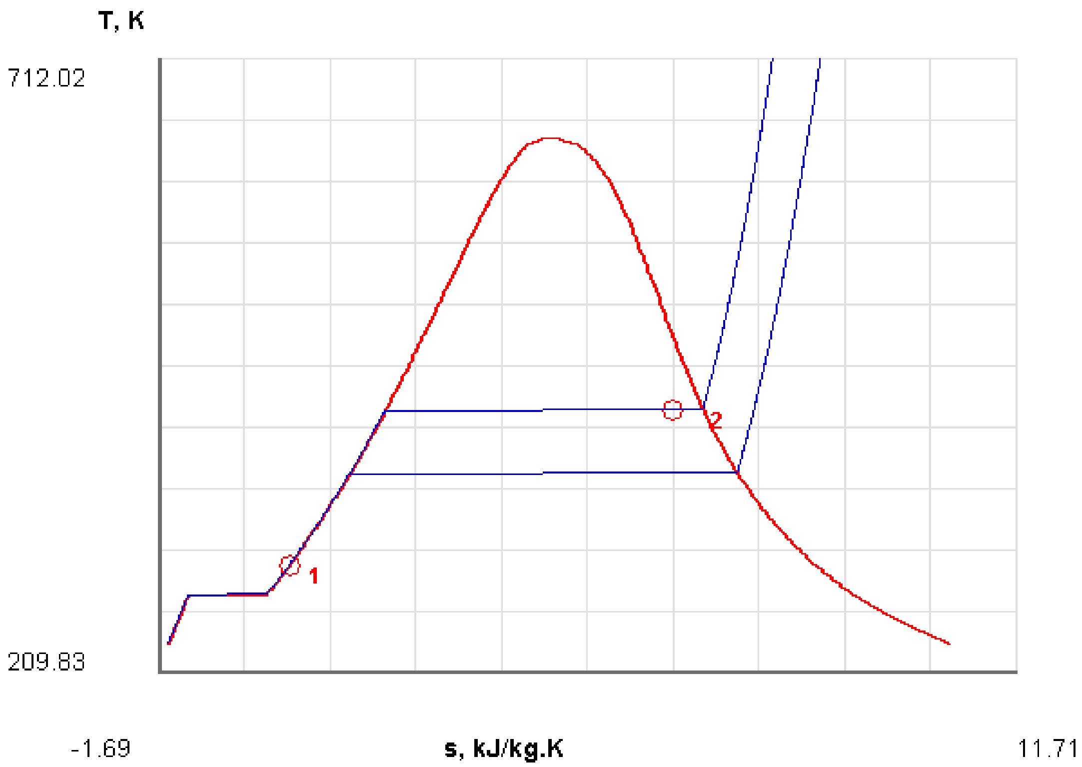
4. Similarly for State 2: enter p2, x2, m2 = m1, and click on Calculate. We get:

5. Go o Process Panel. Enter b-state and f-state, and W_B = 0 and W_O = 0; click on Calculate. We get:



Note that: Delta_E = 4528.298 kJ …. Ans.

6. Draw the T-s diagram. Constant pressure lines are also shown (in blue):



7. Click on Super Calculate. TEST code is produced, and see it in I/O panel:

```
#        Daemon Path: Systems>Closed>Process>Generic>Uniform>PC-Model; v-10.bb06

#--------------------Start of TEST-code -----------------------------------------------------------------------

 States   {
            State-1: H2O;
            Given: { p1= 100.0 kPa; T1= 25.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 2.0 kg; }
            State-2: H2O;
            Given: { p2= 500.0 kPa; x2= 0.9 fraction; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1" kg; }
            }

 Analysis {
            Process-A: b-State = State-1; f-State = State-2;
            Given: { W_B= 0.0 kJ; W_O= 0.0 kJ; T_B= 298.15 K; }
            }
#----------------------End of TEST-code ---------------------------------------------------------------------
```

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	100.0	298.2		0.001	104.88	104.98	0.367
# 02	500.0	425.0	0.9	0.3385	2369.03	2537.75	6.326

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1; f-State = State-2;

Given: W_B= 0.0 kJ; W_O= 0.0 kJ; T_B= 298.15 K;

Calculated: Q= 4528.298 kJ; S_gen= -3.2710671 kJ/K; **Delta_E= 4528.298 kJ**; Delta_S= 11.916918 kJ/K;

 # Verify:

m1*(u2-u1) = 4528.298 kJ.

==

4.4 References:

1. *Yunus A. Cengel & Michael A. Boles*, Thermodynamics, An Engineering Approach, 7th Ed. McGraw Hill, 2011.
2. *Sonntag, Borgnakke & Van Wylen*, Fundamentals of Thermodynamics, 6th Ed. John Wiley & Sons, 2005.
3. *Michel J. Moran & Howard N. Shapiro*, Fundamentals of Engineering Thermodynamics, 4th Ed. John Wiley & Sons, 2000.
4. *P.K. Nag*, Engineering Thermodynamics, 2nd Ed. Tata McGraw Hill Publishing Co., 1995.
5. *R.K. Rajput,* A Text Book of Engineering Thermodynamics, Laxmi Publications, New Delhi, 1998.

5 I Law of Thermodynamics applied to Flow Processes

Learning objectives:

1. In this chapter, we consider 'Steady Flow Energy Equation (SFEE)' and 'conservation of mass' for a control volume.
2. These two principles, viz. **Conservation of mass** (i.e. continuity equation) and the **conservation of energy** (i.e. First Law) are applied to a number of practically important devices such as Nozzles and Diffusers, Turbines and Compressors, Throttling devices, Heat Exchangers and Mixing chambers etc.
3. Transient processes such as filling a tank with a fluid or discharging from a tank are also considered. These are known as **Uniform State, Uniform Flow (USUF) processes.**

5.1 Formulas used:

5.1.1 Steady Flow Energy Equation (SFEE) for a control volume:

For unit mass flow, i.e. m = 1 kg/s:

Let: 1 - inlets, 2 - exits

$h = \text{enthalpy}$ kJ/kg $V = \text{velocity}$ m/s

$z = \text{height\_above\_datum}$ m $A = \text{area\_of\_flow}$ m^2

$q = \text{heat\_transfer}$ kJ $w = \text{work\_transfer}$ kJ

Heat going ***in to*** the system is positive, work done ***by*** the system is positive.

Easier way is to remember: Energy going in = Energy going out, in steady state:

$$q_1 + h_1 + \frac{V_1^2}{2} + g \cdot z_1 = w_1 + h_2 + \frac{V_2^2}{2} + g \cdot z_2 \quad \text{....eqn. (5.1)}$$

i.e. $$q_1 - w_1 = (h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g \cdot (z_2 - z_1) \quad \text{...eqn. (5.2)}$$

i.e. $q_1 - w_1 = \Delta h + \Delta ke + \Delta pe$ ..where all terms are for unit mass flow rate....eqn. (5.3)

When mass flow rate of stream is m_1 kg/s:

$$Q + m_1 \cdot \left(h_1 + \frac{V_1^{\,2}}{2} + g \cdot z_1 \right) = W + m_1 \cdot \left(h_2 + \frac{V_2^{\,2}}{2} + g \cdot z_2 \right)$$

...if there is one stream only....eqn. (5.3-a)

Note: If there are more than one stream, add additional terms for each stream to take in to account respective enthalpies, K.E. and P.E.

5.1.2 Mass balance:

$$\rho_1 \cdot A_1 \cdot V_1 = \rho_2 \cdot A_2 \cdot V2$$

...kg/s......eqn.(5.4)

or:

$$\frac{A_1 \cdot V_1}{v_1} = \frac{A_2 \cdot V_2}{v_2}$$

....kg/s/... where v = sp. volume .... eqn.(5.5)

5.1.3 Examples of Steady flow processes:

1. **Nozzle and Diffuser:**

From eqn. (5.1), we have:

$$q_1 + h_1 + \frac{V_1^{\,2}}{2} + g \cdot z_1 = w_1 + h_2 + \frac{V_2^{\,2}}{2} + g \cdot z_2$$

....eqn. (5.1)

Here, q1 = 0, w1 = 0.

Therefore: If change in P.E. is zero and velocity of approach V1 = 0, we get:

$$h_1 = h_2 + \frac{V_2^{\,2}}{2}$$

...eqn.(5.6)

Or: $V_2 = \sqrt{2 \cdot (h_1 - h_2)}$ m/s...exit velocity

2. **Turbines and compressors:**

For Turbine, it can be taken as insulated, flow velocities small, and K.E. and P.E. terms neglected:

Then, SFEE for a turbine becomes:

$$h_1 = h_2 + w \quad \text{....for unit mass flow}$$

i.e. $$w = \frac{W}{m} = h_1 - h_2 \quad \text{.for unit mass flow rate...eqn.(5.7)}$$

Similarly, SFEE for an adiabatic pump or compressor:

$$h_1 = h_2 - w = h_2 - \frac{W}{m}$$

i.e. $$w = h_2 - h_1 \quad \text{...for unit maas flow rate...eqn.(5.8)}$$

---

3. **For Throttling device:**

Here,q = 0, w = 0, and changes in P.E. can be neglected.

Then SFEE reduces to:

$$h_1 + \frac{V_1^{\ 2}}{2} = h_2 + \frac{V_2^{\ 2}}{2} \qquad \text{...eqn.(5.9)}$$

Often, pipe velocities are small. If we neglect changes in K.E. we get:

$$h_1 = h_2 \qquad \text{....eqn. (5.10)}$$

---

4. **Heat Exchangers:**

When the two streams do not mix, as in a normal HX or condenser:

Let: c --- cold stream, h --- hot stream; 1 - inlets, 2 - exits

Here, Q = 0, W = 0, and SFEE becomes:

$$m_c \cdot h_{c1} + m_h \cdot h_{h1} = m_c \cdot h_{c2} + m_h \cdot h_{h2} \qquad \text{...eqn.(5.11)}$$

When the two streams mix, as in a de-super-heater or cooling tower, or mixing chambers:

Here, q = 0, w = 0.

Mass balance:

$$m_1 + m_2 = m_3 \qquad \text{....eqn.(5.12)}$$

SFEE:

$$m_1 \cdot h_1 + m_2 \cdot h_2 = m_3 \cdot h_3 \qquad \text{neglecting changes in P.E. and K.E.....eqn.(5.13)}$$

5.1.4 Uniform State, Uniform Flow (USUF) process:

ex: filling closed tanks with a gas or liquid, discharge from closed vessels etc.:

Let:
Q_{cv} = heat entering the control volume
W_{cv} = Work leaving the control volume
i = inlets to control volume
e = exits from control volume
m_1 = initial mass in control volume
m_2 = final mass in control volume
(m2-m1) = net mass that enters or leaves the control volume
h = enthalpy
V = velocity of fluid
u = internal energy
z = height from datum
1 - initial conditions
2 - final conditions

Then, for a time period t, the First Law for USUF process is:

$$Q_{cv} + \sum_{inlets} \left(h_i + \frac{V_i^2}{2} + g \cdot Z_i \right) = \sum_{exits} \left(h_e + \frac{V_e^2}{2} + g \cdot Z_e \right) + \left[m_2 \cdot \left(u_2 + \frac{V_2^2}{2} + g \cdot Z_2 \right) - m_1 \cdot \left(u_1 + \frac{V_1^2}{2} + g \cdot Z_1 \right) \right] + W_{cv}$$

......eq.(5.14)

As an example of applying the equation (5.14), consider the following:

Variable flow process: Filling or emptying a tank:

1. **Filling a tank:**

We assume that changes in P.E. and K.E. are negligible.

Then, we get:

Let:
m1 = initial mass in tank
m2 = final mass in tank
(m2-m1) = mass that enters the tank from the pipe
Q = heat transfer = 0
W = Work transfer = 0
h_p = enthalpy of fluid in pipe
V_p = velocity of fluid in pipe
u = internal energy
1 - initial conditions
2 - final conditions

Making an energy balance:

$$m_1 \cdot u_1 + (m_2 - m1)\cdot\left(h_p + \frac{V_p^{\,2}}{2}\right) = m_2 \cdot u_2 \qquad \text{...eqn.(5.15)}$$

If, initially, the tank is empty, then m1 = 0

Then,

$$h_p + \frac{V_p^{\,2}}{2} = u_2 \qquad \text{....eqn.(5.16)..... if m1 = 0}$$

Also, if pipe velocity (i.e. KE) is negligible, then:

$$h_p = u_2 \qquad \text{....eqn. (5.17) ... if K.E. is negligible}$$

Note: For an Ideal gas, h = cp. T, u = cv.T

---

2. **For emptying the tank:**

$$(m_1 - m_2)\cdot\left(h\_prime + \frac{V\_prime^2}{2}\right) - Q = m_1 \cdot u_1 - m_2 \cdot u_2 \quad \text{...eqn.(5.18)}$$

where:

h_prime = sp.enthalpy of leaving fluid

V_prime = velocity of leaving fluid

===

5.2 Problems solved with EES:

"**Prob.5.1.** A Nozzle is a device for increasing the velocity of a steadily flowing stream. At the inlet to a certain nozzle, the enthalpy of the fluid is 3000 kJ/kg and the velocity is 60 m/s. At the discharge end, the enthalpy is 2762 kJ/kg. The nozzle is horizontal and there is negligible heat loss from it. (i) Find the velocity at the exit of the nozzle (ii) If the inlet area is 0.1 m^2 and the sp. volume at inlet is 0.187 m^3/kg, find the mass flow rate (iii) If the sp.vol. at the exit of nozzle is 0.498 m^3/kg, find the diameter of exit section. [VTU-July 2004]"

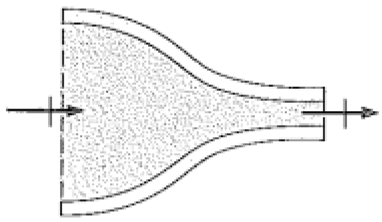


Fig.Prob.5.1

EES Solution:

"Data:"

h_1=3000E03 [J/kg]"…enthalpy at inlet"
C_1=60 [m/s]"…inlet velocity"
h_2=2762E03[J/kg] "…enthalpy at exit"

A_1=0.1 [m^2]"…area at inlet"
v_1=0.187 [m3/kg]"…sp. volume at inlet"
v_2=0.498 [m3/kg]"…sp. volume at exit"

"Calculations:"

m_1= A_1 * C_1/ v_1 "kg/s…finds mass flow rate"
m_1= m_2 "…continuity eqn"
m_2= A_2 * C_2/ v_2 "…finds finds area at exit"
A_2= pi * D_2^2/4 "…..finds diameter at exit"
Q-W = DELTAh + DELTAKE + DELTAPE "…First Law for Open system"
Q=0 "…by data, for nozzle"
W=0 "…by data, for nozzle"
DELTAh = h_2-h_1"[J/kg]"
DELTAKE=(C_2^2/2)-(C_1^2/2)"[J/kg]"
DELTAPE=0"…by data"

Results:

Unit Settings: SI K kPa kJ molar deg

A_1 = 0.1 [m^2]	A_2 = 0.02307 [m^2]	C_1 = 60 [m/s]
C_2 = 692.5 [m/s]	Δh = -238000 [J/kg]	ΔKE = 238000 [J/kg]
ΔPE = 0 [J/kg]	D_2 = 0.1714 [m]	h_1 = 3.000E+06 [J/kg]
h_2 = 2.762E+06 [J/kg]	m_1 = 32.09 [kg/s]	m_2 = 32.09 [kg/s]
Q = 0 [J/kg]	v_1 = 0.187 [m3/kg]	v_2 = 0.498 [m3/kg]
W = 0 [J/kg]		

Thus:

Velocity at exit = C2 = 692.5 m/s … Ans.

Mass flow rate = m1 = 32.09 kg/s … Ans.

Dia at exit = D2 = 0.1714 m … Ans.

==

"**Prob.5.2.** 12 kg of air per min. is delivered by a centrifugal air compressor. The inlet and outlet conditions of air are: V1 = 12 m/s, p1 = 1 bar, v1 = 0.5 m^3/kg, and V2 = 90 m/s, p2 = 8 bar, v2 = 0.14 m^3/kg. The increase in enthalpy of air passing through the compressor is 150 kJ/kg and heat loss to surroundings is 700 kJ/min. Calculate: (i) Power required to drive the compressor, (ii) ratio of inlet to outlet pipe diameters. [VTU-Jan. 2003]"

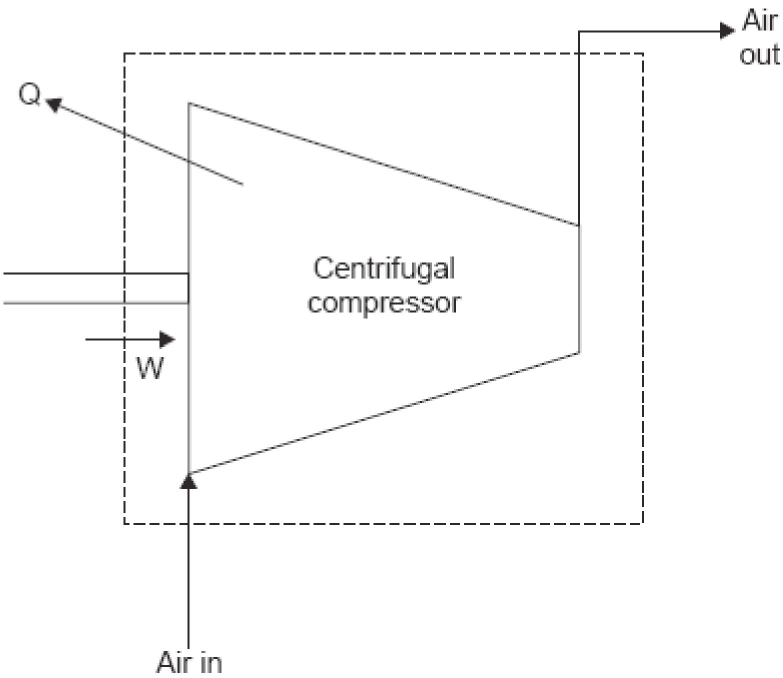


Fig.Prob.5.2

EES Solution:

"Data:"

m=12 * convert(kg/min, kg/s) "[kg/s]"
C_1=12 [m/s]"…inlet velocity"
p1 = 10^5 "Pa … inlet pressure"
v_1=0.5"m^3/kg … sp. volume at inlet"
C_2 = 90[m/s] "…exit velocity"
p2 = 8E05"Pa …. exit pressure"
v_2 = 0.14"..m^3/kg … sp. vol. at exit"
Q= – (700E03)/(m * 60)"…J/kg"
DELTAh=150E03" J/kg…. change in enthalpy"
DELTAKE=(C_2^2/2)-(C_1^2/2)"J/kg….change in K.E."
DELTAPE=0"… change in P.E."

"Calculations:"

Q – W = DELTAh + DELTAKE + DELTAPE "…First Law for open system"
A_1= m * v_1/C_1"..finds area at inlet, m^2"
A_2= m * v_2/C_2"…finds area at exit, m^2"
D1byD2= sqrt(A_1/A_2)"…finds dia ratio"
W_act = W * m "…finds Work required, W"

Results:

Unit Settings: SI K kPa kJ molar deg

A_1 = 0.008333 [m2]	A_2 = 0.0003111 [m2]	C_1 = 12 [m/s]	C_2 = 90 [m/s]
D1byD2 = 5.175	Δh = 150000 [J/kg]	ΔKE = 3978 [J/kg]	ΔPE = 0 [J/kg]
m = 0.2 [m/s]	p1 = 100000 [Pa]	p2 = 800000 [Pa]	Q = -58333 [J/kg]
v_1 = 0.5 [m3/kg]	v_2 = 0.14 [m3/kg]	W = -212311 [J/kg]	W_{act} = -42462 [W]

Thus:

Power required for compressor = -42462 W … Ans. (negative sign indicates power input to system)

Ratio of inlet to exit diameters = 5.175 …. Ans.

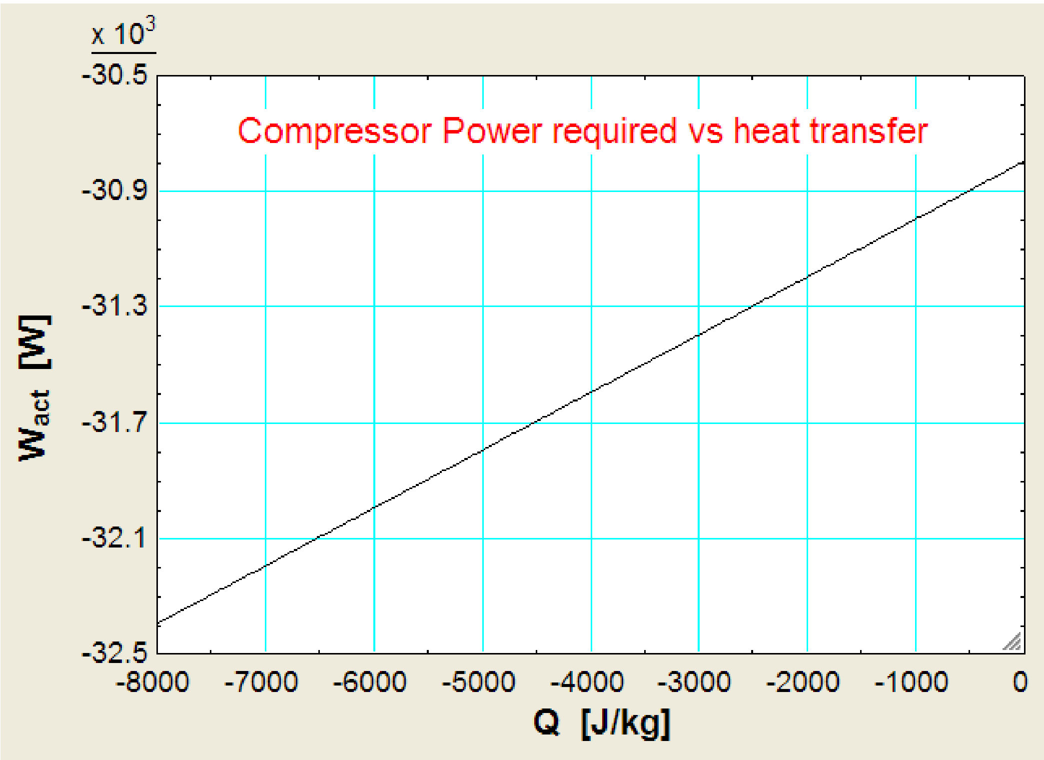
(b) Plot the variation of Power required as the heat loss varies from 0 to -8000 J/kg:

First, compute the Parametric Table:

Table 1

1..9	Q [J/kg]	W_{act} [W]
Run 1	0	-30796
Run 2	-1000	-30996
Run 3	-2000	-31196
Run 4	-3000	-31396
Run 5	-4000	-31596
Run 6	-5000	-31796
Run 7	-6000	-31996
Run 8	-7000	-32196
Run 9	-8000	-32396

Now, plot the results:



Note that as the heat transfer increases, compressor power required also increases.

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"Prob.5.3. Air flows steadily through a rotary compressor. At entry, the air is at 20 C and 101 kPa. At the exit, the air is at 200 C and 600 kPa. Assuming the flow to be adiabatic, (i) evaluate the work done per unit mass of air if the velocities at inlet and exit are negligible (ii) what would be the increase in work input if the velocities at inlet and exit are 50 m/s and 110 m/s? [VTU-Jan. 2005]"

EES Solution:

"Data:"

DELTAKE=0
DELTAPE=0
Q=0 "…since adiabatic"
T1=20 "C"
T2=200 "C"
p1=101E03 "Pa"
p2=600E03 "Pa"
R=287 "J/kg.K …. for air"
gamma=1.4 "for air"

"Calculations:"

"Case 1: Inlet and exit velocities are negligible:"

cp = R * gamma/(gamma – 1) "… sp. heat at const. pressure, J/kg.K"
DELTAh = cp * (T2-T1) "J/kg … change in enthalpy"
Q – W = DELTAh + DELTAKE + DELTAPE "…by First Law to Open systems"

"Case 2: Inlet and exit vel. not negligible:"

Q1=0 "…since adiabatic"
Q1- W1= cp * (T2-T1) + (V2^2-V1^2)/2 "…First Law for Open system, including the change in K.E."
V2=110 "m/s … exit velocity"
V1=50 "m/s … inlet velocity"

Results:

Unit Settings: SI K kPa kJ molar deg

cp = 1005 [J/kg-C]	Δh = 180810 [J/kg]	ΔKE = 0 [J/kg]
ΔPE = 0 [J/kg]	γ = 1.4	p1 = 101000 [Pa]
p2 = 600000 [Pa]	Q = 0 [J/kg]	Q1 = 0 [J/kg]
R = 287 [J/kg-C]	T1 = 20 [C]	T2 = 200 [C]
V1 = 50 [m/s]	V2 = 110 [m/s]	W = -180810 [J/kg]
W1 = -185610 [J/kg]		

Thus:

W = -180.81 kJ/kg when K.E. and P.E. are neglected…Ans.

W1 = -185.61 kJ/kg when K.E. is not negligible …i.e. an increase of about 5 kJ/kg… Ans.

(Note: negative sign indicates work input in to the system.)

==

"Prob.5.4. In a gas turbine unit, the gases flow through the turbine at 15 kg/s and the power developed by the turbine is 12000 kW. The enthalpies of the gases at the inlet and outlet are 1260 kJ/kg and 400 kJ/kg respectively, and the velocities of gases at the inlet and outlet are 50 m/s and 110 m/s respectively. Calculate (i) rate at which heat is rejected by the turbine (ii) the area of inlet pipe, given the sp. vol. of gases at inlet is 0.45 m^3/kg. [VTU-Jan. 2005]"

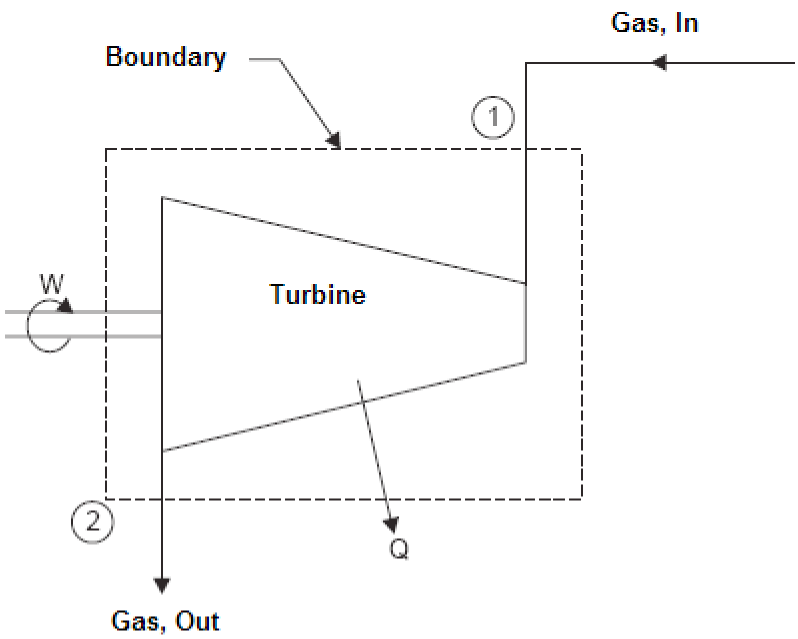


Fig.Prob.5.4

EES Solution:

"Data:"

h_1=1260E03 "J/kg … enthalpy at inlet"
h_2=400E03 "J/kg … enthalpy at outlet"
C_1=50 [m/s] "…velocity at inlet"
C_2=110 [m/s] "…velocity at outlet"
v_1=0.45 [m^3/kg]"..sp. vol. at inlet"
m_1=15 [kg/s]"…mass flow rate"

"Calculations:"

m_1=A_1 * C_1/ v_1 "…finds area at inlet, m^2"
Q – W = DELTAh + DELTAKE + DELTAPE "…First Law for Open System …. finds Q"
W = 12E06[J/s]/15 [kg/s] "J/kg…..work output of turbine, by data"
DELTAh = (h_2-h_1) "J/kg…enthalpy change"
DELTAKE=(C_2^2/2)-(C_1^2/2)"J/kg … change in K.E."
DELTAPE=0"…change in P.E."

Results:

Unit Settings: SI K kPa kJ molar deg

A_1 = 0.135 [m^2]	C_1 = 50 [m/s]	C_2 = 110 [m/s]
Δh = -860000 [J/kg]	ΔKE = 4800 [J/kg]	ΔPE = 0 [J/kg]
h_1 = 1.260E+06 [J/kg]	h_2 = 400000 [J/kg]	m_1 = 15 [kg/s]
Q = -55200 [J/kg]	v_1 = 0.45 [m^3/kg]	W = 800000 [J/kg]

Thus:

Heat rejected by turbine = Q = 55200 J/kg….negative sign indicates heat going out of the system….Ans.

Area of inlet pipe = A1 = 0.135 m^2 … Ans.

==

"**Prob. 5.5.** In a steady flow system, 50 kJ of work is done per kg of fluid; values of sp. vol., pressure and velocity at inlet and exit sections are: 0.4 m^3/kg, 600 kPa, 15 m/s and 0.6 m^3/kg, 100 kPa, and 250 m/s, respectively. The inlet is 30 m above the exit. The heat loss from the system is 8 kJ/kg. Calculate the change in internal energy per kg of fluid. [VTU-July 2003]"

EES Solution:

"Data:"

Q = – 8E03 "J/kg … heat rej."
W=50E03 "J/kg …. work done by fluid"
p1=600E03 "Pa …inlet pressure"
v1=0.4 "m3/kg… inlet sp. vol."
C1=15 "m/s .. inlet velocity"
p2=100E03 "Pa … exit pressure"
v2=0.6 "m3/kg … exit sp. vol."
C2=250 "m/s … exit velocity"
Z2=0 "m … exit datum level"
Z1=30 "m … inlet datum level"

"Calculations:"

Q – W = DELTAh + DELTAKE + DELTAPE "…First Law for Open System …. finds DELTAh"
DELTAKE=(C2^2-C1^2)/2 "J/kg …, change in K.E."

DELTAPE=g * (Z2 – Z1) "J/kg …, change in P.E."
g=9.81 "m/s2 … accn. due to gravity"
DELTAh = DELTAu + (p2 * v2 – p1 * v1) "….from h = u + pV ….. finds DELTAu"

Results:

Unit Settings: SI K kPa kJ molar deg

C1 = 15 [m/s]	C2 = 250 [m/s]	Δh = -88843 [J/kg]
ΔKE = 31138 [J/kg]	ΔPE = -294.3 [J/kg]	Δu = 91157 [J/kg]
g = 9.81 [m/s^2]	p1 = 600000 [Pa]	p2 = 100000 [Pa]
Q = -8000 [J/kg]	v1 = 0.4 [m^3/kg]	v2 = 0.6 [m^3/kg]
W = 50000 [J/kg]	Z1 = 30 [m]	Z2 = 0 [m]

Thus:

Change in Internal energy = DELTAu = 91157 J/kg …. Ans.

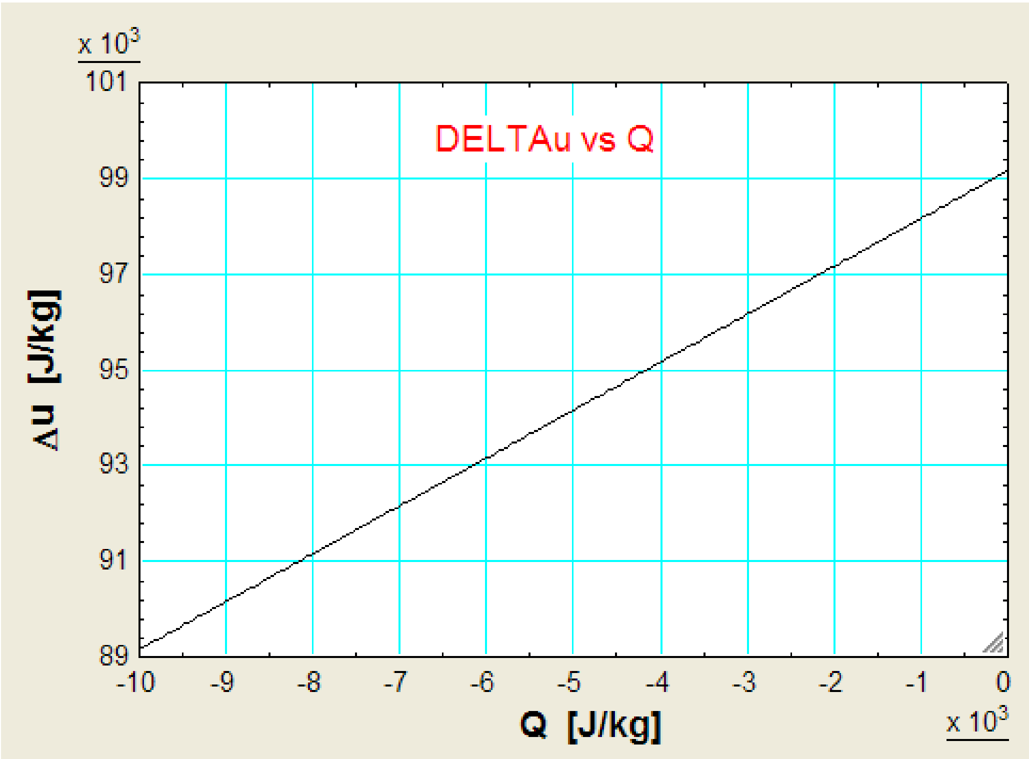
(b) Plot the variation of DELTAu as heat rejected Q varies from 0 to -10 kJ/kg:

First, calculate the Parametric Table:

Table 1

1..11	Q [J/kg]	Δu [J/kg]
Run 1	0	99157
Run 2	-1000	98157
Run 3	-2000	97157
Run 4	-3000	96157
Run 5	-4000	95157
Run 6	-5000	94157
Run 7	-6000	93157
Run 8	-7000	92157
Run 9	-8000	91157
Run 10	-9000	90157
Run 11	-10000	89157

Now, plot the results:



Note: Negative sign for Q only indicates that heat is being rejected.

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"Prob.5.6. Air flows steadily at a rate of 0.5 kg/s through a compressor, entering at 7 m/s velocity, 100 kPa pressure and 0.95 m^3/kg sp. volume, and leaves at 700 kPa, 5 m/s, and 0.19 m^3/kg. The internal energy of air leaving is 90 kJ/kg greater than that of air entering. Cooling water in the compressor jacket absorbs heat at a rate of 58 kW. Compute the shaft work input and the ratio of inlet to exit pipe diameters. [VTU-July 2002]"

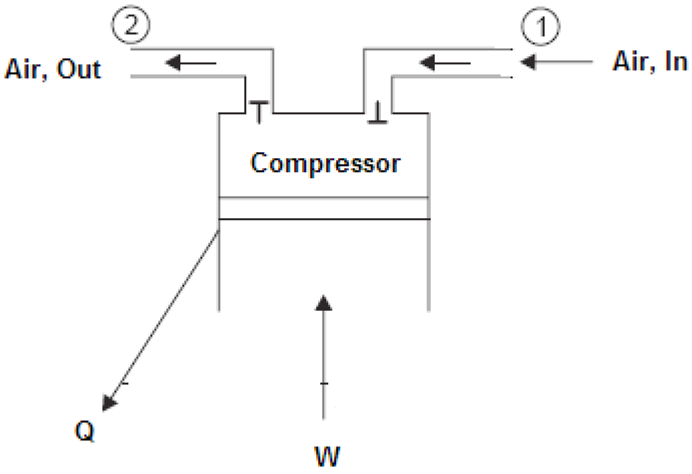


Fig.Prob.5.6

EES Solution:

"Data:"

m=0.5 "kg/s …. mass flow rate"
Q= – 58E03"J/s …heat rejection rate"
p1=100E03 "Pa … inlet pressure"
p2=700E03 "Pa …. exit pressure"
C1=7.0 "m/s … inlet velocity"
C2=5.0 "m/s …. exit velocity"
DELTAu=90E03 "J/kg …. change in internal energy"
v1=0.95 "m^3/kg … sp. vol. at inlet"
v2=0.19 "m^3/kg …. sp. vol. at exit"

"Calculations:"

Q – W = m * (DELTAu+(p2 * v2 – p1 * v1)) + m * (C2^2-C1^2)/2 "…by First Law for Open system… finds W"
A1=m * v1/C1 "m^2 … inlet pipe area"
A2=m * v2/C2 "m^2 … exit pipe area"
D1byD2=sqrt(A1/A2) "…diameter ratio"

Results:

Unit Settings: SI K kPa kJ molar deg

A1 = 0.06786 [m^2]	A2 = 0.019 [m^2]	C1 = 7 [m/s]
C2 = 5 [m/s]	D1byD2 = 1.89	Δu = 90000 [J/kg]
m = 0.5 [kg/s]	p1 = 100000 [Pa]	p2 = 700000 [Pa]
Q = -58000 [W]	v1 = 0.95 [m^3/kg]	v2 = 0.19 [m^3/kg]
W = -121994 [W]		

Thus:

Work *input* to compressor, W = -121.994 kW …. Ans.

Diameter ratio = D1/D2 = 1.89 … Ans.

===

"Prob.5.7. A centrifugal air compressor compresses 5.7 m^3/min of air from 85 kPa to 650 kPa. The initial sp. vol. is 0.35 m^3/kg and final sp. vol. is 0.1 m^3/kg. If the suction line dia is 10 cm and the discharge line dia is 6.25 cm, determine: (i) the change in flow work (ii) the mass rate of flow, and (iii) the velocity change. [VTU-Aug. 2000]"

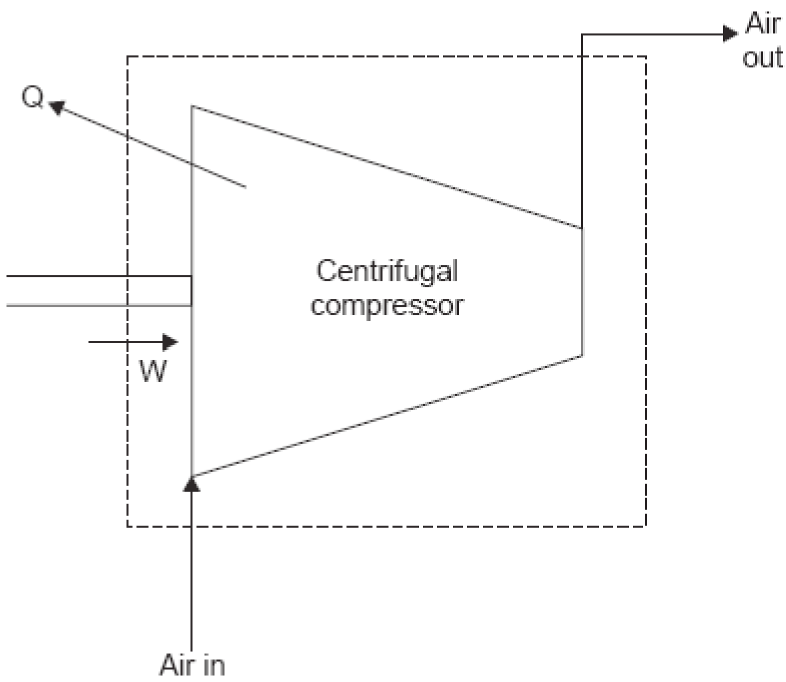


Fig.Prob.5.7

EES Solution:

"Data:"

V1=5.7/60"m3/s .... volume flow rate"
p1=85E03"Pa ... inlet pressure"
p2=650E03 "Pa .... exit pressure"
rho1=1/0.35"kg/m3 ... inlet density"
rho2=1/0.1"kg/m3 ... exit density"
d1=0.1"m .. inlet dia"
d2=0.0625"m .. exit dia"

"Calculations:"

m = V1 * rho1"kg/s .... mass flow rate"
A1=pi*d1^2/4 "m2 ... inlet area"
A2=pi*d2^2/4 "m2 .... exit area"

"Change in Flow work:"

DELTAPV= m * (p2/rho2 – p1/rho1) "J/s …. change in flow work"

"Velocity change:"

m = A1 * C1 * rho1 "… finds inlet velocity, C1, m/s"
m = A2 * C2 * rho2 "… finds exit velocity, C2, m/s"

Results:

Unit Settings: SI K kPa kJ molar deg

A1 = 0.007854 [m^2]	A2 = 0.003068 [m^2]	C1 = 12.1 [m/s]	C2 = 8.847 [m/s]
d1 = 0.1 [m]	d2 = 0.0625 [m]	ΔPV = 9568 [J/s]	m = 0.2714 [kg/s]
p1 = 85000 [Pa]	p2 = 650000 [Pa]	rho1 = 2.857 [kg/m^3]	rho2 = 10 [kg/m^3]
V1 = 0.095 [m3/s]			

Thus:

Change in flow work = DELTApv = 9568 W … Ans.

Mass flow rate = m = 0.2714 kg/s … Ans.

Velocities: C1 = 12.1 m/s, C2 = 8.847 m/s …. Ans.

===

"**Prob.5.8.** A steam turbine receives steam with a flow rate of 900 kg/min. and experiences a heat loss of 840 kJ/min. The exit pipe is 3 m below the level of inlet pipe. Find the power developed by the turbine if the pressure decreases from 62 bar to 9.8 kPa, velocity increases from 30.5 m/s to 274.3 m/s, internal energy decreases by 938.5 kJ/kg, and sp. vol. increases from 0.058 m^3/kg to 13.36 m^3/kg. [VTU-Feb. 2002]"

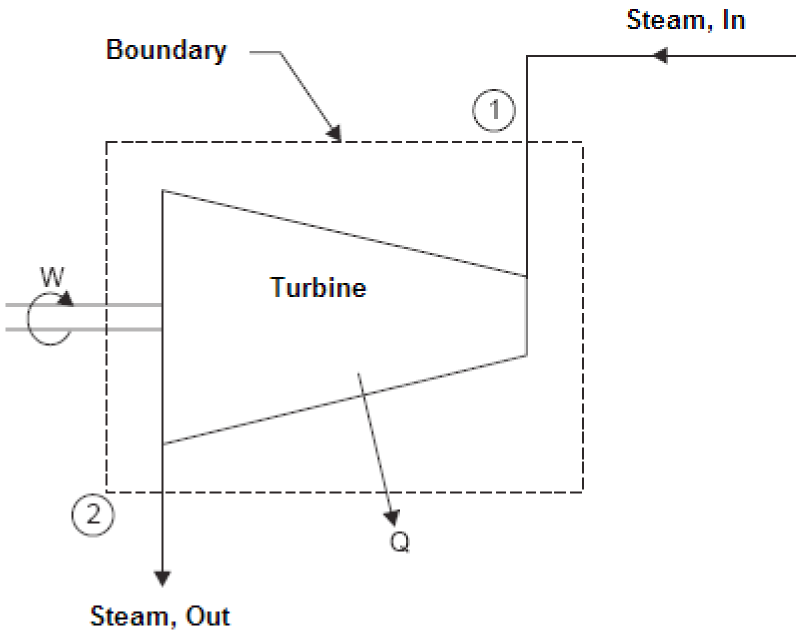


Fig.Prob.5.8

EES Solution:

"Data:"

m = 900/60 "kg/s"

Q = – 840E03/60"J/s"

Z1= 3 "m"

Z2 = 0 "m"

p1= 62E05 "Pa"

p2 = 9.86E03 "Pa"

C1= 30.5 "m/s"

C2 = 274.3 "m/s"

DELTAu = – 938.5E03 "J/kg"

v1= 0.058 "m3/kg"

v2=13.36 "m3/kg"

g=9.81"m/s2"

"Calculations:"

Q – W = m * (DELTAu + (p2 * v2 – p1 * v1)) + m * (C2^2-C1^2)/2 + m * g * (Z2-Z1) "…First Law for Open system"

Results:

Unit Settings: SI K kPa kJ molar deg

C1 = 30.5 [m/s]	C2 = 274.3 [m/s]	Δu = -938500 [W]	g = 9.81 [m/s²]
m = 15 [kg/s]	p1 = 6.200E+06 [Pa]	p2 = 9860 [Pa]	Q = -14000 [W]
v1 = 0.058 [m³/kg]	v2 = 13.36 [m³/kg]	W = 1.692E+07 [W]	Z1 = 3 [m]
Z2 = 0 [m]			

Thus:

Power developed by turbine = W = 1.692E07 W …. Ans.

===

"Prob. 5.9. A fluid flows through a steady flow system at the rate of 3 kg/s. The inlet and outlet conditions are: p1 = 5 bar, C1 = 150 m/s, u1 = 2000 kJ/kg, and p2 = 1.2 bar, C2 = 80 m/s, and u2 = 1300 kJ/kg. The change in sp. vol. is from 0.4 m^3/kg to 1.1 m^3/kg. The fluid loses 25 kJ/kg heat during the process. Neglecting potential energy, determine the power output of the system. [VTU-Dec. 2006–Jan. 2007]:"

EES Solution:

"Data:"

m = 3 "kg/s"
P1 = 500 "kPa"
C1 = 150 "m/s"
u1 = 2000 "kJ/kg"
P2 = 120 "kPa"
C2 = 80 "m/s"
u2 = 1300 "kJ/kg"
v1 = 0.4 "m3/kg"
v2 = 1.1 "m3/kg"
q = -25 "kJ/kg….heat loss"
"Neglecting Potential energy, determine the Power output:"

"Write SFEE for 1 kg:"

q – w = (h2 – h1) + ((C2^2 – C1^2)/2)*10^(-3) "…First Law for Open system…all quantities in kJ/kg"
h1 = u1 + P1 * v1"kJ/kg … inlet enthalpy"
h2 = u2 + P2 * v2 "kJ/kg … exit enthalpy"

"Power output:"

Work = w * m "kJ/s"

Results:

Unit Settings: SI C kPa kJ mass deg

C1 = 150 [m/s]	C2 = 80 [m/s]	h1 = 2200 [kJ/kg]	h2 = 1432 [kJ/kg]
m = 3 [kg/s]	P1 = 500 [kPa]	P2 = 120 [kPa]	q = -25 [kJ/kg]
u1 = 2000 [kJ/kg]	u2 = 1300 [kJ/kg]	v1 = 0.4 [m^3/kg]	v2 = 1.1 [m^3/kg]
w = 751.1 [kJ/kg]	Work = 2253 [kW]		

Thus: Work done by the system = Work = 2253 kW … Ans.

===

"**Prob.5.10.** A fluid flows through a steam turbine at a steady rate of 5000 kg/h, while energy is transferred as heat at a rate of 6279 kJ/h from the turbine. The condition of the fluid at the turbine inlet and exit are: h1 = 3153 kJ/kg, C1 = 60 m/s, Z1 = 6 m, and h2 = 2713 kJ/kg, C2 = 185 m/s, Z2 = 4 m. Find the power output from the turbine. Comment on K.E. and P.E. changes. [VTU-Dec. 08–Jan. 09]"

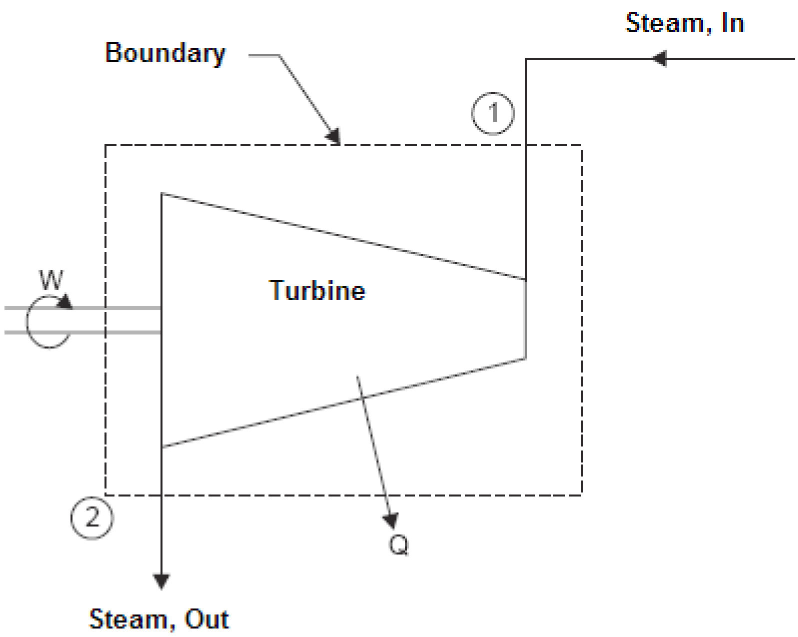


Fig.Prob.5.10

EES Solution:

"Data:"

mass_flow = 5000/3600 "kg/s"
q = (-6279/3600) / mass_flow "kJ/kg….heat transf. from turbine"
h1 = 3153 "kJ/kg"
h2 = 2713 "kJ/kg"
C1 = 60 "m/s"
C2 = 185 "m/s"
Z1 = 6 "m"
Z2 = 4 "m"
g = 9.81"m/s2"

"Find the Power output from Turbine and comment on K.E. and P.E. changes:"

q – w = DELTAh + DELTAke + DELTApe "..First Law for a turbine….all terms are in kJ/kg"
DELTAh = (h2 – h1) "kJ/kg"
DELTAke = ((C2^2 – C1^2)/2) * 10^(-3) "kJ/kg"
DELTApe = g * (Z2 – Z1) * 10^(-3) "kJ/kg"
Work = mass_flow * w "kJ/s"

Results:

Unit Settings: SI C kPa kJ mass deg

C1 = 60 [m/s]	C2 = 185 [m/s]
Δh = -440 [kJ/kg]	Δke = 15.31 [kJ/kg]
Δpe = -0.01962 [kJ/kg]	g = 9.81 [m/s^2]
h1 = 3153 [kJ/kg]	h2 = 2713 [kJ/kg]
mass$_{flow}$ = 1.389 [kg/s]	q = -1.256 [kJ/kg]
w = 423.5 [kJ/kg]	Work = 588.1 [kW]
Z1 = 6 [m]	Z2 = 4 [m]

Thus:

Work done by turbine = 588.1 kW …. Ans.

DELTAke = 15.31 kJ/kg, DELTApe = -0.01962 kJ/kg .. *both are negligible* compared to the enthalpy difference DELTAh = -440 kJ/kg …. Ans.

(b) Plot the variation of Work as heat loss q varies from 0 to -4 kJ/kg:

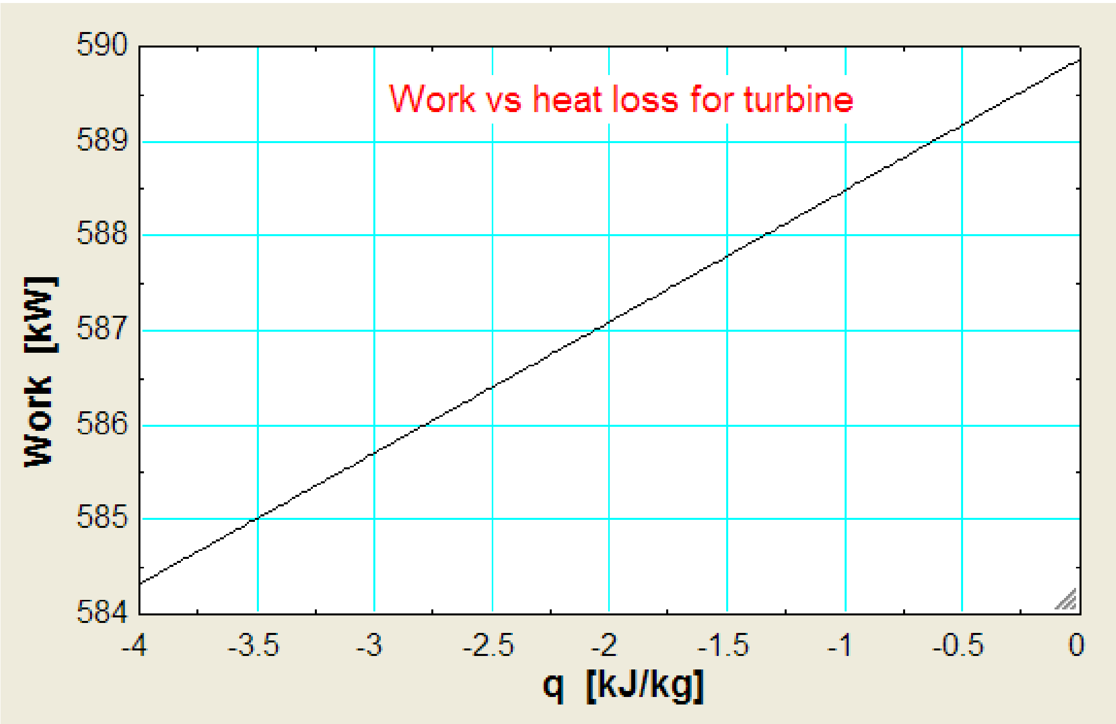
First, compute the Parametric Table:

Parametric Table

Table 1

1..9	q [kJ/kg]	Work [kW]
Run 1	0	589.9
Run 2	-0.5	589.2
Run 3	-1	588.5
Run 4	-1.5	587.8
Run 5	-2	587.1
Run 6	-2.5	586.4
Run 7	-3	585.7
Run 8	-3.5	585
Run 9	-4	584.3

Now, plot the results:



Note: Negative sign for q only indicates that heat is being rejected from turbine. As the heat rejected increases, work output from the turbine decreases.

"**Prob.5.11**. The working fluid in a steady flow process flows at a rate of 220 kg/min. The fluid rejects 100 kJ/s of heat passing through the system. The conditions of fluid at inlet and outlet are: C1 = 220 m/s, p1 = 6 bar, u1 = 2000 kJ/kg, v1 = 0.36 m^3/kg, and C2 = 140 m/s, p2 = 1.2 bar, u2 = 1400 kJ/kg, v2 = 1.3 m^3/kg. Suffix 1 indicates inlet, and 2 the outlet. Determine the power capacity of the system in MW. [VTU-BTD-June–July 2009:]"

EES Solution:

"Data:"

mass_flow = 220/60 "kg/s"
q = -100/mass_flow "kJ/kg"
C1 = 220 "m/s"
P1 = 600 "kPa"
u1 = 2000 "kJ/kg"
v1 = 0.36 "m3/kg"
C2 = 140 "m/s"
P2 = 120 "kPa"
u2 = 1400 "kJ/kg"
v2 = 1.3 "m3/kg"

"Determine the Power capacity of the system in MW:"

"Apply I Law to Open System: Energy going In = Energy going Out:"
(u1+ P1 * v1) + (C1^2/2)/1000 + q = (u2 + P2 * v2) + (C2^2/2)/1000 + w "…where w is work done in kJ/kg"
Work = w * mass_flow /1000 "MW"

Results:

Unit Settings: SI C kPa kJ mass deg

C1 = 220 [m/s]	C2 = 140 [m/s]	$mass_{flow}$ = 3.667 [kg/s]
P1 = 600 [kPa]	P2 = 120 [kPa]	q = -27.27 [kJ/kg]
u1 = 2000 [kJ/kg]	u2 = 1400 [kJ/kg]	v1 = 0.36 [m^3/kg]
v2 = 1.3 [m^3/kg]	w = 647.1 [kJ/kg]	Work = 2.373 [MW]

Thus:

Work done by turbine = 2.373 MW … Ans.

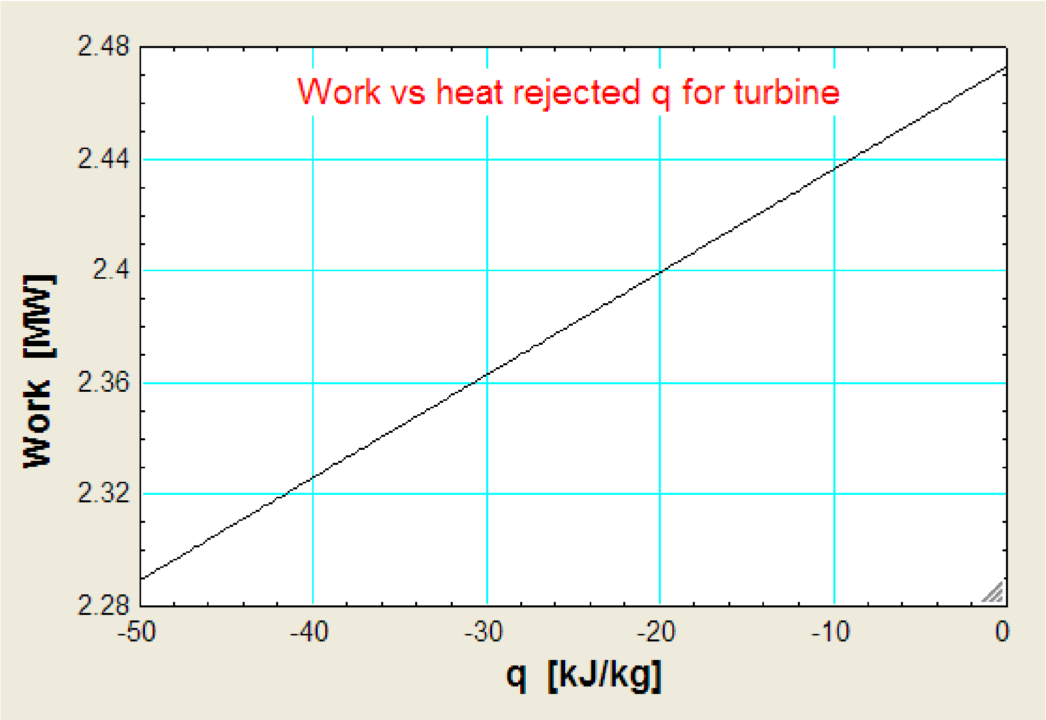
(b) Plot the variation of Work as heat rejected q varies from 0 to -50 kJ/kg:

First, compute the Parametric Table:

Parametric Table — Table 1

1..11	q [kJ/kg]	Work [MW]
Run 1	0	2.473
Run 2	-5	2.454
Run 3	-10	2.436
Run 4	-15	2.418
Run 5	-20	2.399
Run 6	-25	2.381
Run 7	-30	2.363
Run 8	-35	2.344
Run 9	-40	2.326
Run 10	-45	2.308
Run 11	-50	2.289

Now, plot the results:



Note: Negative sign for q only indicates that heat is being rejected from turbine. As the heat rejected increases, work output from the turbine decreases.

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"**Prob.5.12.** A turbine operating under steady flow conditions receives steam at the following state: Pressure = 13.8 bar, sp. vol. = 0.143 m^3/kg, sp. int. energy = 2590 kJ/kg, Velocity = 30 m/s. The state of steam leaving the turbine is: pressure = 0.35 bar, sp. vol. = 4.37 m^3/kg, sp. int. energy = 2360 kJ/kg, velocity = 90 m/s. Heat is rejected to surroundings at the rate of 0.25 kW and the rate of steam flow through the turbine is 0.38 kg/s. Calculate the power developed by the turbine. [VTU-BTD-June–July 2008:]"

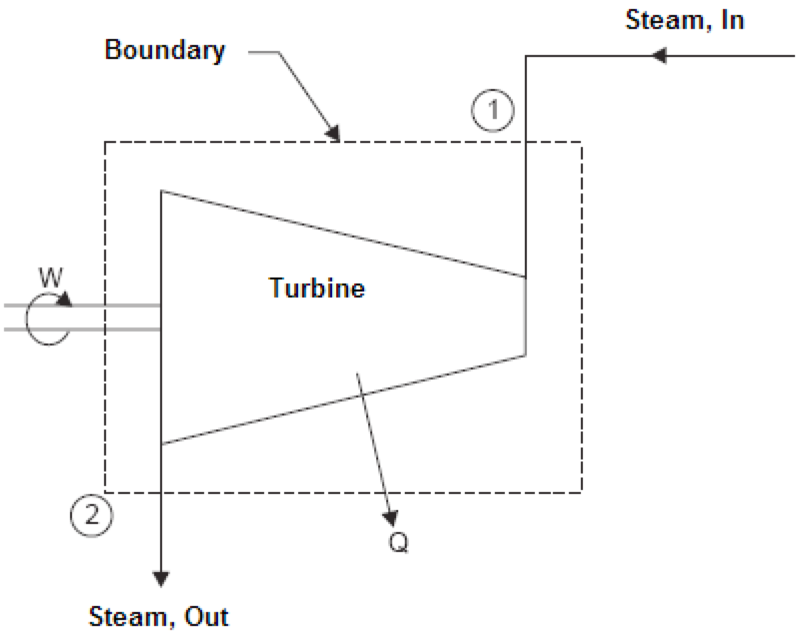


Fig.Prob.5.12

EES Solution:

"Data:"

mass_flow = 0.38 "kg/s"
q = – 0.25[kJ/s] / mass_flow "kJ/kg"
C1 = 30 "m/s"
P1 = 1380 "kPa"
u1 = 2590 "kJ/kg"
v1 = 0.143 "m3/kg"
C2 = 90 "m/s"
P2 = 35 "kPa"
u2 = 2360 "kJ/kg"
v2 = 4.37 "m3/kg"

"Determine the Power capacity of the Turbine:"

"Apply I Law to Open System: Energy going In = Energy going Out:"

(u1+P1 * v1) + (C1^2/2)/1000 + q = (u2 + P2 * v2) + (C2^2/2)/1000 + w "..finds w, where w is work done in kJ/kg"
Work = w * mass_flow "kW"

Results:

Unit Settings: SI C kPa kJ mass deg

C1 = 30 [m/s]	C2 = 90 [m/s]	$mass_{flow}$ = 0.38 [kg/s]
P1 = 1380 [kPa]	P2 = 35 [kPa]	q = -0.6579 [kJ/kg]
u1 = 2590 [kJ/kg]	u2 = 2360 [kJ/kg]	v1 = 0.143 [m^3/kg]
v2 = 4.37 [m^3/kg]	w = 270.1 [kJ/kg]	Work = 102.7 [kW]

Thus: Power developed by the turbine = 102.7 kW … Ans.

===

"**Prob.5.13.** Air enters an adiabatic horizontal nozzle at 400 C with a velocity of 50 m/s. The inlet area is 240 cm^2. Temp of air at exit is 80 C. Given that the sp. vol. of air at the inlet and exit are respectively 0.2 m^3/kg and 1.02 m^3/kg, find the area of cross-section of the nozzle at the exit. Assume that enthalpy of air is a function of temp only and that cp = 1.005 kJ/kg.K. [VTU-BTD-July 2006:]"

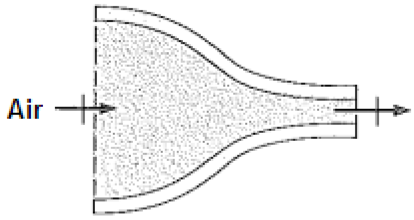


Fig.Prob.5.13

EES Solution:

"Data:"

T1 = 400+273 "K"

C1 = 50 "m/s … velocity at inlet"

A1 = 240*10^(-4)"m2 … area at inlet"

T2 = 80+273 "K"

v1 = 0.2 "m3/kg"

v2 = 1.02 "m3/kg"

cp = 1.005 "kJ/kg.K"

q = 0 "…since adiabatic"

w = 0 "…since there is no work output in nozzle"

"Calculations:"

DELTAh = cp * (T2 – T1) "kJ/kg… change in enthalpy"

q – w = DELTAh + ((C2^2 – C1^2)/2) * 10^(-3) "… First Law for Nozzle …Finds Velocity at exit"

A1 * C1/ v1 = A2 * C2 / v2 "Finds A2, area at exit"

Results:

Unit Settings: SI C kPa kJ mass deg

A1 = 0.024 [m^2]	A2 = 0.007616 [m^2]	C1 = 50 [m/s]
C2 = 803.6 [m/s]	cp = 1.005 [kJ/kg-K]	Δh = -321.6 [kJ/kg]
q = 0 [kJ/kg]	T1 = 673 [K]	T2 = 353 [K]
v1 = 0.2 [m^3/kg]	v2 = 1.02 [m^3/kg]	w = 0 [kJ/kg]

Thus: Area of cross-section of nozzle at exit = A2= 76.16 cm^2 … Ans.

===

"Prob.5.14. At the inlet to a certain nozzle, the enthalpy of the fluid is 3025 kJ/kg and the velocity is 60 m/s. At the exit of the nozzle, the enthalpy is 2790 kJ/kg. The nozzle is horizontal and there is a heat loss of 100 kJ/kg from it. Calculate the velocity of fluid at nozzle exit. Also find the mass flow rate of fluid if inlet area is 0.1 m^2 and sp. vol. at inlet is 0.19 m^3/kg. [VTU-BTD-July-2007:]"

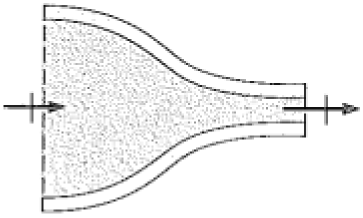


Fig.Prob.5.14

EES Solution:

"Data:"

h1 = 3025 "kJ/kg"
C1 = 60 "m/s"
h2 = 2790 "kJ/kg"
q = -100 "kJ/kg….heat loss from Nozzle"

"Calculations:"

A1 = 0.1 "m2"

v1 = 0.19 "m3/kg….sp. vol. at inlet"

q – w = (h2 – h1) + ((C2^2 – C1^2)/2) * 10^(-3) "First Law for nozzle, neglecting PE …. finds C2"

w = 0 "No work done in Nozzle"

"Mass flow rate:"

mass_flow = A1 * C1/ v1 "kg/s"

Results:

Unit Settings: SI C kPa kJ mass deg

A1 = 0.1 [m^2]	C1 = 60 [m/s]	C2 = 523.1 [m/s]	h1 = 3025 [kJ/kg]
h2 = 2790 [kJ/kg]	$mass_{flow}$ = 31.58 [kg/s]	q = -100 [kJ/kg]	v1 = 0.19 [m^3/kg]
w = 0 [kJ/kg]			

Thus:

Exit velocity, C2 = 523.1 m/s … Ans.

Mass flow rate = 31.58 kg/s … Ans.

===

"**Prob.5.15.** An air receiver of volume 6 m^3 contains air at 15 bar and 40.5 C. A valve is opened and some air is allowed to blow out to atmosphere. The pressure of air in the receiver drops rapidly to 12 bar and then the valve is closed. Calculate the mass of air blown out. [Ref. 4]"

EES Solution:

"Data:"

Vol1 = 6[m^3]

P1 = 15E05[Pa]

T1 = 40.5 + 273 [K]

P2 = 12E05[Pa]

R_air = 287[J/kg-K]"…Gas const. for air"

gamma = 1.4 "…ratio of sp. heats for air"

"Calculations:"

T2/T1 = (P2/P1)^ ((gamma – 1) /gamma) "..for isentropic expn…. finds T2 (K)"
m_1 = (P1 * Vol1) / (R_air * T1) " kg … initial mass of air in the receiver"
m_2 = (P2 * Vol1) / (R_air * T2) " kg … final mass of air in the receiver"
mass_blown = (m_1 – m_2) "kg … mass blown out"

Results:

Unit Settings: SI C kPa kJ mass deg

γ = 1.4	$mass_{blown}$ = 14.74 [kg]	m_1 = 100 [kg]
m_2 = 85.29 [kg]	P1 = 1.500E+06 [Pa]	P2 = 1.200E+06 [Pa]
R_{air} = 287 [J/kg-K]	T1 = 313.5 [K]	T2 = 294.1 [K]
Vol1 = 6 [m^3]		

Thus:

Final temp of air in the receiver = T2 = 294.1 K … Ans.

Mass of air blown out = 14.74 kg … Ans.

(b) Plot the final temp and mass blown out as the P2 varies from 6 bar to 12 bar:

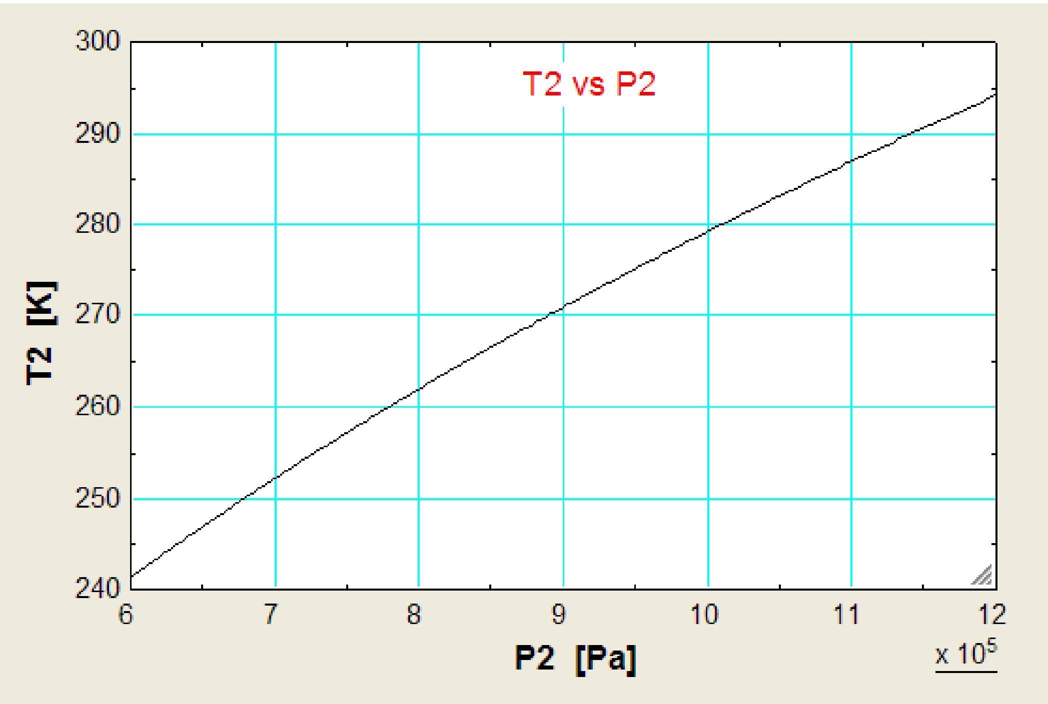
First, compute the Parametric Table:

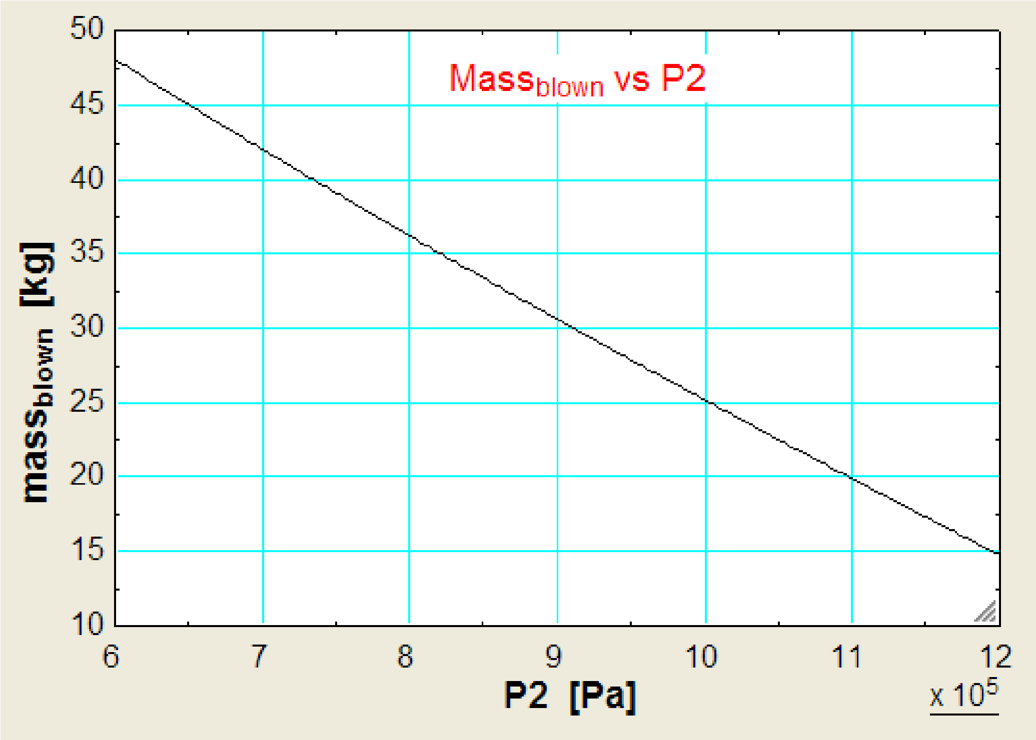
Parametric Table

Table 1

1..13	P2 [Pa]	T2 [K]	$mass_{blown}$ [kg]
Run 1	600000	241.3	48.04
Run 2	650000	246.9	44.98
Run 3	700000	252.2	41.99
Run 4	750000	257.2	39.06
Run 5	800000	262	36.18
Run 6	850000	266.5	33.36
Run 7	900000	270.9	30.58
Run 8	950000	275.1	27.85
Run 9	1000000	279.2	25.15
Run 10	1.050E+06	283.1	22.5
Run 11	1.100E+06	286.9	19.88
Run 12	1.150E+06	290.6	17.29
Run 13	1.200E+06	294.1	14.74

Now, plot the results:





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"Prob.5.16. A tank has a volume of 0.4 m^3 and is evacuated. Steam at a pressure of 1.4 MPa, 300 C is flowing in a pipe and is connected to this tank. The valve is opened and the tank is filled with steam until the pressure is 1.4 MPa, and then the valve is closed. If the process takes place adiabatically and K.E. and P.E. are negligible, determine the final temp of steam in the tank, and the amount filled in. [Ref.2]"

EES Solution:

"Data:"

Vol1 = 0.4 [m^3]
m1 = 0 "…initial mass, since the tank is evacuated"
P_pipe = 1400[kPa]
T_pipe = 300[C]
h_pipe = Enthalpy(Steam_NBS,T=T_pipe,P=P_pipe)"kJ/kg …. note the use of built-in Function for enthalpy of Steam in EES"

"Let the final temp of fluid after filling in in the tank be T2 deg.C"

"Then: h_pipe = u2 by First Law;"

u2 = IntEnergy(Steam_NBS,T=T2,P=P_pipe) "kJ/kg … since tank is filled to a pressure of the steam in the pipe"

"Note the use of built-in Function for Int. energy of Steam in EES"

h_pipe = u2 "…finds T2"

v2 = Volume(Steam_NBS,T=T2,P=P_pipe)"m^3/kg …. sp. vol. of steam in tank"

mass = Vol1/v2 "kg … mass filled in the tank"

Results:

Unit Settings: SI C kPa kJ mass deg

h_{pipe} = 3040 [kJ/kg]	m1 = 0 [kg]	mass = 1.697 [kg]	P_{pipe} = 1400 [kPa]
T2 = 452 [C]	T_{pipe} = 300 [C]	u2 = 3040 [kJ/kg]	v2 = 0.2357
Vol1 = 0.4 [m^3]			

Thus:

Final temp of steam in tank = T2 = 452 deg.C…. Ans.

Amount of steam filled in the tank = 1.697 kg … Ans.

===

"Prob.5.17. Let the tank in the previous example contain initially sat. vapour at 350 kPa. Now the valve is opened and the tank is filled with steam until the pressure is 1.4 MPa, and then the valve is closed. If the process takes place adiabatically and K.E. and P.E. are negligible, determine the final temp of steam in the tank, and the amount filled in. [Ref.2]"

EES Solution:

"Data:"

Vol1 = 0.4 [m^3] "..volume of tank"

P1 = 350[kPa] "…Initial pressure of steam in tank"

x1 = 1 "…sat. vapour"

P_pipe = 1400[kPa] "…pressure of steam in pipe"

T_pipe = 300[C] "…temp of steam in pipe"

"Calculations:"

u1 = IntEnergy(Steam_NBS,x=x1,P=P1) "kJ/kg …Int. energy of steam in the beginning"

v1 = Volume(Steam_NBS,x=x1,P=P1) "m^3/kg …. sp. vol. of steam present initially in tank"

m1 = Vol1 / v1 "…initial mass of steam in the tank "

h_pipe = Enthalpy(Steam_NBS,T=T_pipe,P=P_pipe) "kJ/kg ….enthalpy of steam in the pipe"

"Let the final mass in tank be m2, temp of fluid after filling in the tank be T2 deg.C"

"Then: (m2-m1)* h_pipe = (m2 * u2 – m1 * u1) … by First Law;"

u2 = IntEnergy(Steam_NBS,T=T2,P=P_pipe) "kJ/kg ..int. energy of steam after the tank is filled to a pressure of the steam in the pipe"

v2 = Volume(Steam_NBS,T=T2,P=P_pipe)"m^3/kg …. sp. vol. of steam in tank, after filling up"

m2 = Vol1 / v2 "kg..mass of steam in tank after filling"

(m2 – m1) * h_pipe = (m2 * u2 – m1 * u1) "….By First Law for filling process"

"Mass of steam flowing in to the tank:"

mass_to_tank = (m2 – m1) "kg"

Results:

Unit Settings: SI C kPa kJ mass deg

h_{pipe} = 3040 [kJ/kg]
$mass_{to,tank}$ = 1.264 [kg]
T2 = 341.8 [C]
u2 = 2855 [kJ/kg]
Vol1 = 0.4 [m^3]
m1 = 0.763 [kg]
P1 = 350 [kPa]
T_{pipe} = 300 [C]
v1 = 0.5243 [m^3/kg]
x1 = 1
m2 = 2.027 [kg]
P_{pipe} = 1400 [kPa]
u1 = 2549 [kJ/kg]
v2 = 0.1973 [m^3/kg]

Thus:

Final temp of steam in tank = 341.8 deg. C … Ans.

Mass of steam entering the tank = 1.264 kg … Ans.

===

Prob.5.18. A balloon initially contains 65 m^3 of helium gas at atmospheric conditions of 100 kPa and 22 C. The balloon is connected by a valve to a large reservoir that supplies helium gas at 150 kPa and 25 C. Now the valve is opened, and helium is allowed to enter the balloon until pressure equilibrium with the supply line is reached. The material of the balloon is such that its volume increases linearly with pressure. If no heat transfer takes place during this process, determine the final temp in the balloon. [Ref:1]

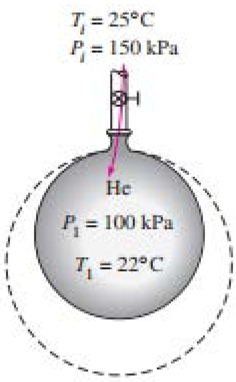


Fig. Prob.5.18

We use eqn. (5.14):

$$Q_{cv} + \sum_{inlets}\left(h_i + \frac{V_i^2}{2} + g\cdot Z_i\right) = \sum_{exits}\left(h_e + \frac{V_e^2}{2} + g\cdot Z_e\right) + \left[m_2\cdot\left(u_2 + \frac{V_2^2}{2} + g\cdot Z_2\right) - m_1\cdot\left(u_1 + \frac{V_1^2}{2} + g\cdot Z_1\right)\right] + W_{cv}$$

......eq.(5.14)

Here, we have: all K.E. and P.E. changes are negligible, Q_{cv} = 0, use 'h' for gas flowing, and 'u' for gas confined to the control volume. Work done is positive since the boundary of balloon is expanding.

EES Solution:

"Data:"

P1 = 100 "kPa"
T1 = 22+273 "K"
Vol1 = 65 "m^3"

P2 = 150 "kPa"
Vol2 = Vol1 * (p2/p1)"m^3 … since volume is proprtional to pressure"

P3 = 150"kPa"
T3 = 25+273"K"

"Calculations:"

Q + m_i * h3 = W + (m2*u2 – m1*u1) "**First Law for this case** of filling a control volume, see Eqn. 5.14"

h3=Enthalpy(Helium,T=T3,P=P3)"kJ/kg"

u1=IntEnergy(Helium,T=T1,P=P1)"kJ/kg"

u2=IntEnergy(Helium,T=T2,P=P2)"kJ/kg"

m_i = m2 – m1"kg.... mass entering the c.v."

v1=Volume(Helium,T=T1,P=P1)"..m^3/kg … sp. vol. in state 1"

v2=Volume(Helium,T=T2,P=P2)"..m^3/kg … sp. vol. in state 2"

m2 = Vol2/v2 "kg…mass in state 2"

m1 = Vol1/v1 "kg…mass in state 1"

W = ((P1 + P2)/2)*(Vol2-Vol1)"kJ…work done by the c.v., since Vol is proportional to pressure"

Q=0 "…heat going into the c.v. is zero"

Solution:

Unit Settings: SI K kPa kJ mass deg

h3 = -0.2942 [kJ/kg]	m1 = 10.6 [kg]	m2 = 21.09 [kg]
m_i = 10.49	P1 = 100 [kPa]	P2 = 150 [kPa]
P3 = 150 [kPa]	Q = 0 [kJ]	T1 = 295 [K]
T2 = 333.6 [K]	T3 = 298 [K]	u1 = -629.1 [kJ/kg]
u2 = -508.9 [kJ/kg]	v1 = 6.131 [m^3/kg]	v2 = 4.622 [m^3/kg]
Vol1 = 65 [m^3]	Vol2 = 97.5 [m^3]	W = 4063 [kJ]

Thus:

Final temp, T2 = 333.6 K …Ans.

Work done, W = 4063 kJ …Ans.

(b) If the final pressure P2 varies from 120 to 150 kPa, plot the variation of T2 and W against P2:

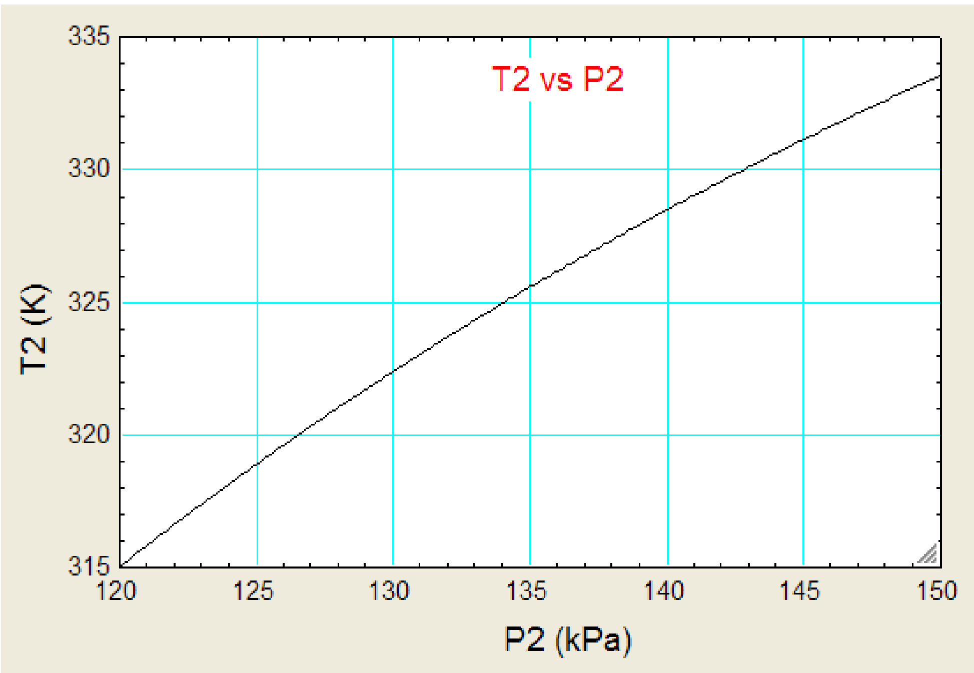
First, compute the Parametric Table:

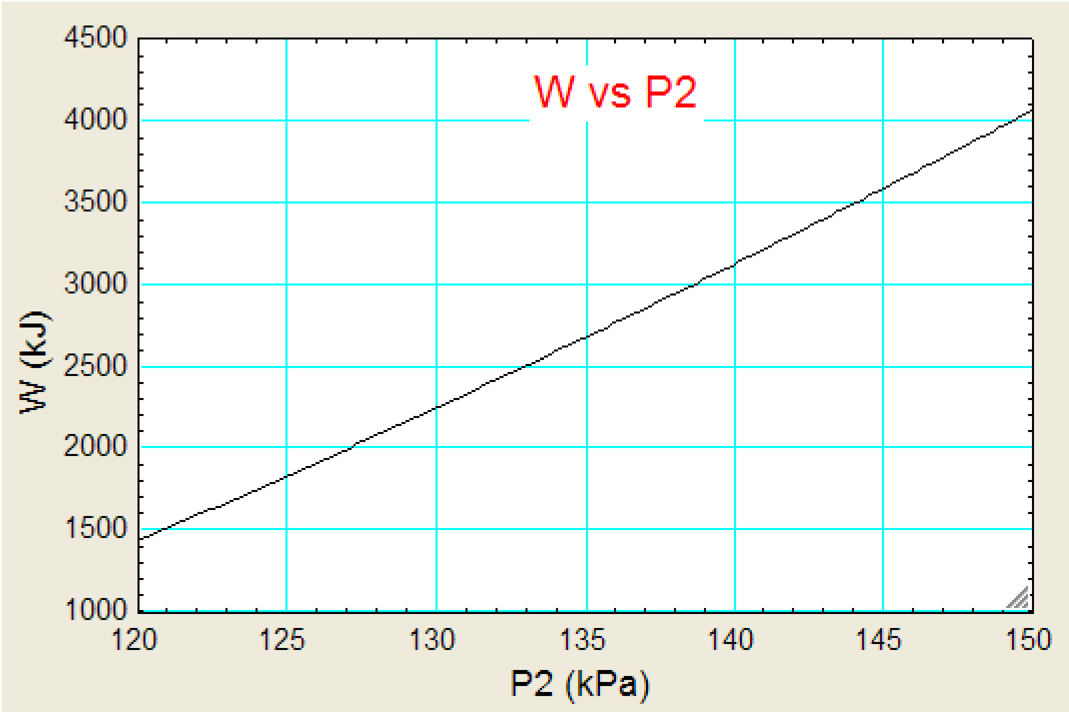
Parametric Table

Table 1

1..7	P2 [kPa]	T2 [K]	W [kJ]
Run 1	120	315	1430
Run 2	125	318.9	1828
Run 3	130	322.4	2243
Run 4	135	325.6	2673
Run 5	140	328.5	3120
Run 6	145	331.1	3583
Run 7	150	333.6	4063

Now, plot the results:




W vs P2
W (kJ)
4500
4000
3500
3000
2500
2000
1500
1000
120
125
130
135
140
145
150
P2 (kPa)

==

"Prob.5.19. A 100-L rigid tank contains carbon dioxide gas at 1 MPa, 300 K. A valve is cracked open, and carbon dioxide escapes slowly until the tank pressure has dropped to 500 kPa. At this point, the valve is closed. The gas remaining inside the tank may be assumed to have undergone a polytropic expansion, with polytropic exponent n =1.15. Find the final mass inside and the heat transferred to the tank during the process. [Ref:2]"

EES Solution:

"Data:"

P1 = 1000 "kPa"

T1 = 300 "K"

Vol1 = 0.1 "m^3"

n = 1.15 "…polytropic index"

P2 = 500 "kPa"

Vol2 = Vol1"m^3"

T2/T1 = (P2/P1)^((n – 1)/n)"[K]…finds temp after polytropic expansion, state 2"

"Calculations:"

"Note: Enthalpy of CO2 exiting goes on varying from state 1 to state 2.

So, we take the average value of enthalpy:"

h1=Enthalpy(CarbonDioxide,T=T1,P=P1)"kJ/kg …. enthalpy in state 1"

h2=Enthalpy(CarbonDioxide,T=T2,P=P2)"kJ/kg …. enthalpy in state 2"

h_avg = (h1 + h2) / 2"kJ/kg … average enthalpy of exiting CO2"

Q = m_e * h_avg + (m2 * u2 – m1* u1) + W "…First Law for this case of filling a control volume, see Eqn. 5.14"

W = 0 "..no work done, since volume is const."

u1=IntEnergy(CarbonDioxide,T=T1,P=P1)"kJ/kg….internal energy"

u2=IntEnergy(CarbonDioxide,T=T2,P=P2)"kJ/kg … internal energy"

m_e = (m1 – m2)"kg…. mass exiting the c.v."

v1=Volume(CarbonDioxide,T=T1,P=P1)"..m^3/kg … sp. vol. in state 1"

v2=Volume(CarbonDioxide,T=T2,P=P2)"..m^3/kg … sp. vol. in state 2"

m2 = Vol2/v2 "kg…mass in state 2"

m1 = Vol1/v1 "kg…mass in state 1"

Results:

Unit Settings: SI K kPa kJ mass deg

h1 = -7.942 [kJ/kg]	h2 = -25.75 [kJ/kg]	h_{avg} = -16.85 [kJ/kg]
m1 = 1.858 [kg]	m2 = 0.9993 [kg]	m_e = 0.8587
n = 1.15	P1 = 1000 [kPa]	P2 = 500 [kPa]
Q = 24.56 [kJ]	T1 = 300 [K]	T2 = 274.1 [K]
u1 = -61.76 [kJ/kg]	u2 = -75.79 [kJ/kg]	v1 = 0.05382 [m^3/kg]
v2 = 0.1001 [m^3/kg]	Vol1 = 0.1 [m^3]	Vol2 = 0.1 [m^3]
W = 0 [kJ]		

Thus:

Q = 24.56 kJ …. Heat transferred …. Ans.

m2 = 0.9993 kg …. Final mass inside the tank … Ans.

T2 = 274.1 K …Final temp of gas inside the tank…. Ans.

(b) As the final pressure (P2) varies from 300 kPa to 600 kPa, plot the variation of T2, m2, and Q with P2:

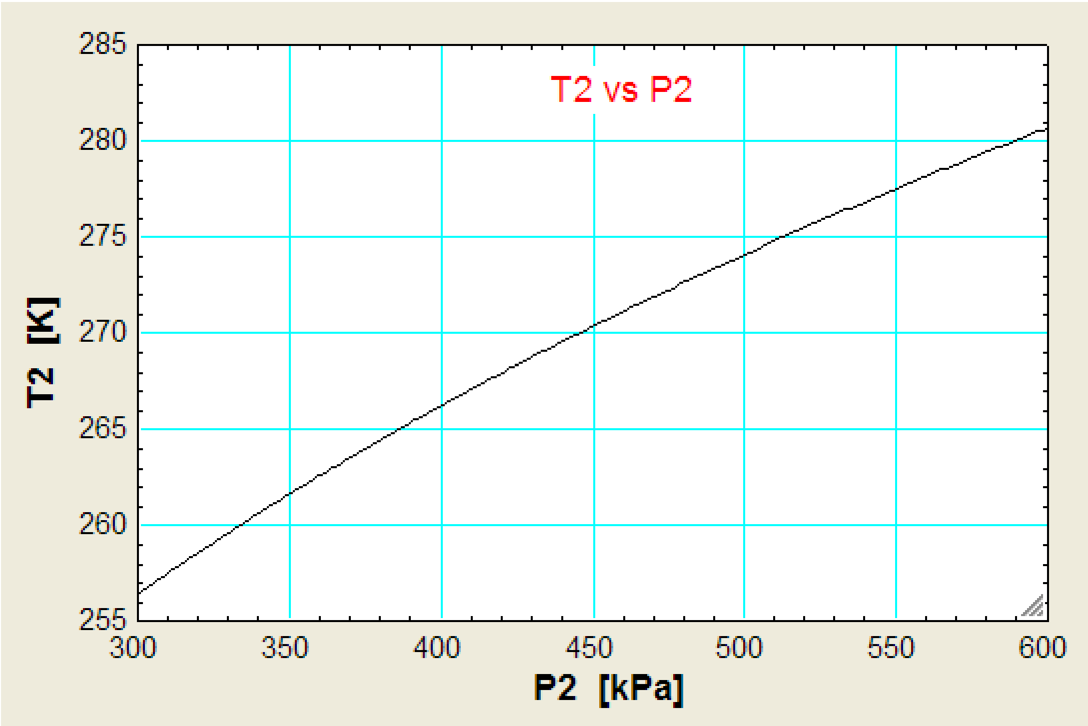
First, compute the Parametric Table:

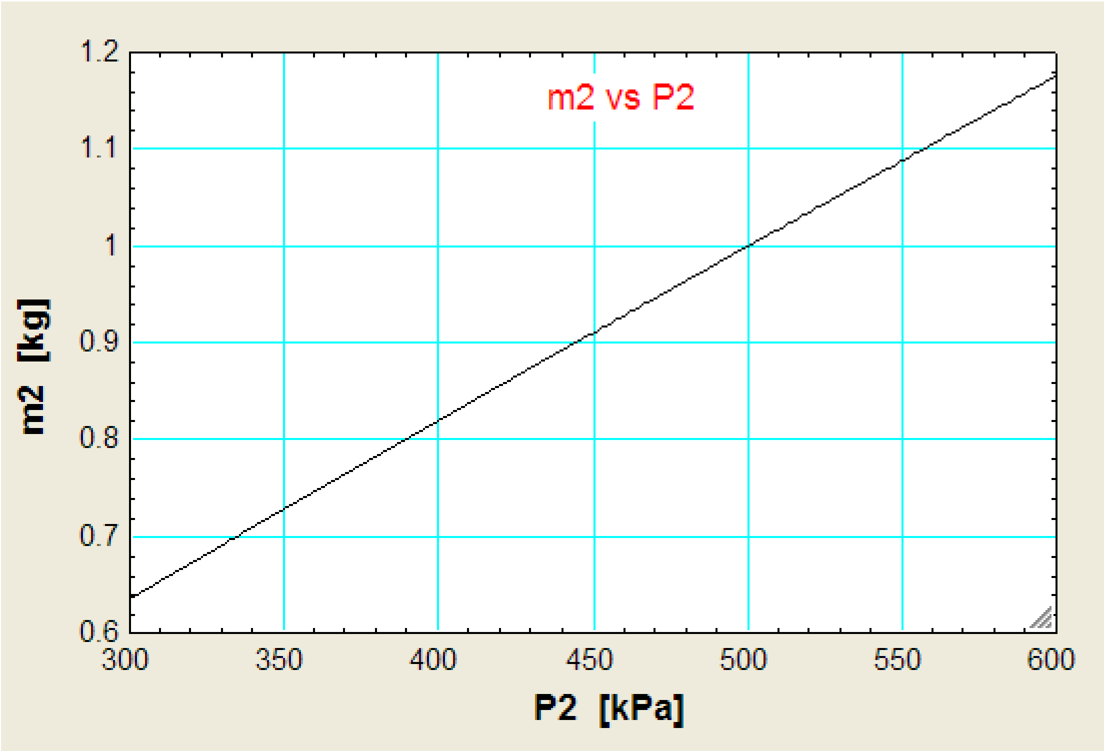
Parametric Table

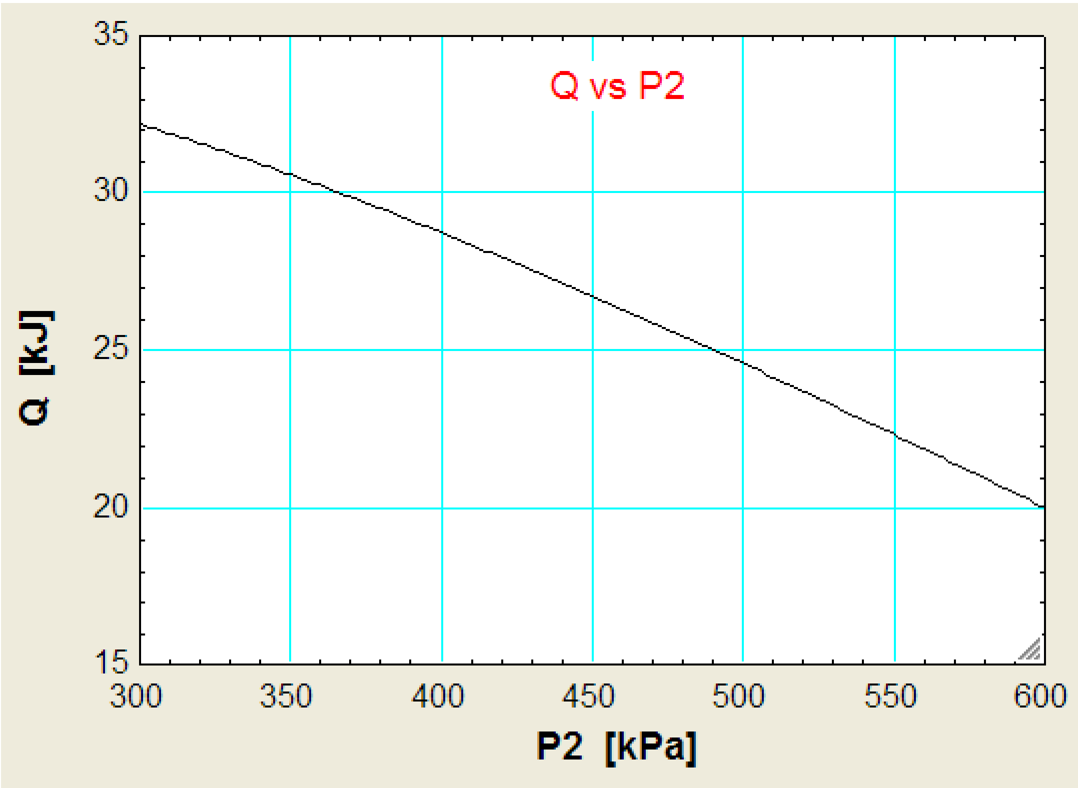
Table 1

1..7	P2 [kPa]	T2 [K]	m2 [kg]	Q [kJ]
Run 1	300	256.4	0.6352	32.18
Run 2	350	261.6	0.728	30.57
Run 3	400	266.2	0.8195	28.72
Run 4	450	270.3	0.9099	26.71
Run 5	500	274.1	0.9993	24.56
Run 6	550	277.5	1.088	22.31
Run 7	600	280.7	1.176	19.98

Now, plot the results:




m2 vs P2
m2 [kg]
1.2
1.1
1
0.9
0.8
0.7
0.6
300
350
400
450
500
550
600
P2 [kPa]


Q vs P2
Q [kJ]
35
30
25
20
15
300
350
400
450
500
550
600
P2 [kPa]

==

5.3 Problems solved with The Expert System for Thermodynamics (TEST):

Nozzles and Diffusers:

Prob.5.20. Superheated vapour Ammonia enters an insulated nozzle at 20 C, 800 kPa, shown in Fig. below, with a low velocity and at a steady rate of 0.01 kg/s. The Ammonia exits at 300 kPa with a velocity of 450 m/s. Determine the temperature (or quality, if saturated) and the exit area of the nozzle. [Ref. 2]

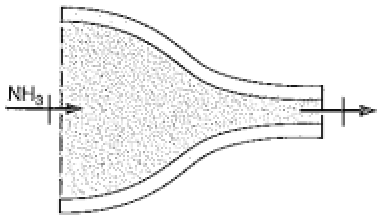
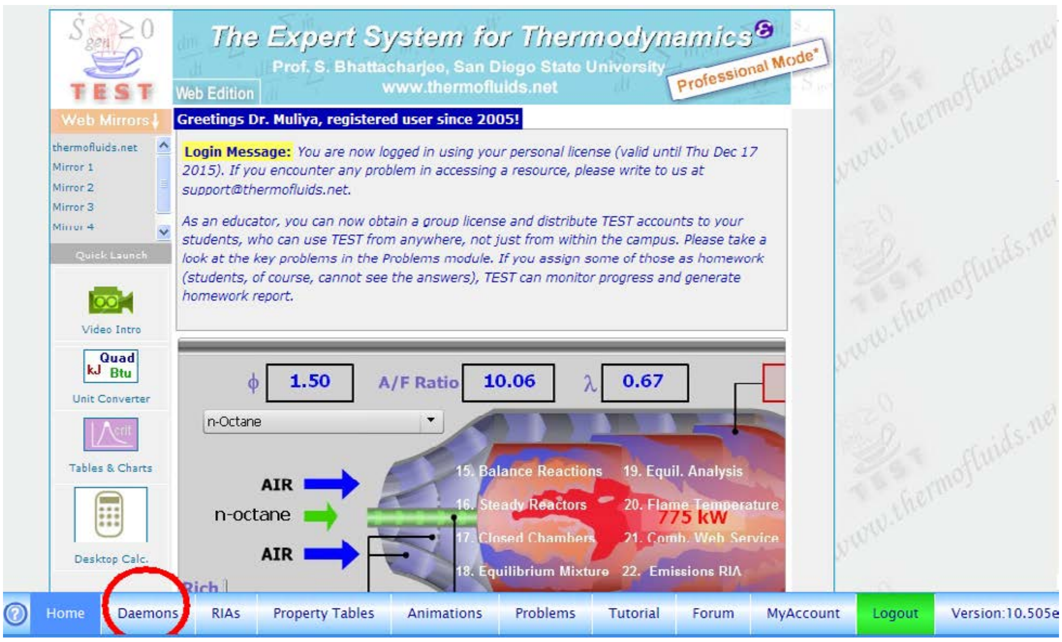


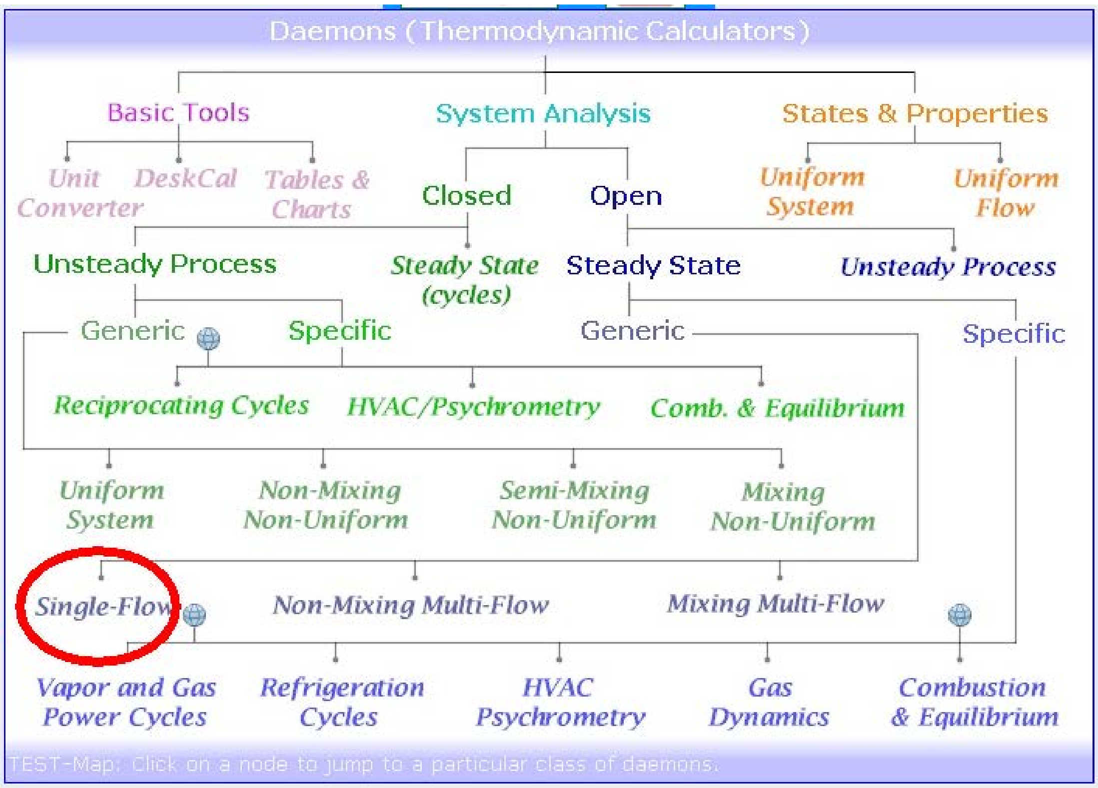
Fig.Prob.5.20

TEST Solution:

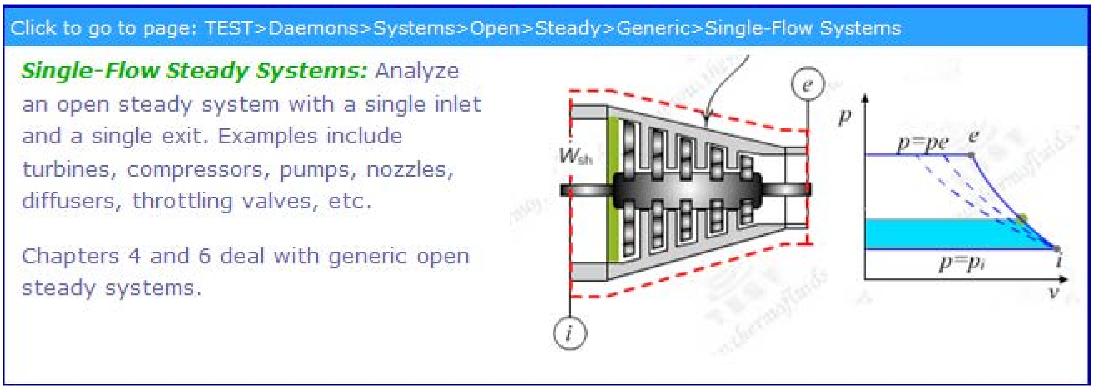
1. Start TEST by going to www.thermofluids.net, enter the required e-mail address and password and, we get the greeting screen. Locate the Daemons tab at the bottom of screen:



2. Click on **Daemons** tab to get the Daemon tree to select the required Daemon:

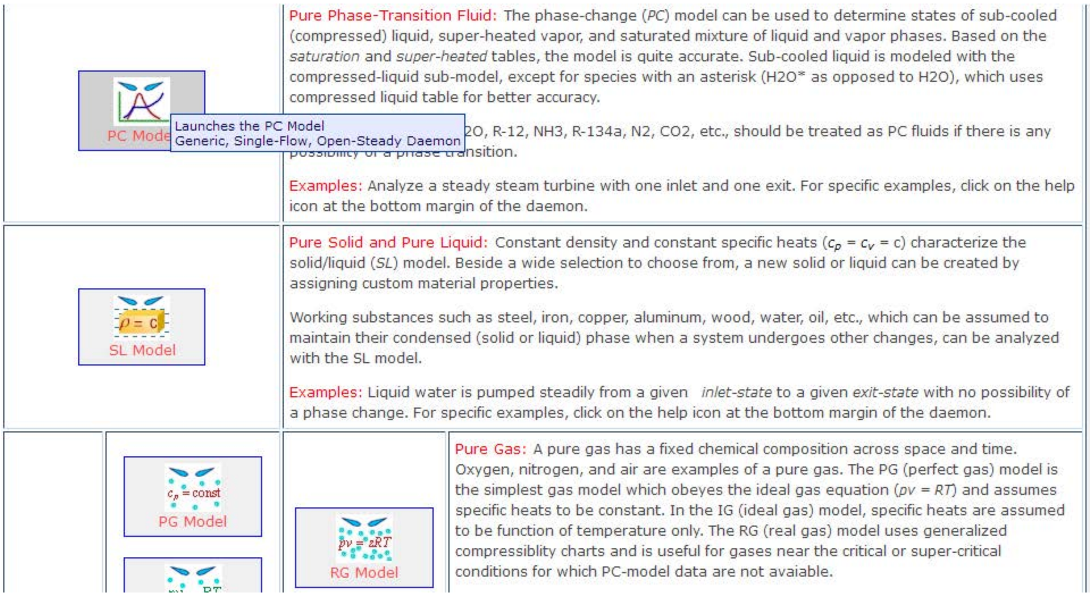


3. Hover the mouse pointer over System Analysis – Open – Generic – Single Flow shown above. We get the following description screen:



We see from the description that this is the daemon to be used for calculations regarding turbines, compressors, pumps, nozzles, diffusers, throttling valves etc. **i.e. for most of this chapter, we will be using this daemon.**

4. Now, click on **Single-Flow**. A window appears where we have to choose the required Material model. In the present case, we deal with vapour/liquid Ammonia; so, we choose PC (i.e. Phase Change) model as shown below:

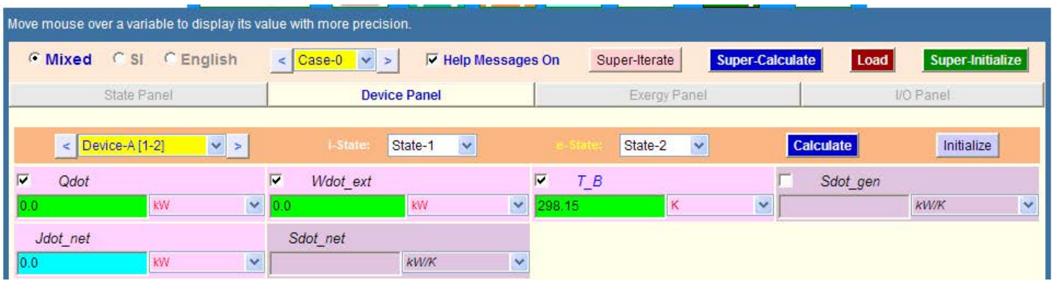


5. On clicking PC model, we get the following screen, where we have chosen Ammonia as the fluid. We have also filled up the data for State 1 as p1 = 800 kPa, T1 = 20 C and mdot1 = 0.01 kg/s. Vel1 = 0 by default. Click on Calculate and rest of the calculations for state 1 are completed in the screen shot shown below:

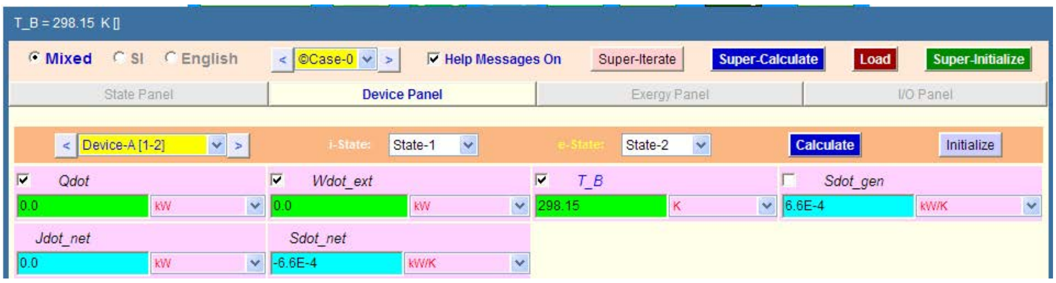
6. Similarly, choose State 2 and fill in the given data, i.e. p2 = 300 kPa, Vel2 = 450 m/s and mdot2 = mdot1. Click on Calculate:

Note that no new calculations are made since data is not enough; however, we will return to this State after entering other data:

7. Go to Device Panel and fill in the known data, i.e. Q = 0, Wdot_ext = 0 for a Nozzle, and click on Calculate. We get:



8. **Now, the important step: click on SuperCalculate** to update all related States calculations. We get:



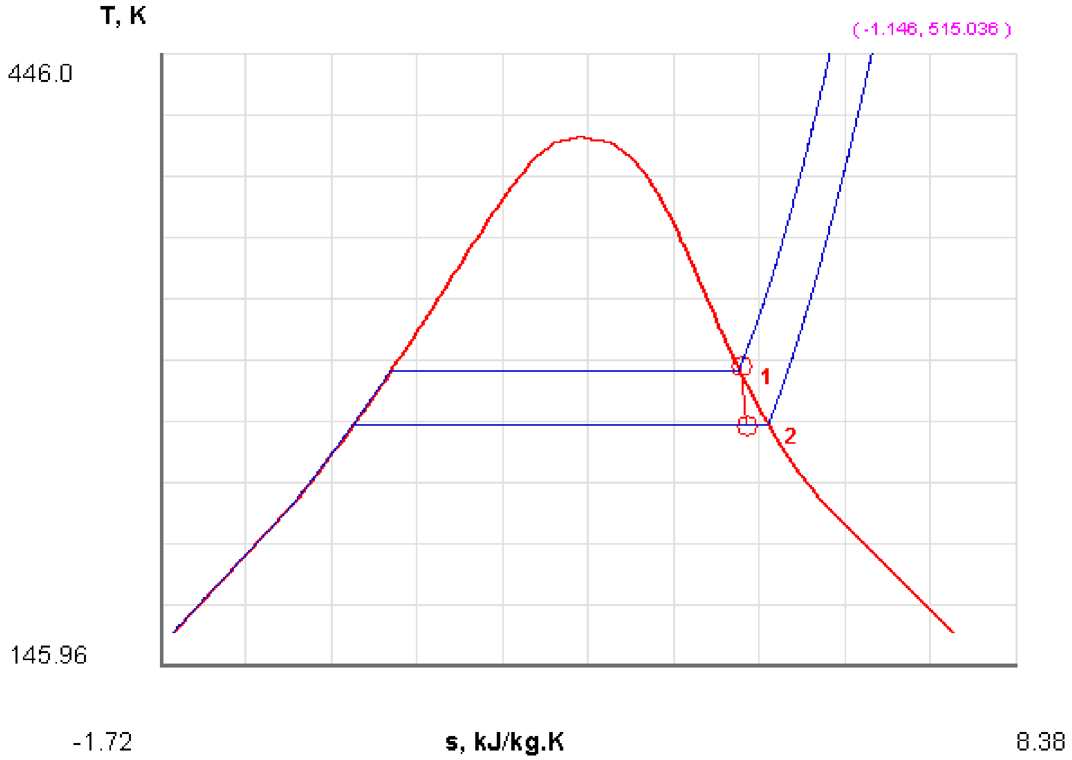
9. Now, go to State Panel and see States 1 and 2:

State 1:

State 2:

Thus: A2 = 8.5668935E-6 m^2 = 8.567 mm^2, T2 = -9.259 C, x2 = 0.94729……Ans.

10. Draw the indicative T-s diagram after choosing the required plot from Plots tab:



11. Now, go to the I/O panel and see the **TEST code** which can be used to regenerate the calculations at a later date, and also other calculations such as property values at different States etc:

#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE (starts from your inputs) OPERATION (for further iteration use SUPER-ITERATE)~~~~~~~~~~~~~~~~~~~~~~~~~

#*******ANALYST: Dr. Muliya; TEST License: Professional*******

Solution logged at: Dec 20, 2013 9:43:40 PM

#*******TEST-code: To save the solution, copy the codes generated below into a text file. To reproduce the solution at a later time, launch the daemon (see path name below), paste the saved TEST-code at the bottom of this I/O panel, and click the Load button.

```
#       Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.bb06
#-------------------Start of TEST-code ----------------------------------------------------------------------

 States  {
         State-1: Ammonia(NH3);
         Given: { p1= 800.0 kPa; T1= 20.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 0.01 kg/s; }
         State-2: Ammonia(NH3);
         Given: { p2= 300.0 kPa; Vel2= 450.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
         }

 Analysis {
         Device-A: i-State = State-1; e-State = State-2;
         Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K; }
         }

#---------------------End of TEST-code ---------------------------------------------------------------------
```

#********DETAILED OUTPUT:**

 # Evaluated States:

State-1: Ammonia(NH3) > Superheated Vapor;
Given: p1= 800.0 kPa; T1= 20.0 deg-C; Vel1= 0.0 m/s;
z1= 0.0 m; mdot1= 0.01 kg/s;
Calculated: v1= 0.1614 m^3/kg; u1= 1335.6714 kJ/kg; h1= 1464.7263 kJ/kg;
s1= 5.1321 kJ/kg.K; e1= 1335.6714 kJ/kg; j1= 1464.7263 kJ/kg;
Voldot1= 0.0016 m^3/s; A1= 161.4154 m^2; MM1= 17.031 kg/kmol;
State-2: Ammonia(NH3) > Saturated Mixture;
Given: p2= 300.0 kPa; Vel2= 450.0 m/s; z2= 0.0 m;
mdot2= "mdot1" kg/s;
Calculated: **T2= -9.2592 deg-C; x2= 0.9473** fraction; y2= 0.9998 fraction;
v2= 0.3855 m^3/kg; u2= 1248.0526 kJ/kg; h2= 1363.4763 kJ/kg;
s2= 5.1985 kJ/kg.K; e2= 1349.3026 kJ/kg; j2= 1464.7263 kJ/kg;
Voldot2= 0.0039 m^3/s; A2= 0.0 m^2; MM2= 17.031 kg/kmol;

#--------Property spreadsheet starts: The following property table can be copied onto a spreadsheet (such as Excel) for further analysis or plots. ---------------

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	800.0	293.2		0.1614	1335.67	1464.73	5.132
# 02	300.0	**263.9**	**0.9**	0.3855	1248.05	1363.48	5.199

 # Mass, Energy, and Entropy Analysis Results:

Device-A: i-State = State-1; e-State = State-2;

Given: Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K;

Calculated: Sdot_gen= "6.64382E-4" kW/K; Jdot_net= 0.0 kW; Sdot_net= "-6.64382E- 4" kW/K;

Note: In the above calculations, j = h + V^2/2 + g.Z, and e = u + V^2/2 + g.Z

===

(b) If the exit pressure varies from 100 to 500 kPa, mass flow rate remaining constant at 0.01 kg/s, plot the variation of T2 and A2 with p2:

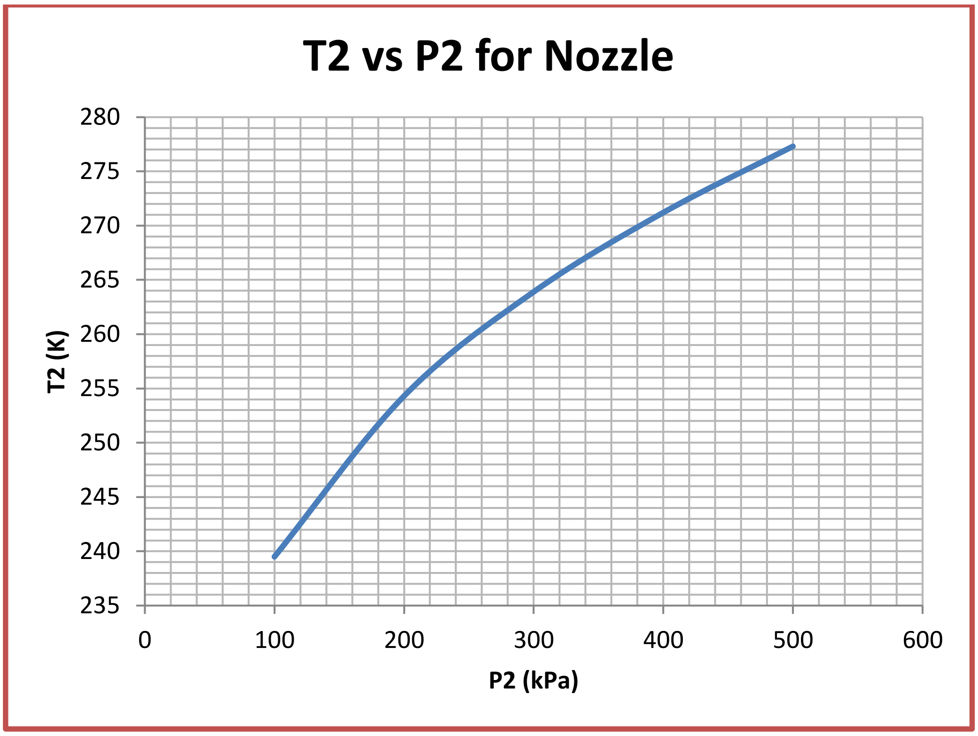
The procedure is quite simple:

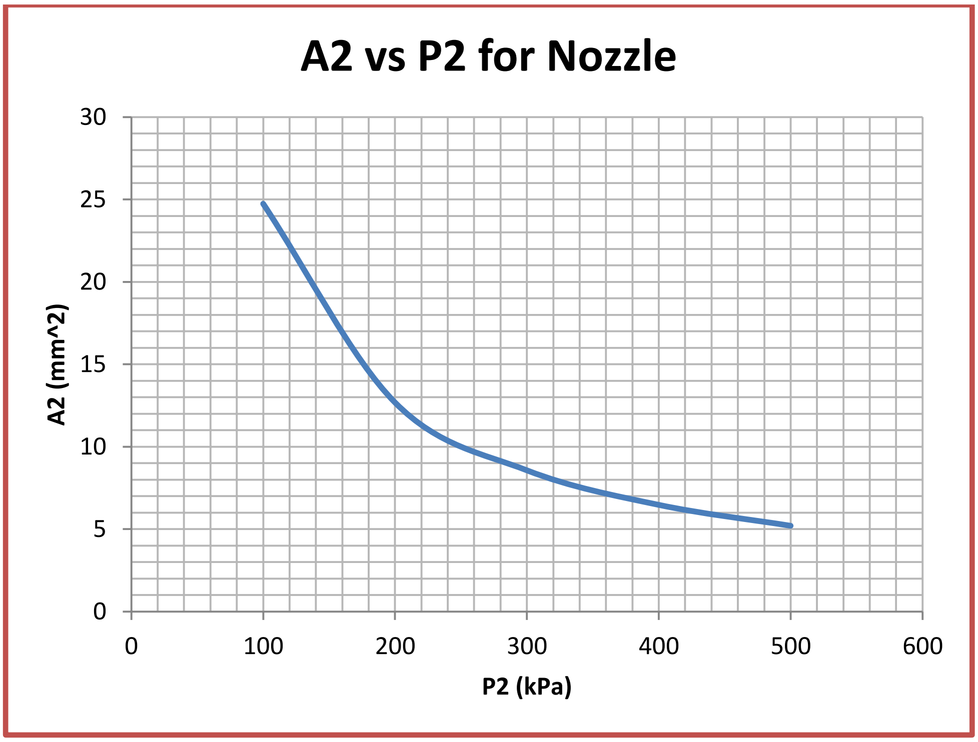
Go to State 2, change the pressure p2 to desired value and click Calculate, then click SuperCalculate. All values are updated.

Do this for all desired values of p2 and separately tabulate p2, T2 and A2:

P2 (kPa)	T2 (K)	A2 (mm^2)
100	239.5	24.74
200	254.3	12.68
300	263.9	8.567
400	271.2	6.472
500	277.3	5.2045

Now, we can copy these values to EXCEL and draw the graphs:




A2 vs P2 for Nozzle
A2 (mm^2)
30
25
20
15
10
5
0
0
100
200
300
400
500
600
P2 (kPa)

==

Prob.5.21. A Diffuser shown in fig. has air entering at 100 kPa, 300 K, with a velocity of 200 m/s. The inlet cross-sectional area of the diffuser is 100 mm^2. At the exit, the area is 860 mm^2, and the velocity is 20 m/s. Determine the exit pressure and temp of air. [Ref. 2]:

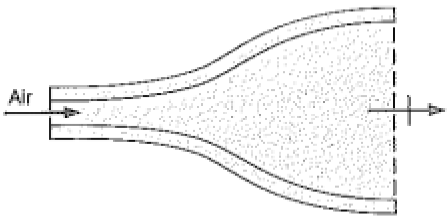
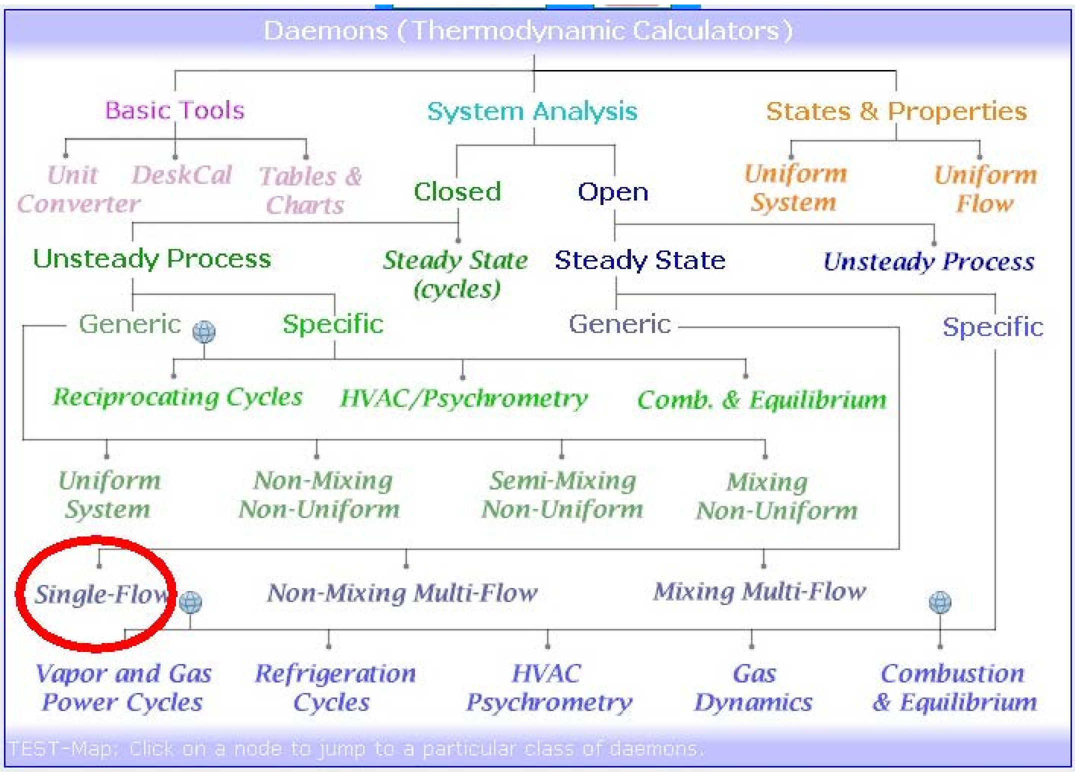


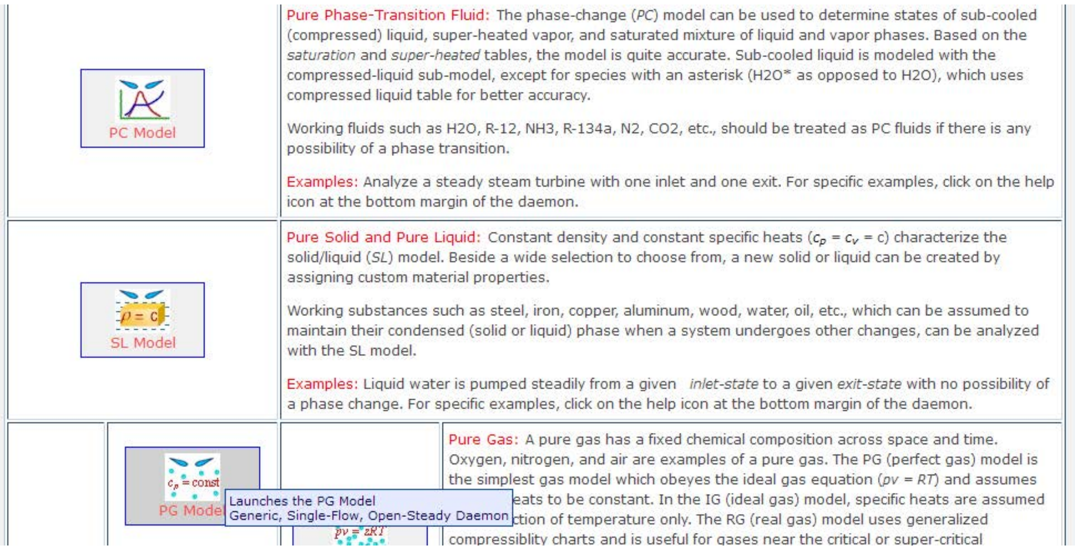
Fig.Prob.5.21

TEST Solution:

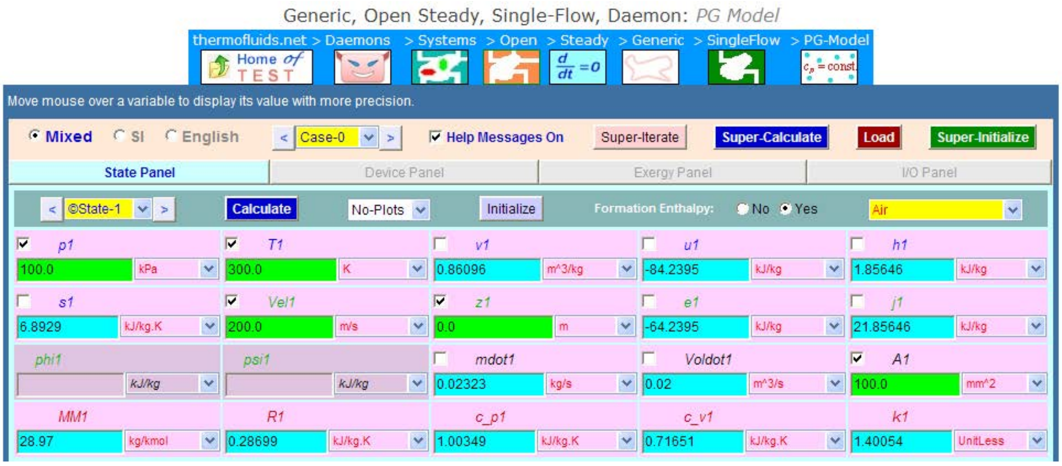
1. Go to the Daemon tree and locate System Analysis – Open – Generic – Single Flow:



2. Select the Perfect Gas (PG) Model (cp = const.) for Material model, since air is the working substance:



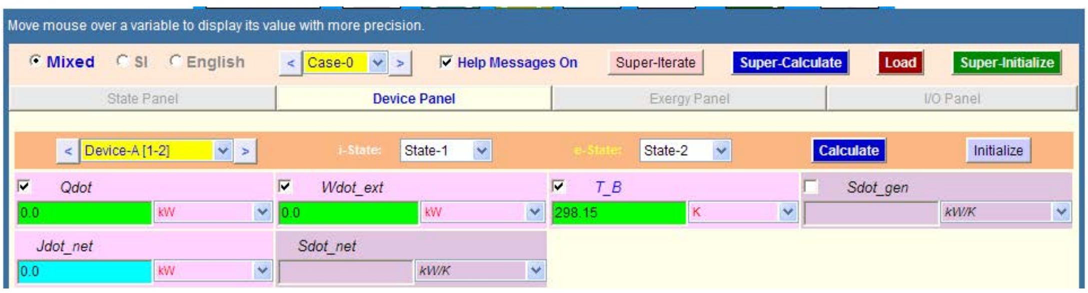
3. We get the following screen after clicking on PG model. Now, choose Air as the Working substance from the drop down menu. Then, enter known values of P1, T1, Vel1 and A1 for State 1. Click on Calculate. We get:



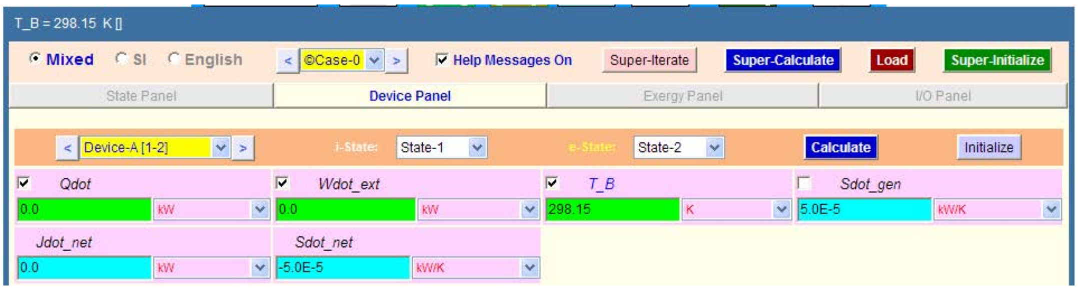
Note that mass flow rate is calculated as mdot1 = 0.02323 kg/s.

4. Now, go to State 2, and enter A2, Vel2 and mdot2 (= mdot1). Click on Calculate. We get:

5. Go to Device Panel, enter b-state and f-state as State 1 and State 2 respectively as shown. Also, enter Qdot = 0 and Wdot_ext = 0, since heat transfer and work transfer for diffuser are zero. Click on Calculate. We get:



6. Now, click on **SuperCalculte.** We get:



7. **Now, go back to States panel:**

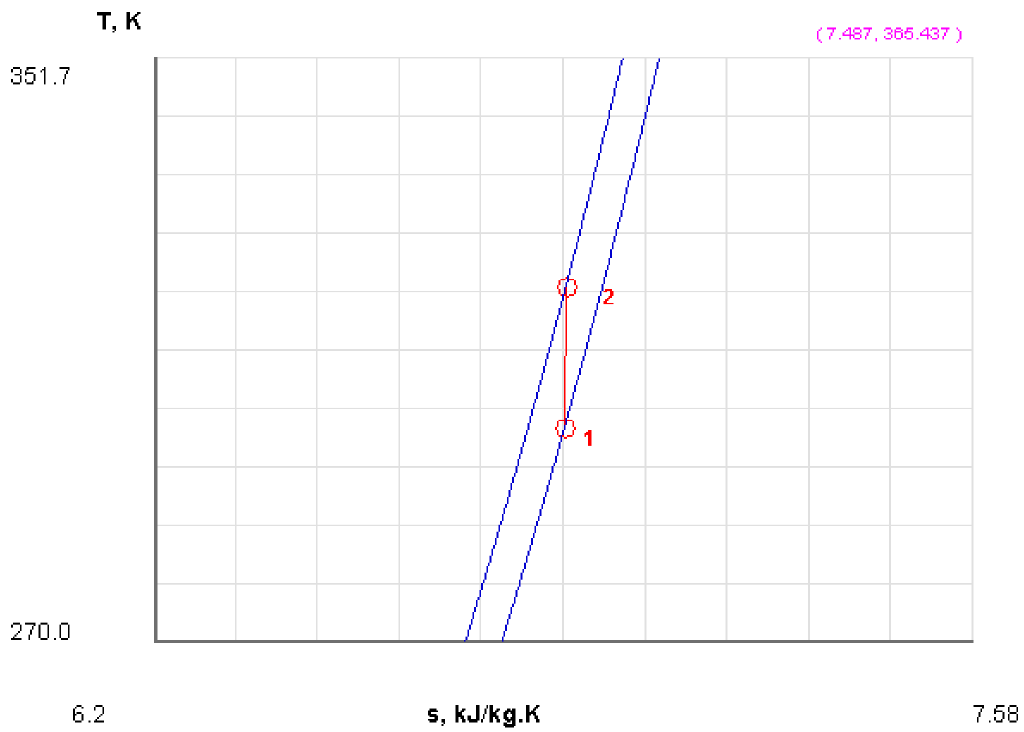
And, observe States 1 and 2:

State 1:

State 2:

Thus: Exit pressure, p2 = 123.93 kPa, exit temp, T2 = 319.73 K … Ans.

8. Draw the indicative T-s diagram from the Plot tag, after choosing T-s plot:



9. SuperCalculate also produces TEST code and the detailed property output etc. in the I/O panel. Part of the output is shown below:

```
#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE :

#       Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PG-Model; v-10.bb05

#--------------------Start of TEST-code ---------------------------------------------------------------------

 States   {
          State-1: Air;
          Given: { p1= 100.0 kPa; T1= 300.0 K; Vel1= 200.0 m/s; z1= 0.0 m; A1= 100.0 mm^2; }
          State-2: Air;
          Given: { Vel2= 20.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; A2= 860.0 mm^2; }
          }

 Analysis {
          Device-A: i-State = State-1; e-State = State-2;
          Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K; }
          }

#----------------------End of TEST-code --------------------------------------------------------------------

#******DETAILED OUTPUT:
# Evaluated States:
#       State-1: Air > PG-Model;
#               Given: p1= 100.0 kPa; T1= 300.0 K; Vel1= 200.0 m/s;
#                       z1= 0.0 m; A1= 100.0 mm^2;
#               Calculated: v1= 0.861 m^3/kg; u1= -84.2395 kJ/kg; h1= 1.8565 kJ/kg;
#                       s1= 6.8929 kJ/kg.K; e1= -64.2395 kJ/kg; j1= 21.8565 kJ/kg;
#                       mdot1= 0.0232 kg/s; Voldot1= 0.02 m^3/s; MM1= 28.97 kg/kmol;
#                       R1= 0.287 kJ/kg.K; c_p1= 1.0035 kJ/kg.K; c_v1= 0.7165 kJ/kg.K;
#                       k1= 1.4005 UnitLess;
#       State-2: Air > PG-Model;
#               Given: Vel2= 20.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s;
#                       A2= 860.0 mm^2;
#               Calculated: p2= 123.9268 kPa; T2= 319.7311 K; v2= 0.7404 m^3/kg;
#                       u2= -70.102 kJ/kg; h2= 21.6565 kJ/kg; s2= 6.8952 kJ/kg.K;
#                       e2= -69.902 kJ/kg; j2= 21.8565 kJ/kg; Voldot2= 0.0172 m^3/s;
#                       MM2= 28.97 kg/kmol; R2= 0.287 kJ/kg.K; c_p2= 1.0035 kJ/kg.K;
#                       c_v2= 0.7165 kJ/kg.K; k2= 1.4005 UnitLess;
```

#--------Property spreadsheet:

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	100.0	300.0	0.861	-84.24	1.86	6.893
#	2	123.93	319.7	0.7404	-70.1	21.66	6.895

#--------Property spreadsheet ends---

 # Mass, Energy, and Entropy Analysis Results:

Device-A: i-State = State-1; e-State = State-2;

Given: Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K;

Calculated: Sdot_gen= “5.472404E-5” kW/K; Jdot_net= 0.0 kW; Sdot_net= “-5.472404E-5” kW/K;

(b) As A1 varies from 50 to 300 mm^2, plot the variation of mdot, p2 and T2, other quantities remaining unchanged:

The procedure is as follows

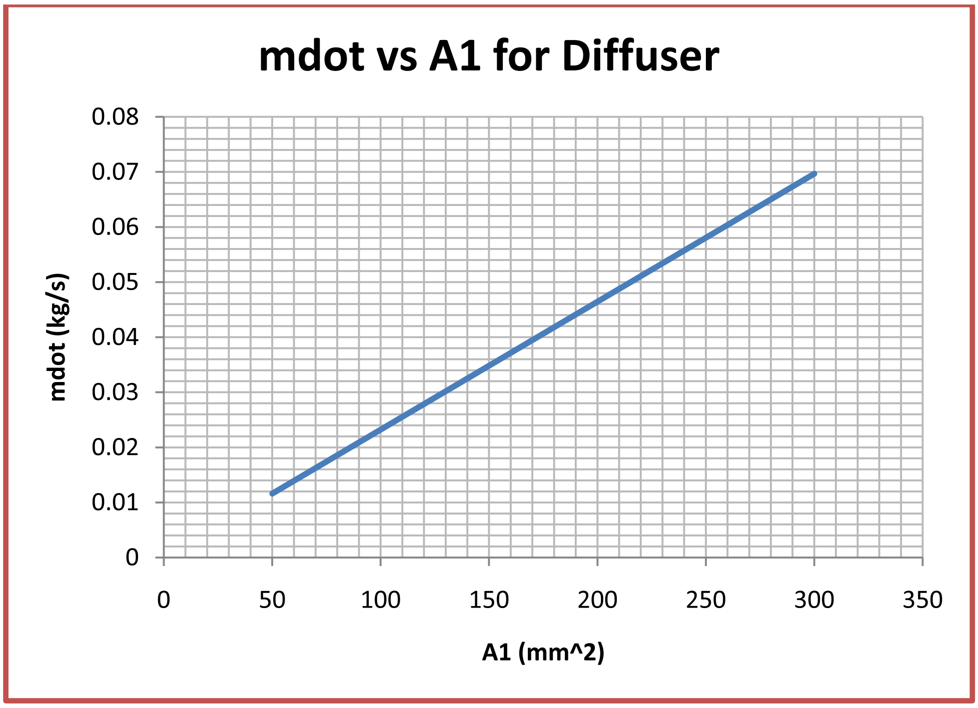
Go to State 1, change the pressure A1 to desired value and click Calculate (or, hit Enter), then click SuperCalculate. All values are updated.

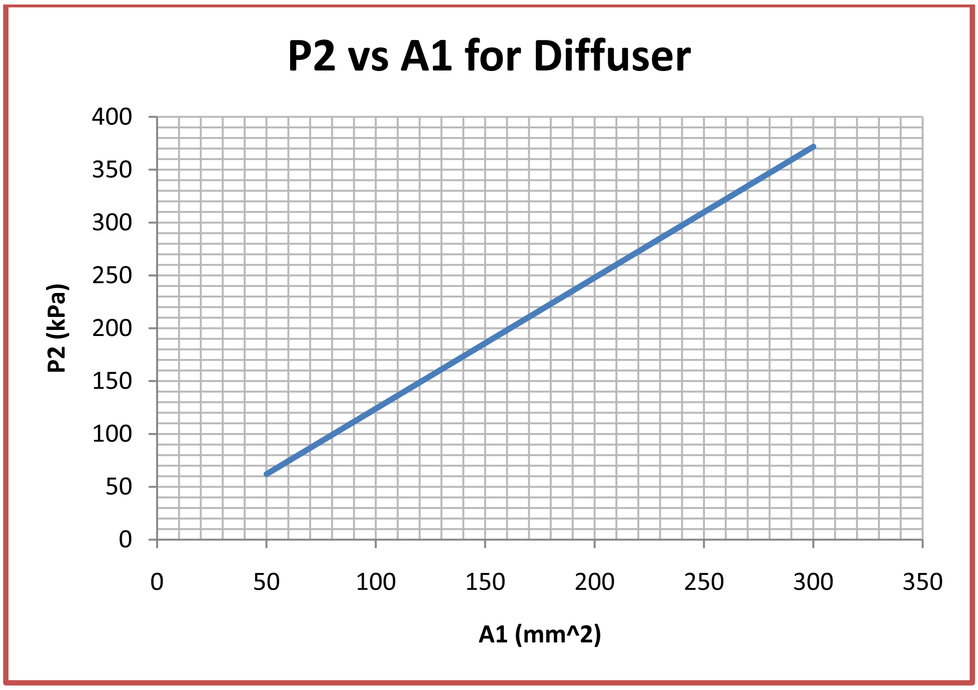
Do this for all desired values of A1and separately tabulate A1, mdot, p2, and T2:

A1 (mm^2)	mdot (kg/s)	P2 (kPa)	T2 (K)
50	0.01161	61.96	319.73
100	0.02323	123.93	319.73
150	0.03484	185.89	319.73
200	0.04646	247.85	319.73
250	0.05807	309.82	319.73
300	0.06969	371.78	319.73

Note that T2 does not change; but, mdot and P2 vary with A2.

Now, plot these results in EXCEL:





==

Prob.5.22. Carbon dioxide enters an adiabatic nozzle steadily at 1 MPa, 500 C with a mass flow rate of 6000 kg/h and leaves at 100 kPa and 450 m/s. The inlet area of the nozzle is 40 cm^2. Determine (a) the inlet velocity, and (b) the exit temperature. [Ref. 1]:

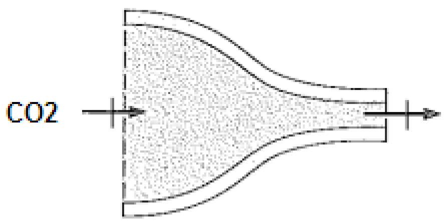
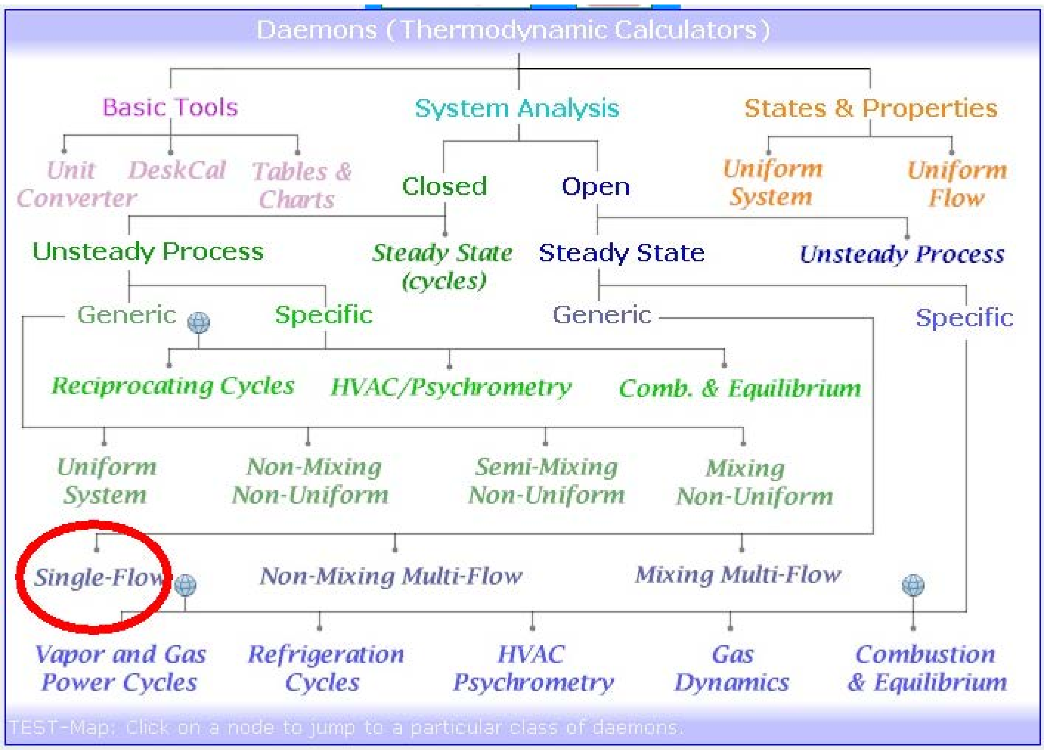


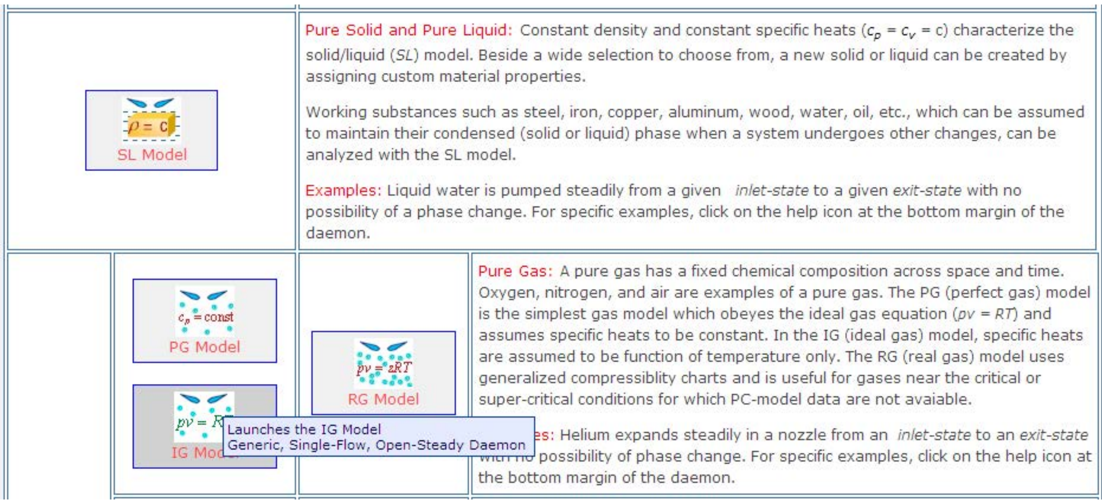
Fig.Prob.5.22

TEST Solution:

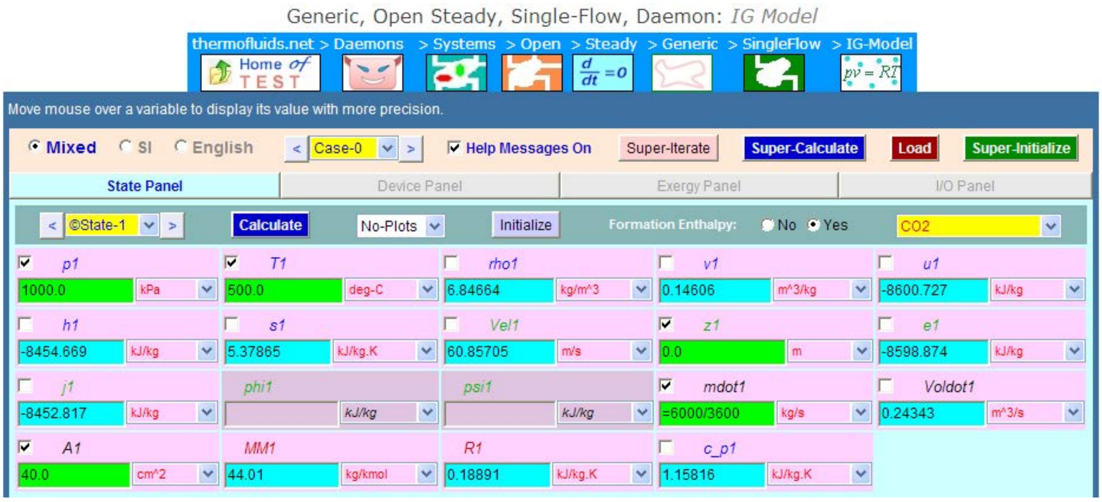
1. Go to Daemon tree, choose System Analysis – Open – Generic – Single Flow as shown below:



2. On clicking Single Flow, we are led to Material model:

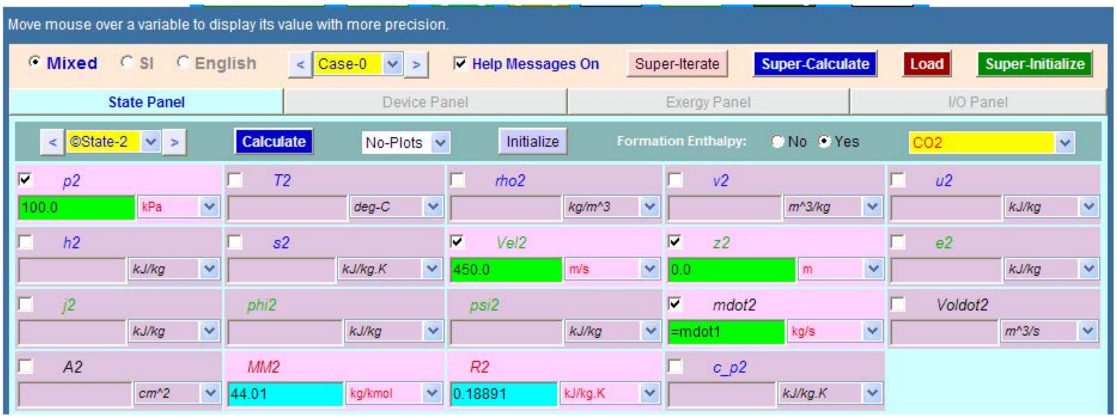


3. Choose Ideal Gas (IG) model and select CO2 as the working fluid. In IG Model, sp. heat is taken as a function of temp. Enter the data given for State 1, i.e. P1, T1, A1 and mdot1; click on Calculate (or, hit Enter). We get:

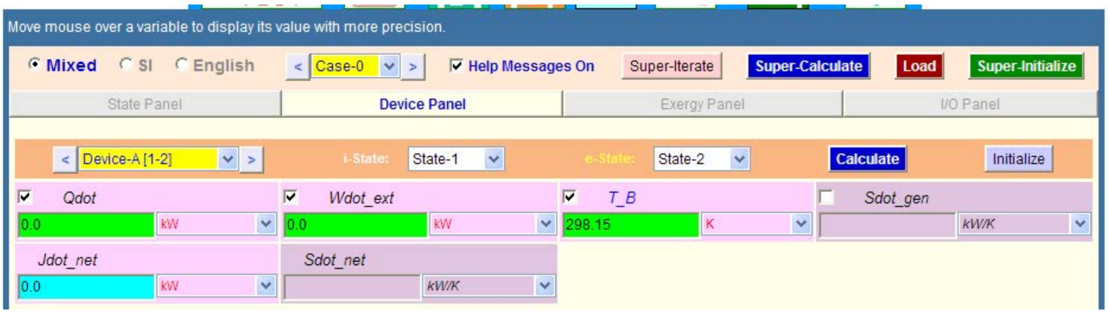


Note that Vel1 is calculated as Vel1 = 60.86 m/s…. Ans.

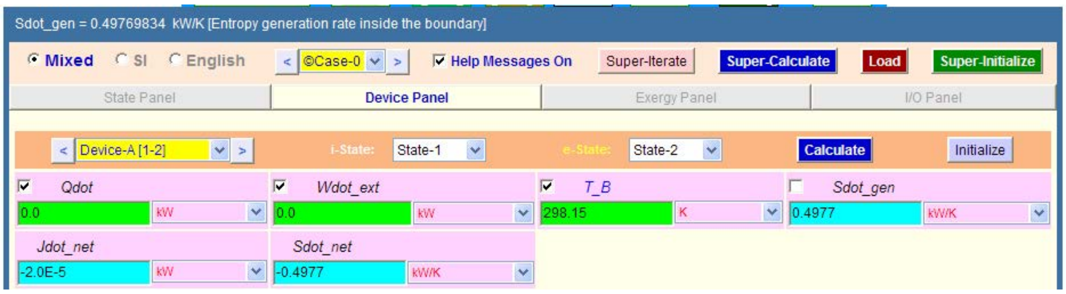
4. Enter data known for State 2, i.e. P2, Vel2 and mdot2 = mdot1. Hit Enter. We get:



5. Go to Device Panel. Enter State 1 for b-state, State 2 for f-state, and Qdot = 0, Wdot_ext = 0. Click on Calculate. We get:



6. Now, click on SuperCalculate. We get:



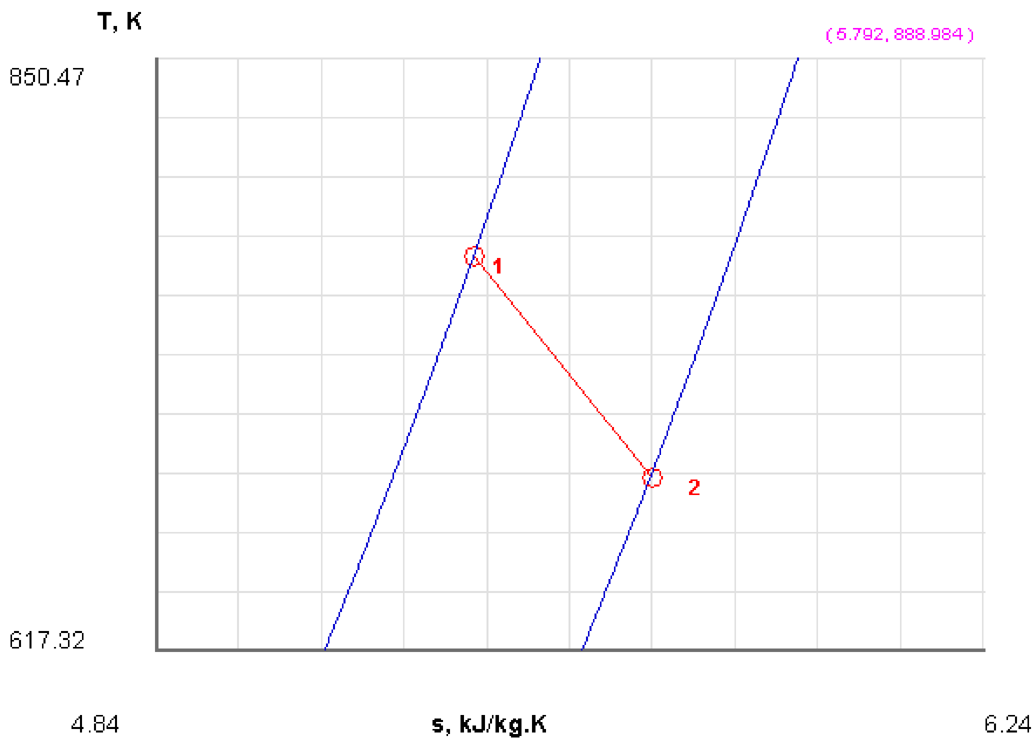
7. **Go back to States Panel: We get:**

State 1:

And, State 2:

Thus: Inlet velocity, Vel1 = 60.86 m/s, exit temp, T2 = 412.76 C … ans.

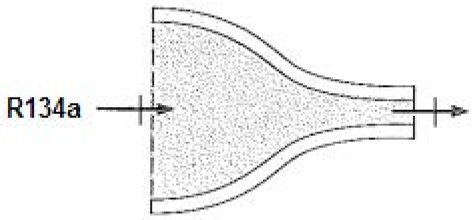
8. Plot the indicative T-s diagram:



9. The I/O panel gives **TEST code** and other details. Part of it is shown below:

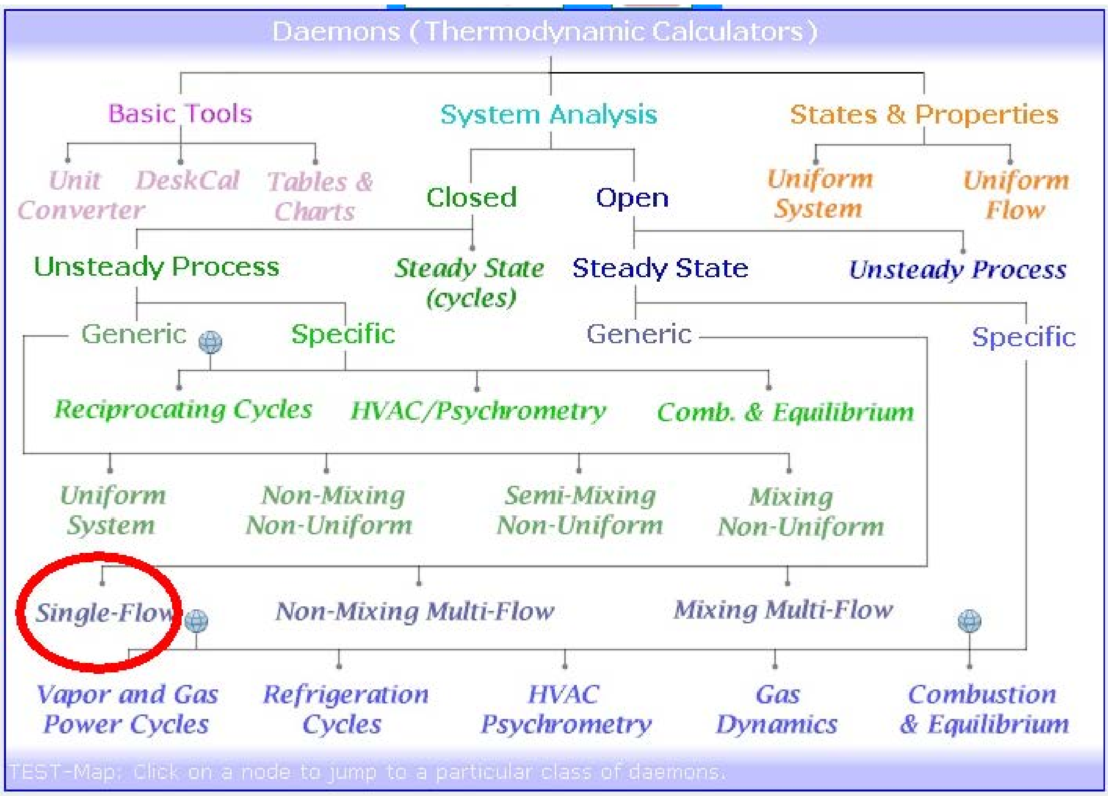
```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE :

#        Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.bb05

#--------------------Start of TEST-code -----------------------------------------------------------------------

 States  {
          State-1: CO2;
          Given: { p1= 1000.0 kPa; T1= 500.0 deg-C; z1= 0.0 m; mdot1= "6000/3600" kg/s; A1= 40.0
          cm^2; }
          State-2: CO2;
          Given: { p2= 100.0 kPa; Vel2= 450.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
          }

 Analysis {
          Device-A: i-State = State-1; e-State = State-2;
          Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; 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      1000.0        773.2    0.1461       -8600.73      -8454.67       5.379
#         2      100.0         685.9    1.2958       -8683.64      -8554.07       5.677

#--------Property spreadsheet ends--------------------------------------------------------------------

# Mass, Energy, and Entropy Analysis Results:
#         Device-A: i-State = State-1; e-State = State-2;
#                  Given: Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K;
#                  Calculated: Sdot_gen= 0.49769834 kW/K; Jdot_net= "-2.1262167E-5" kW; Sdot_net=
-0.49769834 kW/K;

==================================================================================
```

Prob.5.23. Refrigerant 134a at 700 kPa and 120 C enters an adiabatic nozzle with a velocity of 20 m/s and leaves at 400 kPa and 30 C. Determine (a) the exit velocity, and (b) ratio of inlet to exit area, A1/A2. [Ref. 1]

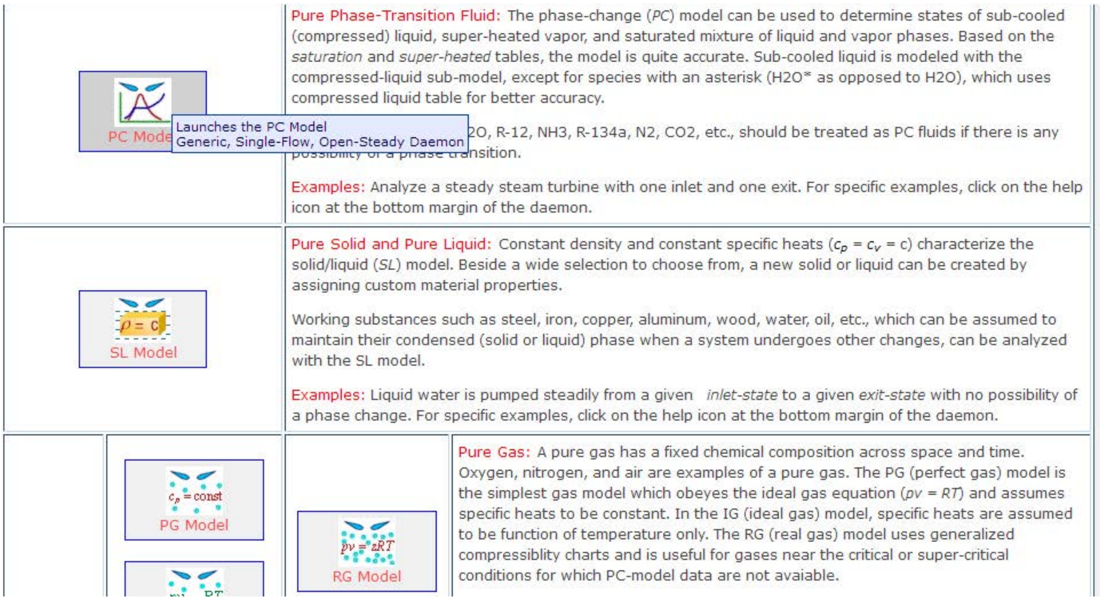


TEST Solution:

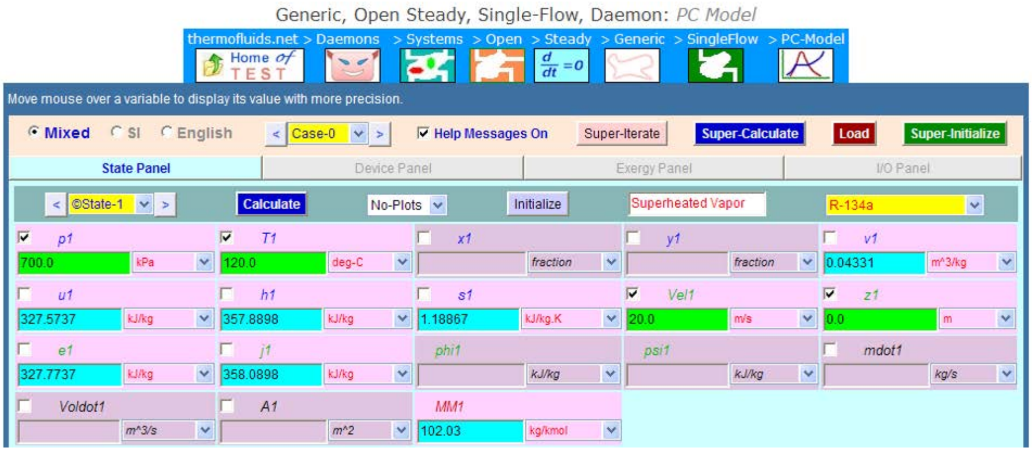
1. In the Daemons tree, select System Analysis – Open – Generic – Single Flow as shown below:



2. For Material model, choose Phase Change (PC) model, since R134a is the working fluid:

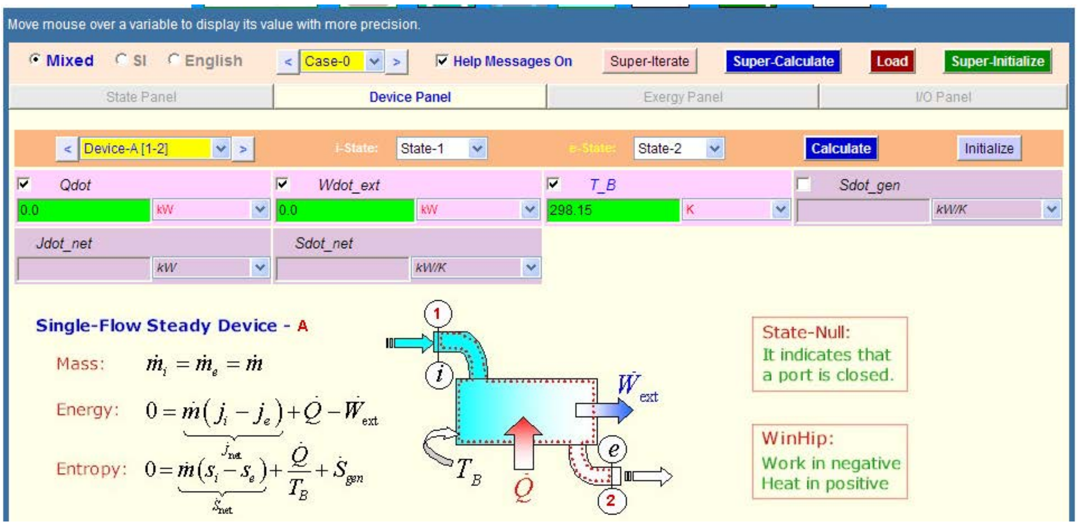


3. In the Window that appears, select the R134a as the substance and enter the data for State 1, i.e. P1. T1 and Vel1, and click Calculate (or, hit Enter). We get:



4. Similarly, fill in data for State 2, press Enter:

5. Go to Device Panel, enter Qdot = 0, Wdot_ext = 0; press Enter:



6. Click on SuperCalculate. Go to States Panel:

State 2:

Thus: Exit velocity = Vel2 = 409.53 m/s … Ans.

7. Use the I/O panel to calculate A1/A2:

We have: rho1 * A1 * Vel1 = rho2 * A2 * Vel2…. By mass balance

i.e. (A1/A2) = (1/v2)*Vel2/(Vel1 * (1/v1))

i.e. (A1/A2) = 15.578 …. Ans.

---

8. **Also, from I/O panel, copy the TEST code etc:**

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE

\# **Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.bb06**

#-------------------Start of TEST-code ---

```
States {
          State-1: R-134a;
          Given: { p1= 700.0 kPa; T1= 120.0 deg-C; Vel1= 20.0 m/s; z1= 0.0 m; }
          State-2: R-134a;
          Given: { p2= 400.0 kPa; T2= 30.0 deg-C; z2= 0.0 m; mdot2= "mdot1" kg/s; }
          }

Analysis {
          Device-A: i-State = State-1; e-State = State-2;
          Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K; }
          }
```

#---------------------End of TEST-code --

#--------Property spreadsheet starts:

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	700.0	393.2		0.0433	327.57	357.89	1.189
# 02	400.0	303.2		0.0569	251.46	274.23	0.99

 # Mass, Energy, and Entropy Analysis Results:

Device-A: i-State = State-1; e-State = State-2;

Given: Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K;

#******CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)', '= sqrt(4*A1/PI)', etc.) and press the Enter key)*********

#(A1/A2) = (1/v2)*Vel2/(Vel1 * (1/v1))

(1/v2)*Vel2/(Vel1 * (1/v1)) = 15.578052777777797

==

Prob.5.24. Air at 80 kPa, 27 C, and 220 m/s enters a Diffuser at a rate of 2.5 kg/s and leaves at 42 C. The exit area of the diffuser is 400 cm^2. The air is estimated to lose heat at a rate of 18 kJ/s during this process. Determine: (a) the exit velocity, and (b) the exit pressure. [Ref. 1]

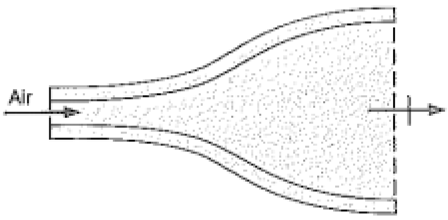
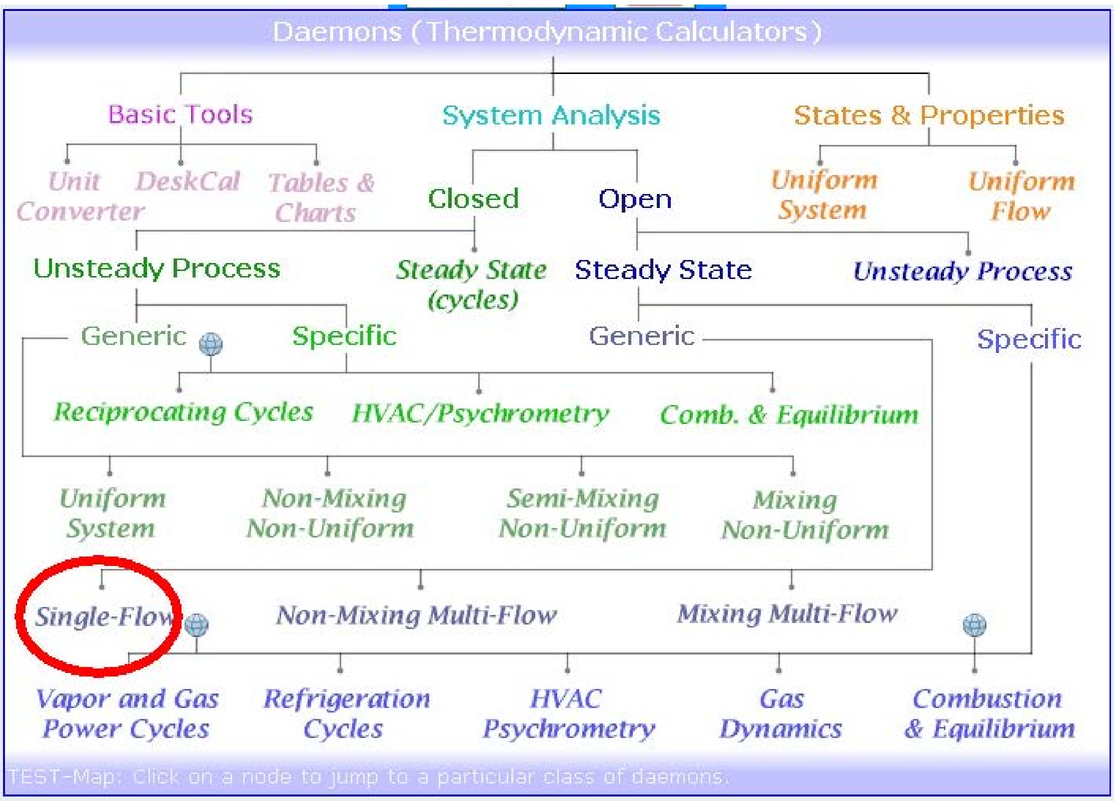


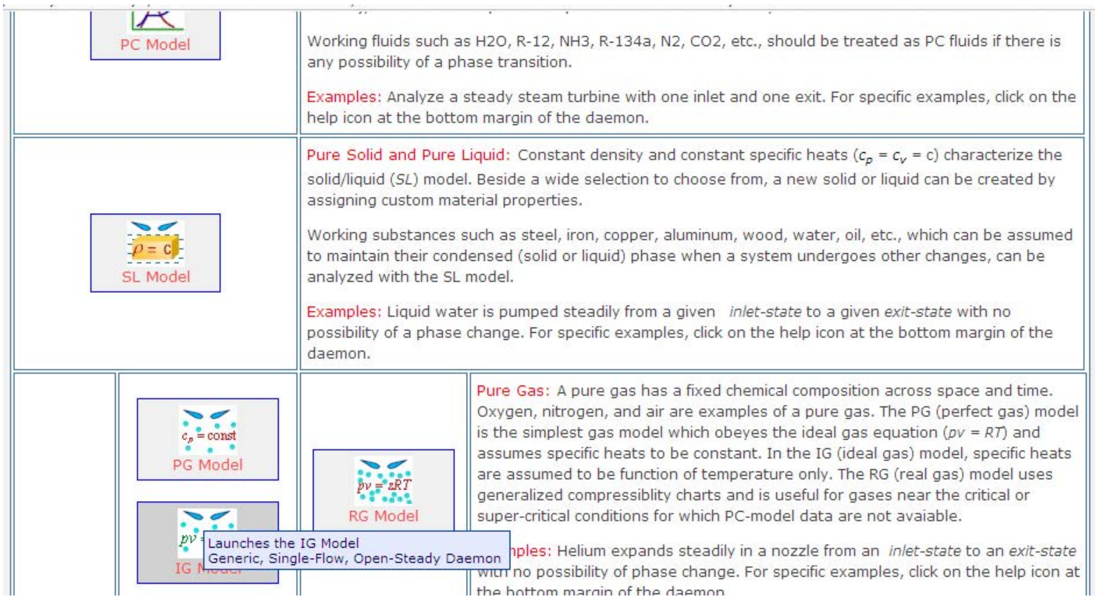
Fig.Prob.5.24

TEST Solution:

1. Go to Daemon tree, choose System Analysis – Open – Generic – Single Flow as shown below:



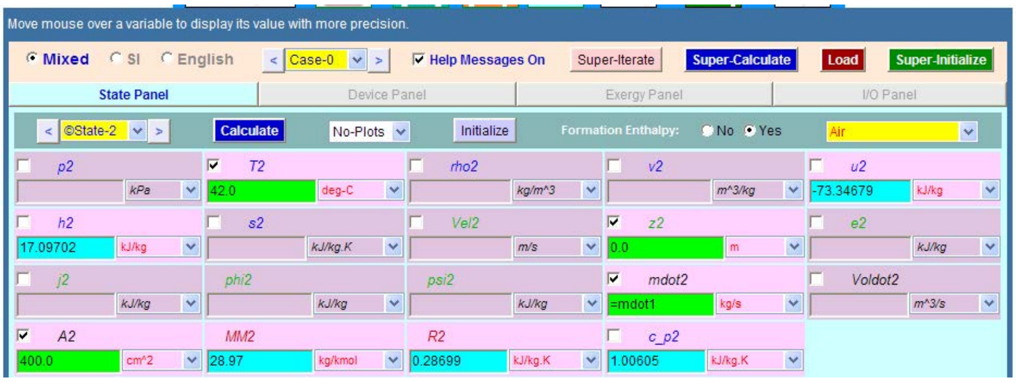
2. For Material model, choose Ideal Gas (IG) model, where cp is taken as a function of temp. (PG model also will give almost the same results):



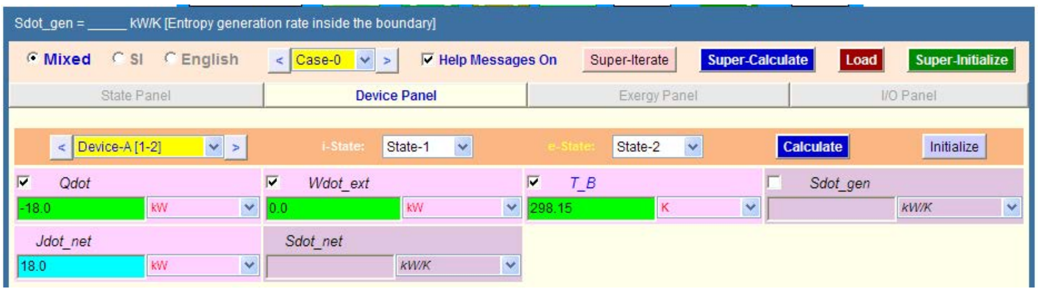
3. Choose Air as the working substance. Enter given data of P1, T1, Vel1, and mdot1 for State 1. Click Enter:

Note that in addition to properties such as u1, h1, s1, volume flow rate Voldot1 and inlet area A1 are also calculated.

4. Similarly, enter data for State 2, i.e. T2, A2 and mdot2, and click Enter:



5. Go to Devices Panel, enter Qdot = -18 kW (negative sign since heat is leaving the system), Wdot_ext = 0. And for i-State = State 1, b-state = State 2. Click Calculate (or, hit Enter):



6. **Now, click on SuperCalculate:**

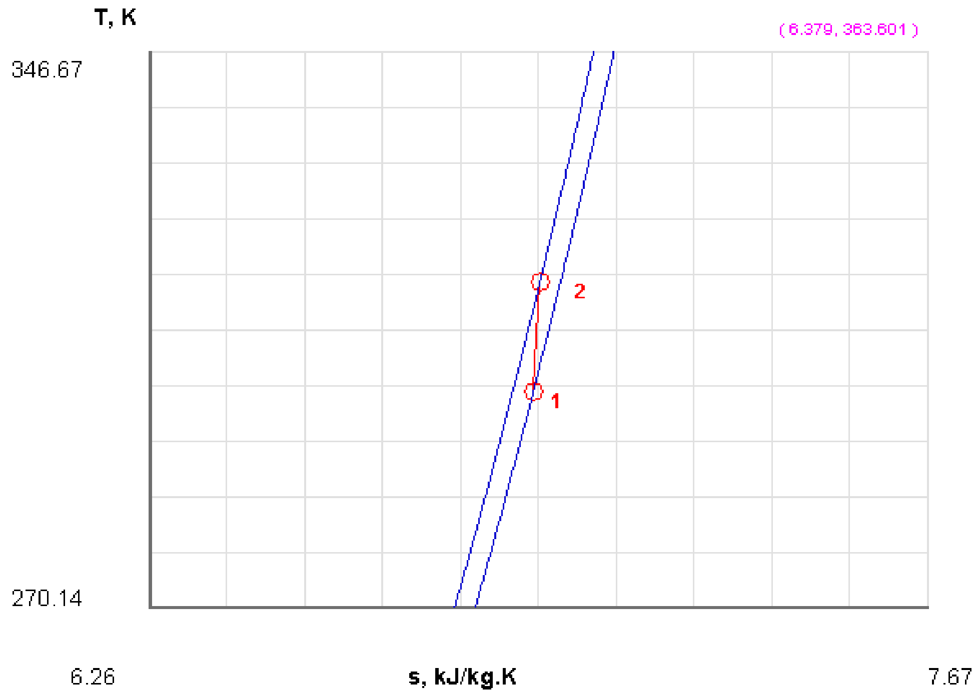
Go to State-1 and 2:

State 1:

State 2:

Thus: Vel2 = 62.07 m/s, p2 = 91.07 kPa…..Ans.

7. Draw the indicative T-s diagram:



8. **From the I/O panel, copy the TEST code etc:**

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

 # Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.bb05

#-------------------Start of TEST-code ---

```
States {
        State-1: Air;
        Given: { p1= 80.0 kPa; T1= 27.0 deg-C; Vel1= 220.0 m/s; z1= 0.0 m; mdot1= 2.5 kg/s; }
        State-2: Air;
        Given: { T2= 42.0 deg-C; z2= 0.0 m; mdot2= "mdot1" kg/s; A2= 400.0 cm^2; }
        }

Analysis {
        Device-A: i-State = State-1; e-State = State-2;
        Given: { Qdot= -18.0 kW; Wdot_ext= 0.0 kW; 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	300.2	1.0767	-84.12	2.02	6.957
#	2	91.07	315.2	0.9931	-73.35	17.1	6.969

==

Prob.5.25. Argon gas enters steadily an adiabatic turbine at 900 kPa and 450 C with a velocity of 80 m/s and leaves at 150 kPa with a velocity of 150 m/s. The inlet area of the turbine is 60 cm^2. If the power output of the turbine is 250 kW, determine the exit temp of argon. [Ref. 1]

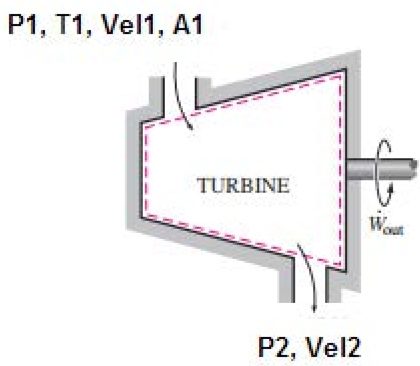
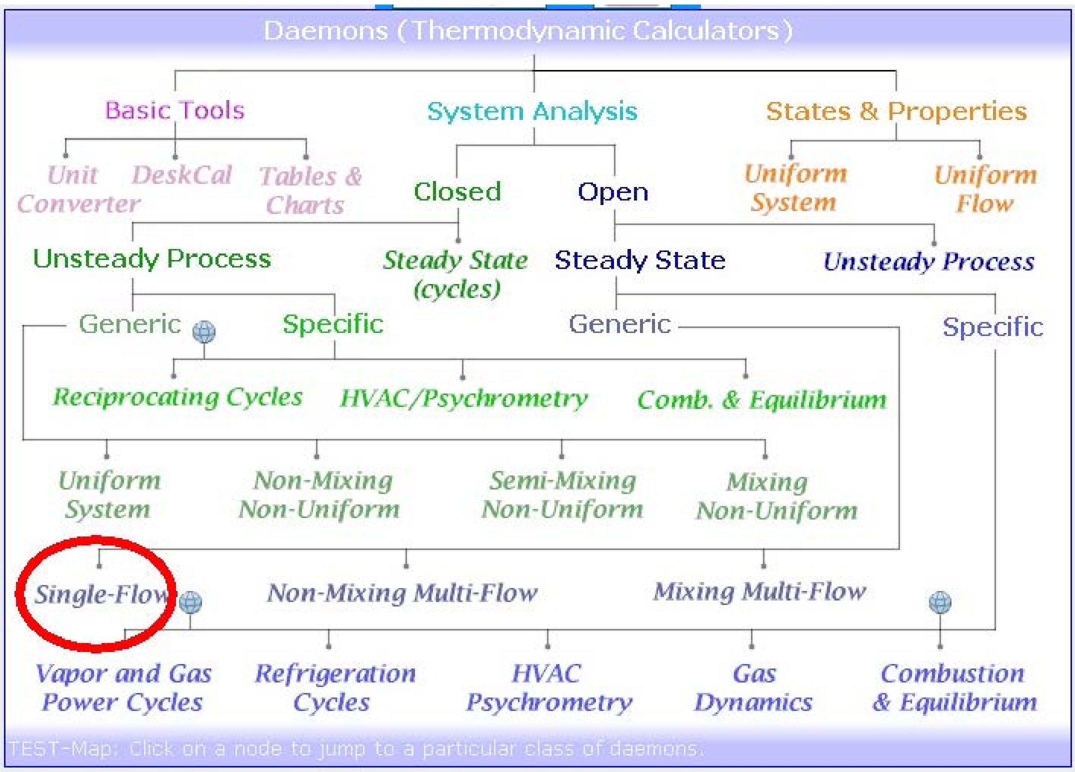


Fig.Prob.5.25

TEST Solution:

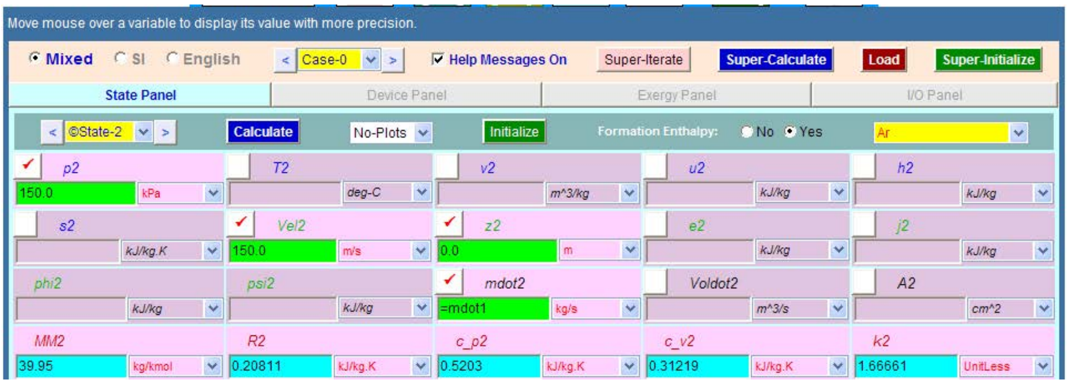
1. Go to System Analysis ---Single Flow daemon as shown below:



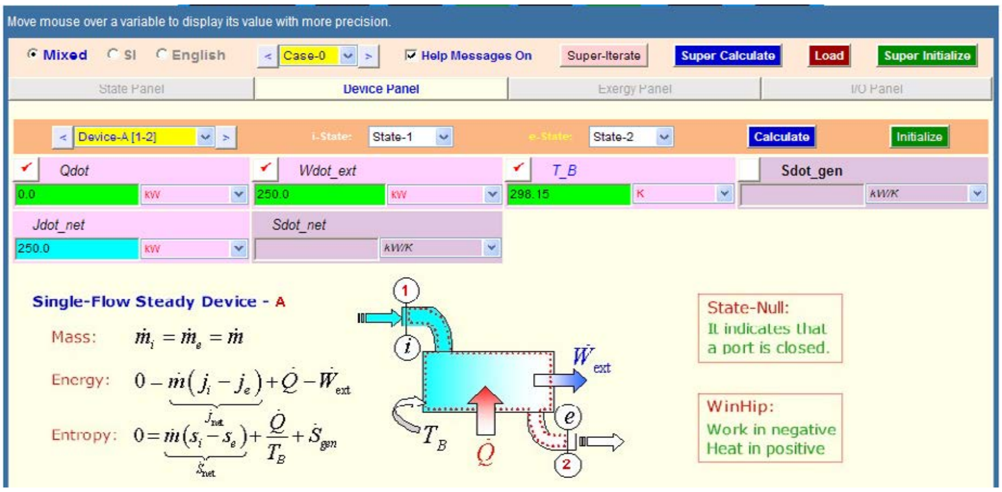
2. For Material Model, choose Perfect Gas (PG) model, and select Argon for the working substance. Enter the data, viz. P1, T1, Vel1 and A1 for State 1, and click on Calculate (or, hit Enter). We get:

Note that additional properties at State 1 and mass flow rate, mdot1 are calculated.

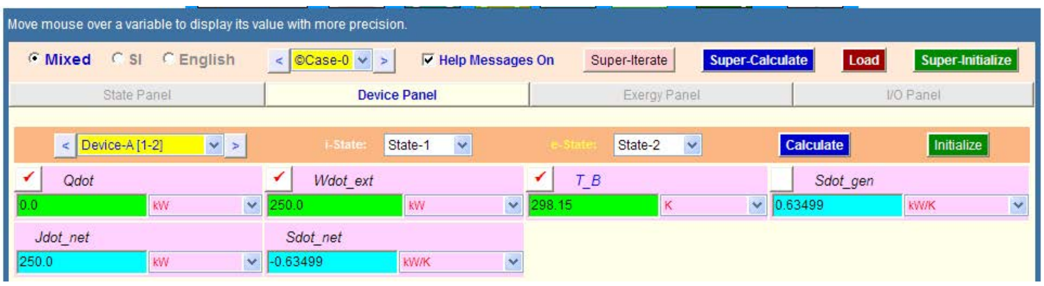
3. Enter given data for State 2, i.e. P2, Vel2 and modot2 = mdot1; hit Enter:



4. Go to Devices Panel. Enter Qdot = 0 and Wdot_ext = 250 kW. Enter State 1 and State 2 for b-state and f-state respectively. Click Calculate:



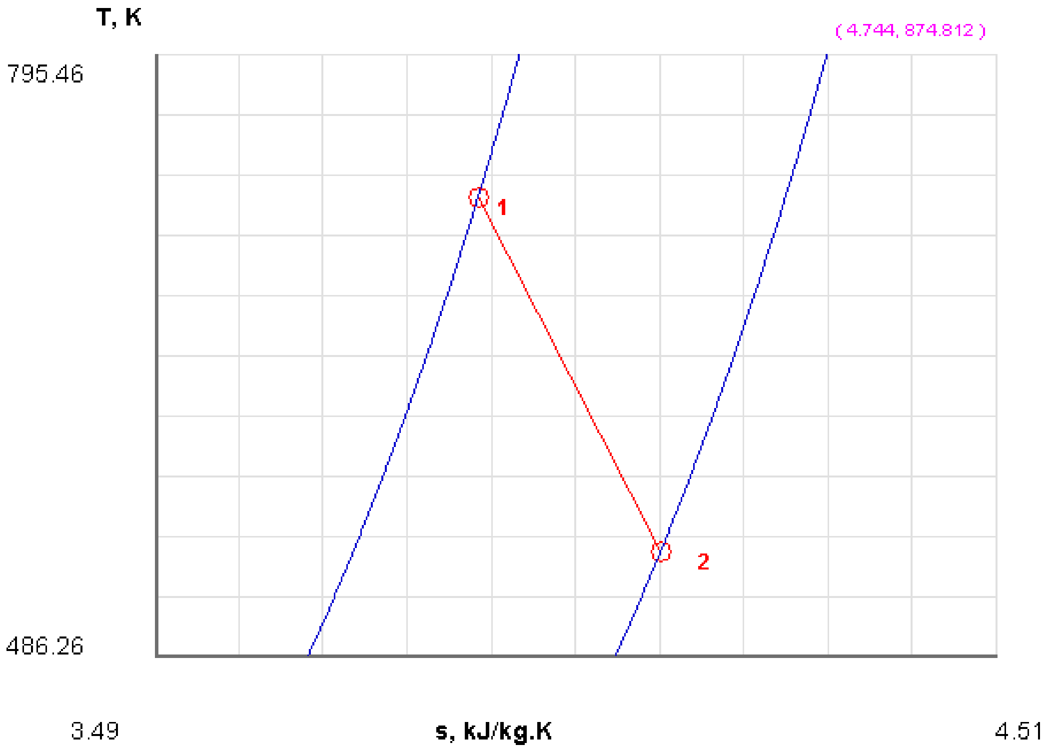
5. Click SuperCalculate:



6. Now, go back to States Panel, see State 2:

Observe that T2 = 267.14 deg. C…..Ans.

7. Indicative T-s diagram, obtained from Plots tab, is as follows:



8. The I/O panel gives the TEST code, and other details:

#~~~~~~~~~~~~~~~~~~~~~~**OUTPUT OF SUPER-CALCULATE :**

#--------------------Start of TEST-code ---

States {
State-1: Ar;
Given: { p1= 900.0 kPa; T1= 450.0 deg-C; Vel1= 80.0 m/s; z1= 0.0 m; A1= 60.0 cm^2; }
State-2: Ar;
Given: { p2= 150.0 kPa; Vel2= 150.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
}

Analysis {
Device-A: i-State = State-1; e-State = State-2;
Given: { Qdot= 0.0 kW; Wdot_ext= 250.0 kW; T_B= 298.15 K; }
}

#---------------------End of TEST-code ---

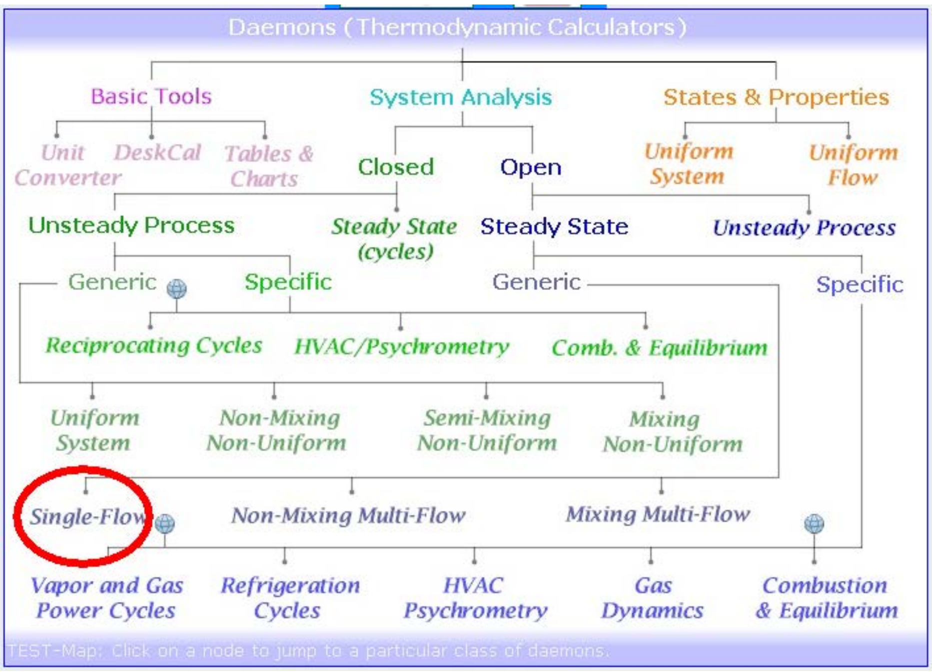
#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	900.0	723.2	0.1672	70.63	221.13	3.882
#	2	150.0	**540.3**	0.7496	13.55	125.99	4.104

===

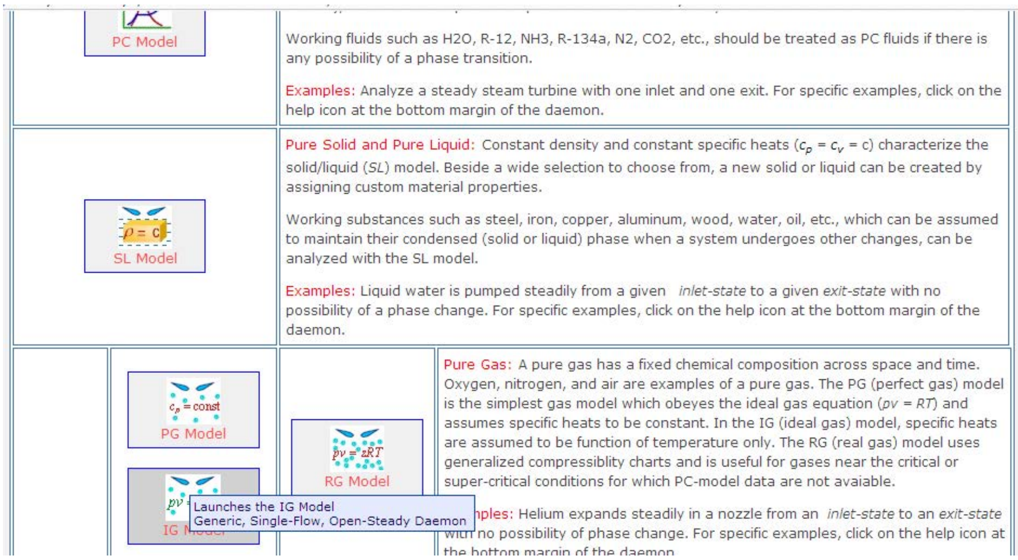
Prob.5.26. Air flows steadily through an adiabatic turbine, entering at 1 MPa, 500 C and 120 m/s and leaving at 150 kPa, 150 C and 250 m/s. The inlet area of turbine is 80 cm^2. Determine (a) the mass flow rate of air, and (b) the power output of turbine. [Ref. 1]

TEST Solution:

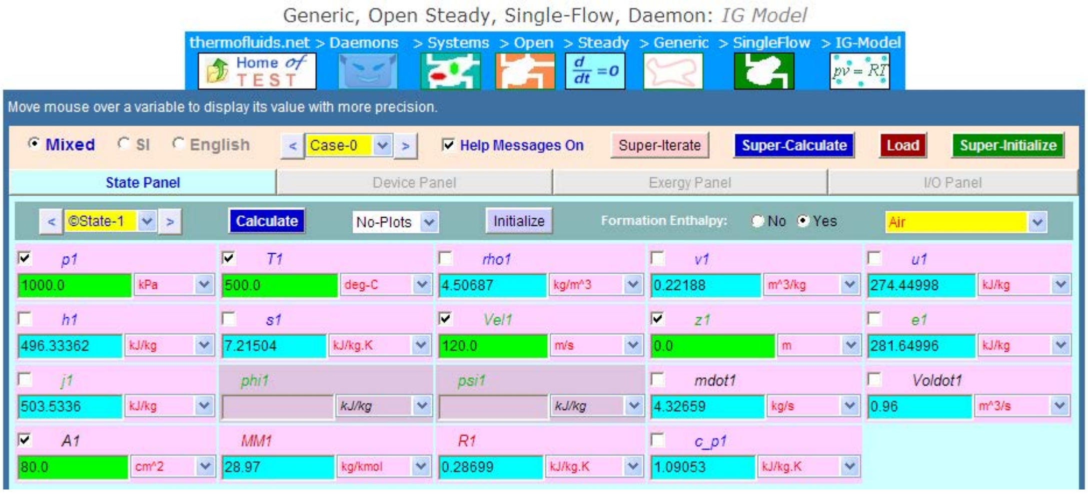
1. Choose System Analysis ….. Single Flow daemon as in previous cases:



2. For Material model, choose Ideal Gas (IG) model, where cp is a function of temp. (We can choose PG model also; results will not be much different):



3. Choose Air for material, enter data, i.e. P1, T1, A1, Vel1 for State 1; press Enter:

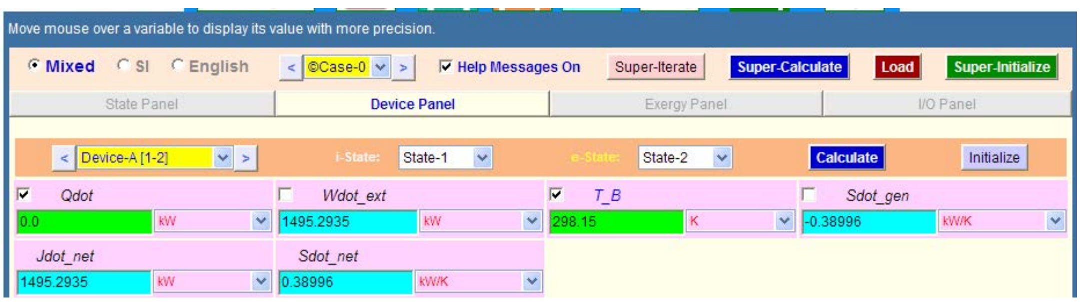


Note that mdot1 is calculated as 4.327 kg/s …. Ans.

4. Now, enter data for State 2, i.e. P2, T2, Vel2, and mdot2 = mdot1. Press Enter:

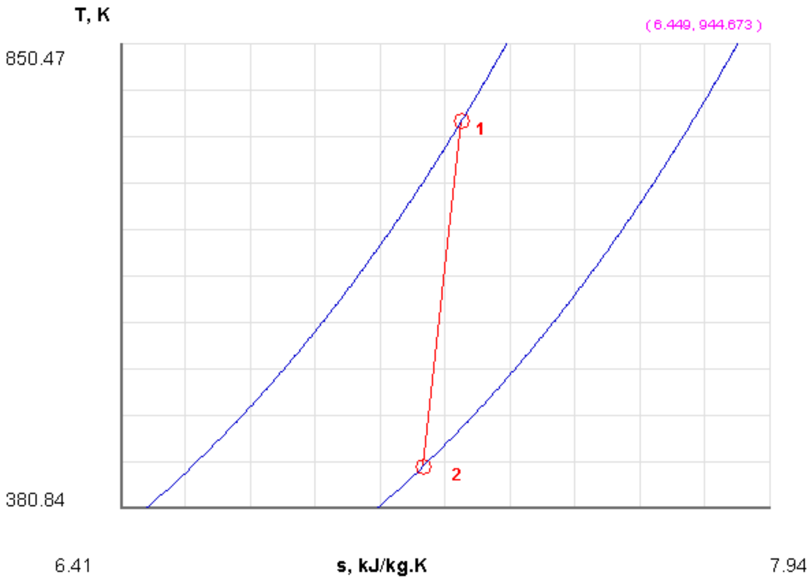
Note that A2 is calculated as 140.11 cm^2.

5. Now, go to Device Panel. Enter State 1 and State 2 for b-state and f-state respectively. Also Qdot = 0. Press Calculate:



Note that work output is calculated as: Wdot_ext = 1495.3 kW …. Ans.

6. Indicative T-s diagram is as follows:



7. Clicking on SuperCalculate gives TEST code etc. in the I/O panel:

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.bb05

#--------------------Start of TEST-code ---

```
States  {
        State-1: Air;
        Given: { p1= 1000.0 kPa; T1= 500.0 deg-C; Vel1= 120.0 m/s; z1= 0.0 m; A1= 80.0 cm^2; }
        State-2: Air;
        Given: { p2= 150.0 kPa; T2= 150.0 deg-C; Vel2= 250.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
        }

Analysis {
        Device-A: i-State = State-1; e-State = State-2;
        Given: { Qdot= 0.0 kW; 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       1000.0    773.2   0.2219       274.45      496.33      7.215
#    2       150.0     423.2   0.8096       5.24        126.68      7.125
#
#--------Property spreadsheet ends------------------------------------------------------------------
#
```

 # Mass, Energy, and Entropy Analysis Results:

```
#    Device-A: i-State = State-1; e-State = State-2;
#         Given: Qdot= 0.0 kW; T_B= 298.15 K;
#         Calculated: Wdot_ext= 1495.2935 kW; Sdot_gen= -0.3899593 kW/K; Jdot_net= 1495.2935 kW; Sdot_net= 0.3899593 kW/K;
```

Wdot_ext= 1495.2935 kW;

===

Prob.5.27. Steam flows steadily through an adiabatic turbine. The inlet conditions of steam are: 6 MPa, 400 C and 80 m/s and the exit conditions are: 40 kPa, 92% quality and 50 m/s. The mass flow rate of steam is 20 kg/s. Determine: (a) the change in K.E. (b) the power output, and (c) the turbine inlet area.

(b) Plot the Power output and exit temp against the exit pressure as exit pressure varies from 10 to 200 kPa. [Ref. 1]

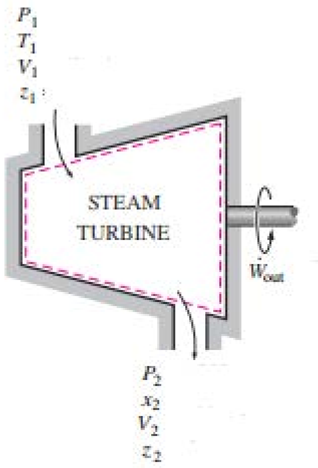
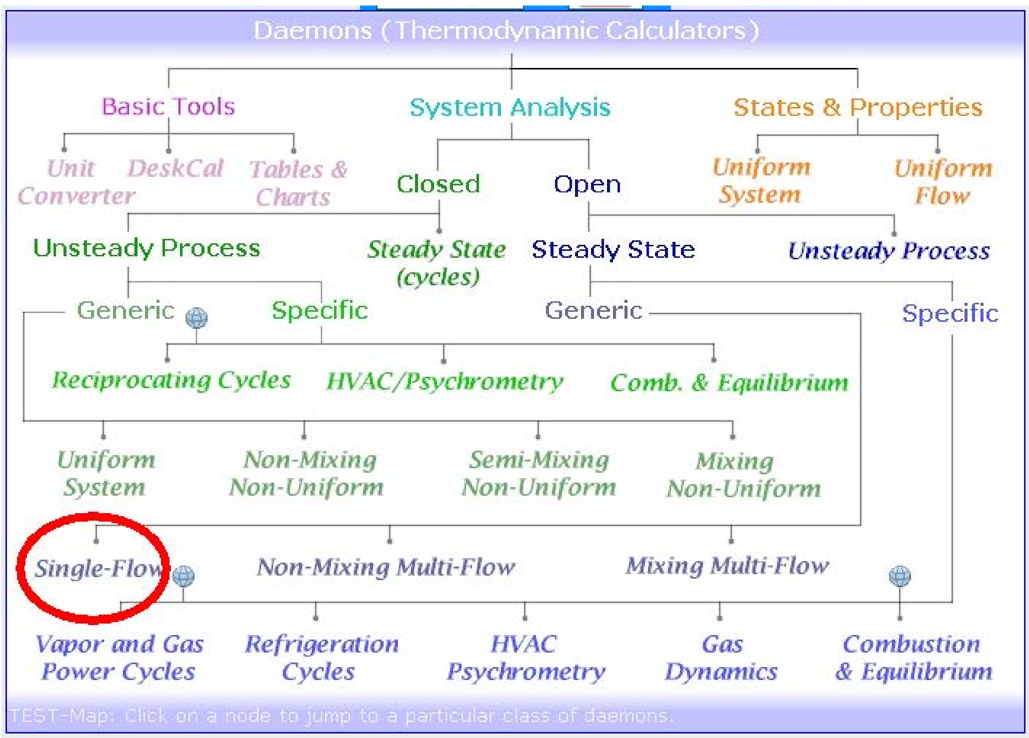


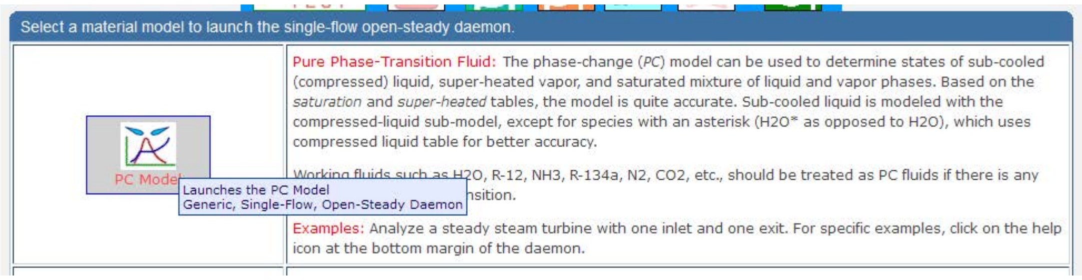
Fig.Prob.5.27

TEST Solution:

1. Go to Daemons tree and choose System Analysis…..Single Flow as shown below:

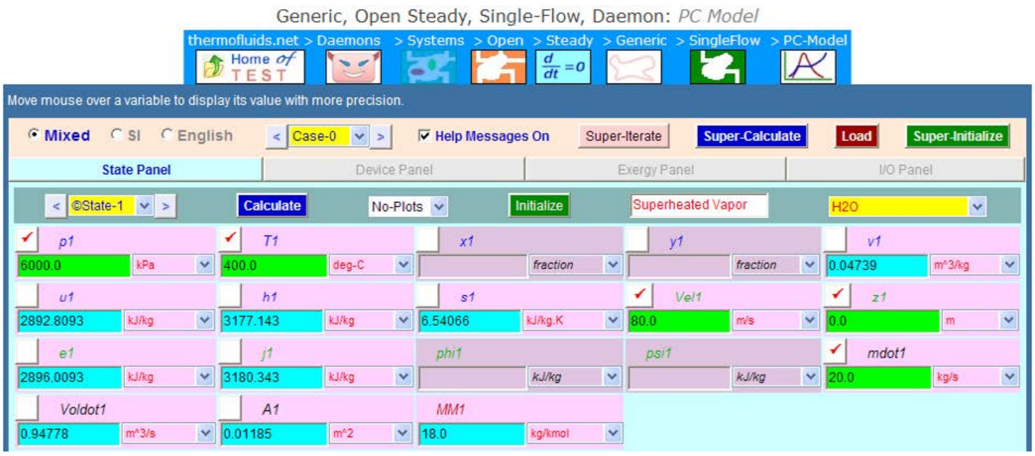


2. Choose PC model for Material Model, since Steam is the working substance:



3. Choose H2O for working substance, enter data for State 1, i.e. enter P1, T1, Vel1 and mdot1, and press Enter (or, Calculate):

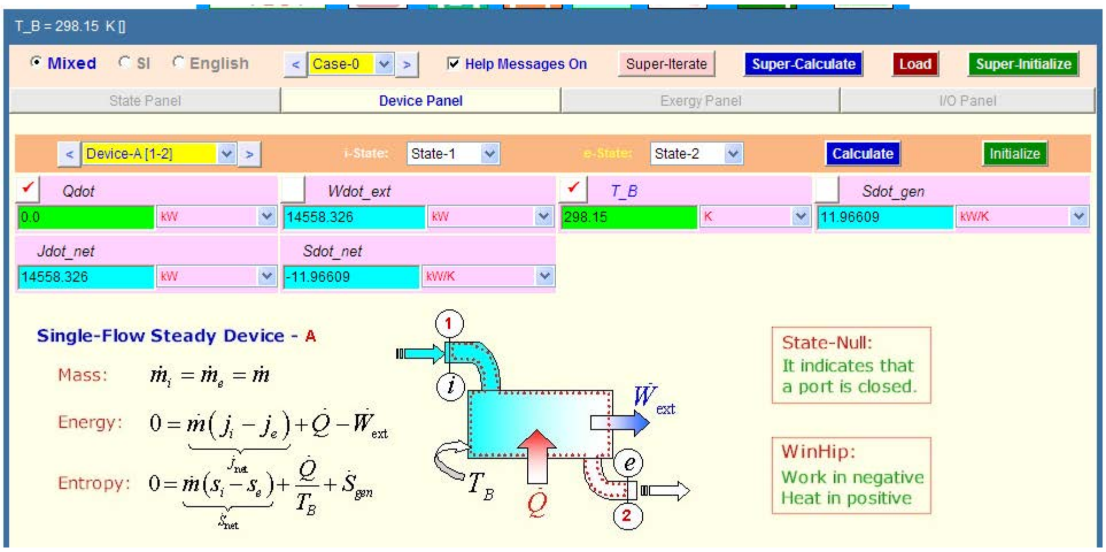
We get:



Note that Turbine inlet area A1 is calculated as: A1 = 0.01185 m^2 … Ans.

4. Enter data for State 2, i.e. P2, x2, Vel2 and mdot1 = mdot2. Press Enter (or, Calculate). We get:

5. Go to Device Panel. Enter State 1 and State 2 for b-state and f-state respectively. Also enter Qdot = 0, and press Calculate. We get:



Note that Wdot_ext is calculated as: 14558.3 kW = 14.558 MW = Work output of turbine… Ans.

Also: Vel2 = 50 m/s, Vel1 = 80 m/s, and therefore, change in K.E. = (Vel2^2 – Vel1^2) / 2.

i.e.

$$\frac{Vel2^2 - Vel1^2}{2} = \frac{50^2 - 80^2}{2} = -1.95 \times 10^3 \quad \textbf{J/kg .... Ans.}$$

6. Click on SuperCalculate and go to I/O panel to get TEST code and other details:

```
#~~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

#          Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.ca08

#--------------------Start of TEST-code -----------------------------------------------------------------------

States    {
            State-1: H2O;
            Given: { p1= 6000.0 kPa; T1= 400.0 deg-C; Vel1= 80.0 m/s; z1= 0.0 m; mdot1= 20.0 kg/s; }
            State-2: H2O;
            Given: { p2= 40.0 kPa; x2= 0.92 fraction; Vel2= 50.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
            }

 Analysis {
            Device-A: i-State = State-1; e-State = State-2;
            Given: { Qdot= 0.0 kW; T_B= 298.15 K; }
            }

#----------------------End of TEST-code -----------------------------------------------------------------------

#--------Property spreadsheet starts:

# State  p(kPa)       T(K)    x      v(m3/kg)     u(kJ/kg)     h(kJ/kg)     s(kJ/kg)
# 01      6000.0       673.2          0.0474       2892.81      3177.14       6.541
# 02      40.0         349.0   0.9    3.682        2304.23      2451.18       7.139

# Mass, Energy, and Entropy Analysis Results:
#          Device-A: i-State = State-1; e-State = State-2;
#                    Given: Qdot= 0.0 kW; T_B= 298.15 K;
#                    Calculated: Wdot_ext= 14558.326 kW; Sdot_gen= 11.966095 kW/K; Jdot_net=
14558.326 kW; Sdot_net= -11.966095 kW/K;

---------------------------------------------------------------------------------------------------------------
```

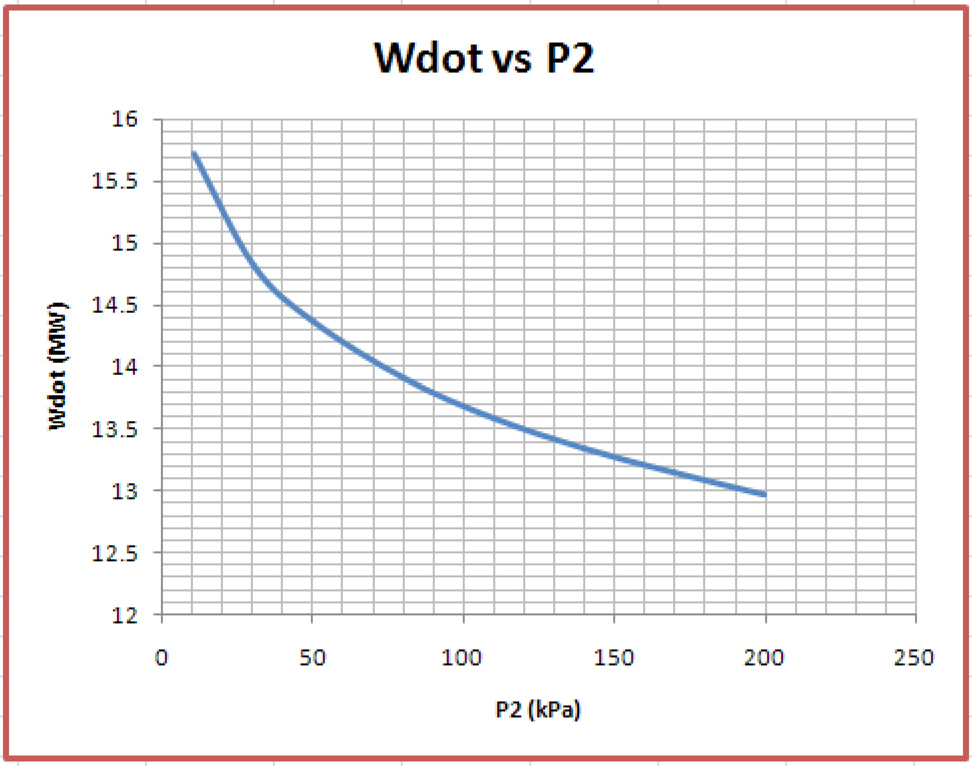
(b) Plot Power output and T2 as P2 varies from 10 to 200 kPa:

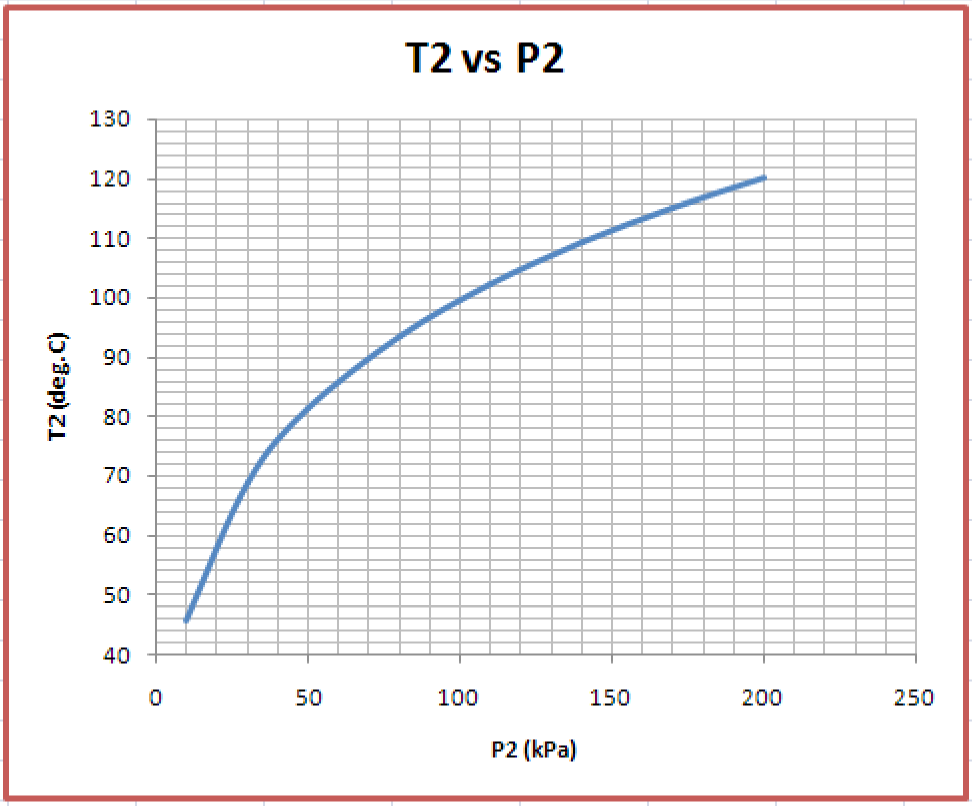
The procedure is quite simple:

Go to State 2, enter the desired value of P2 and press Enter. Then, press SuperCalculate. Read the value of T2 and Wdot_ext and tabulate the values. Results are shown below:

P2(kPa)	Wdot_ext (MW)	T2 (deg.C)
10	15.717	45.81
30	14.815	69.08
50	14.354	81.31
80	13.907	93.48
110	13.59	102.3
140	13.345	109.29
170	13.143	115.17
200	12.972	120.23

Plot the above results in EXCEL:




T2 vs P2
T2 (deg.C)
130
120
110
100
90
80
70
60
50
40
0
50
100
150
200
250
P2 (kPa)

==

Prob.5.28. Air enters the compressor of a gas turbine plant at 100 kPa, 25 C with a low velocity and exits at 1 MPa and 347 C with a velocity of 90 m/s. The compressor is cooled at a rate of 1500 kJ/min and the power input to the compressor is 250 kW. Determine the mass flow rate of air through the compressor. [Ref. 1]

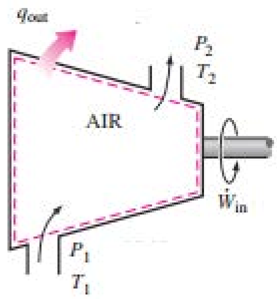
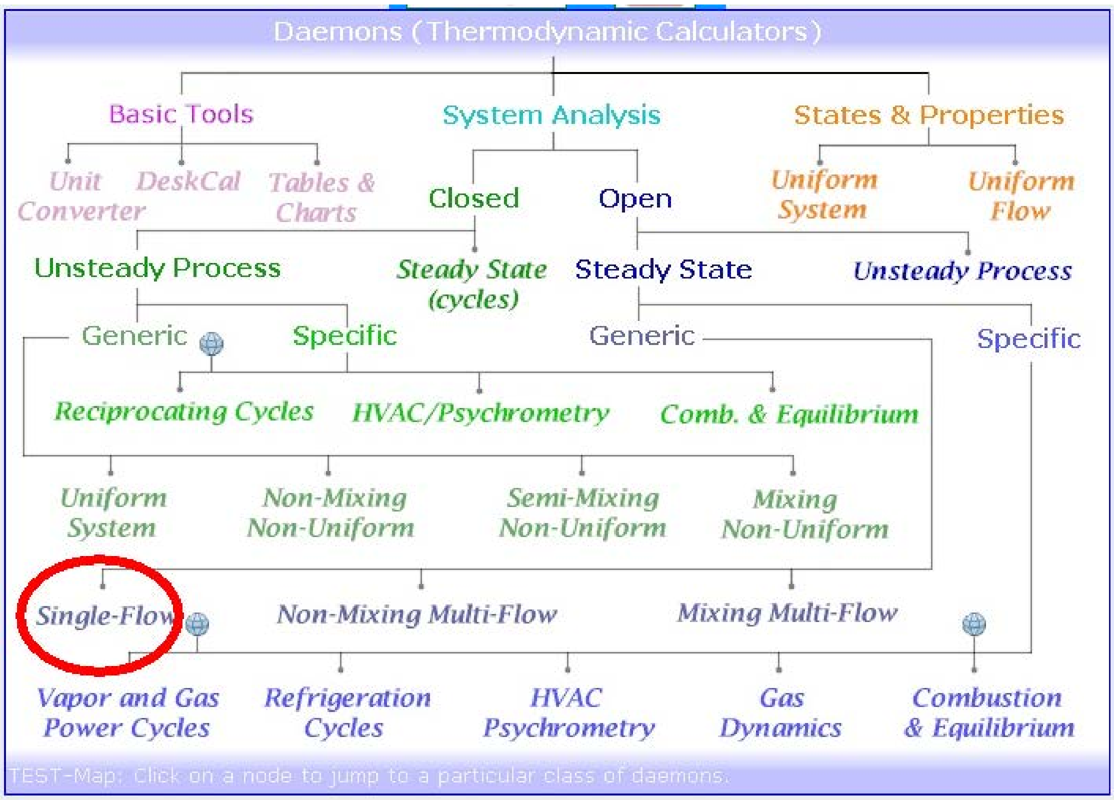


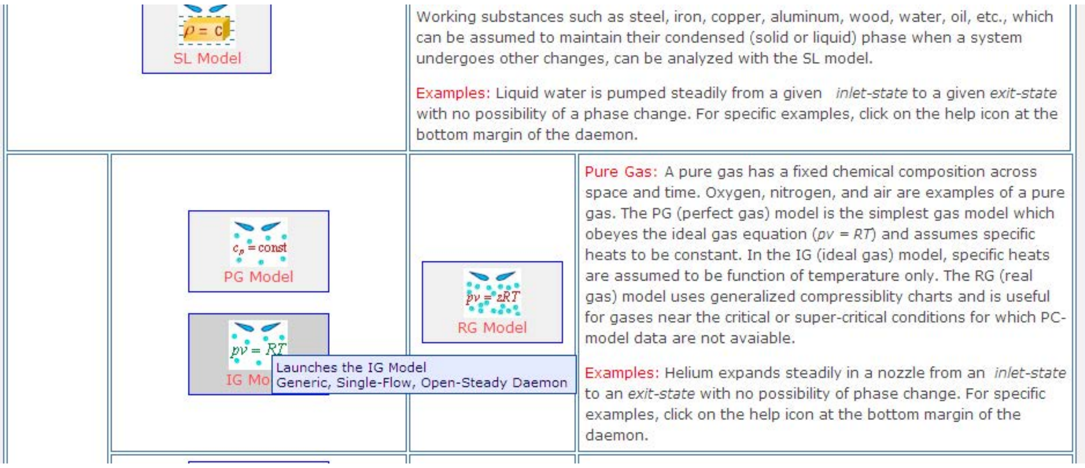
Fig.Prob.5.28

TEST Solution:

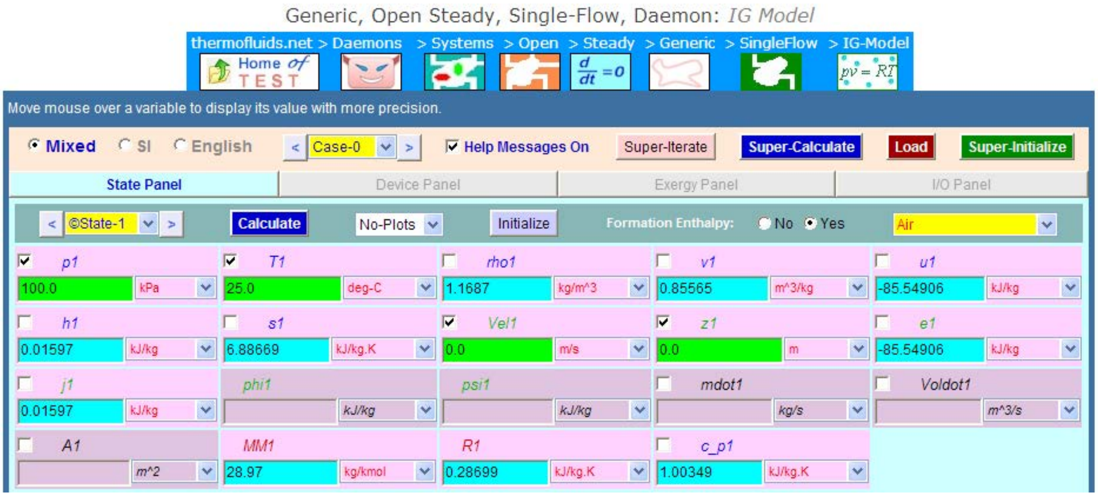
1. Go to System Analysis ….. Single Flow daemon, as in the case of previous problems:



2. Choose the Ideal Gas (IG) model, since we are going to use Air as working substance:

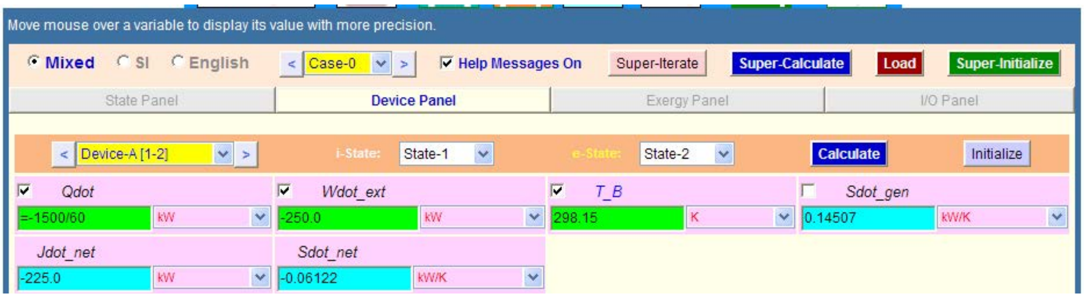


3. Choose Air for working substance, enter data i.e. P1, T1, Vel1 for State 1 and press Enter:



4. Enter P2, T2 and Vel2 and mdot2 = mdot1 for State 2; press Enter:

5. Go to Device Panel, enter b-state and f-state, and also Qdot = 0, Wdot_ext = -250 (negative sign since work is input to compressor), press Enter:



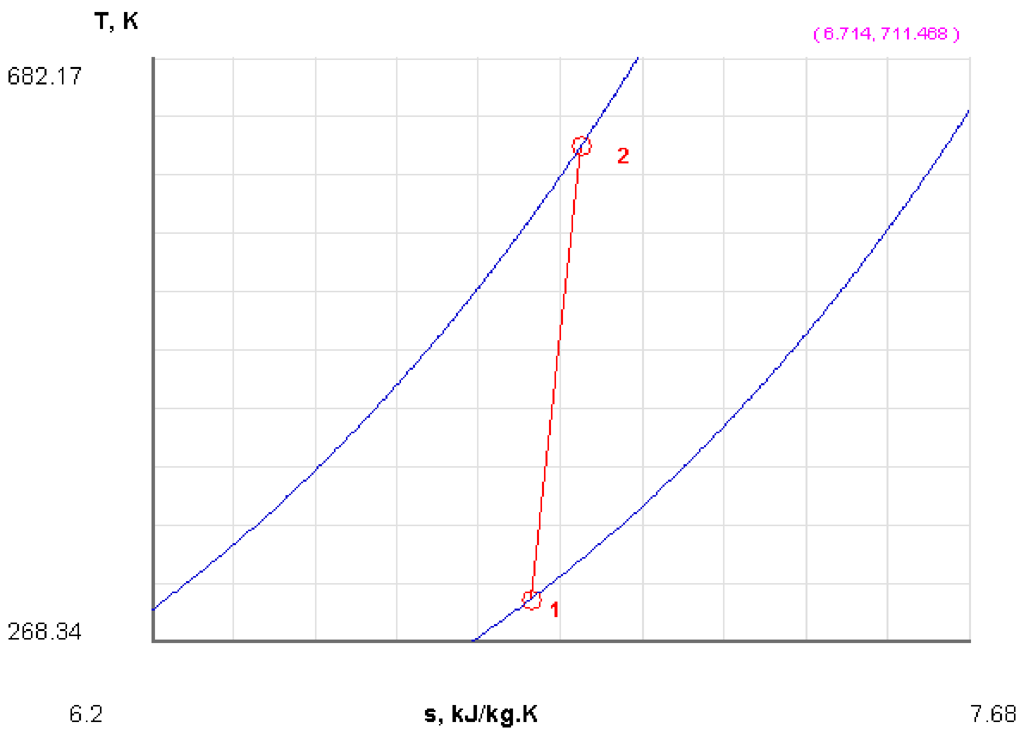
6. Now, click on SuperCalculate to up-date all calculations:

Go to State Panel, State 1:

And, State 2:

Thus: mdot1 = 0.6699 kg/s …. Ans.

7. Indicative T-s diagram is as follows:



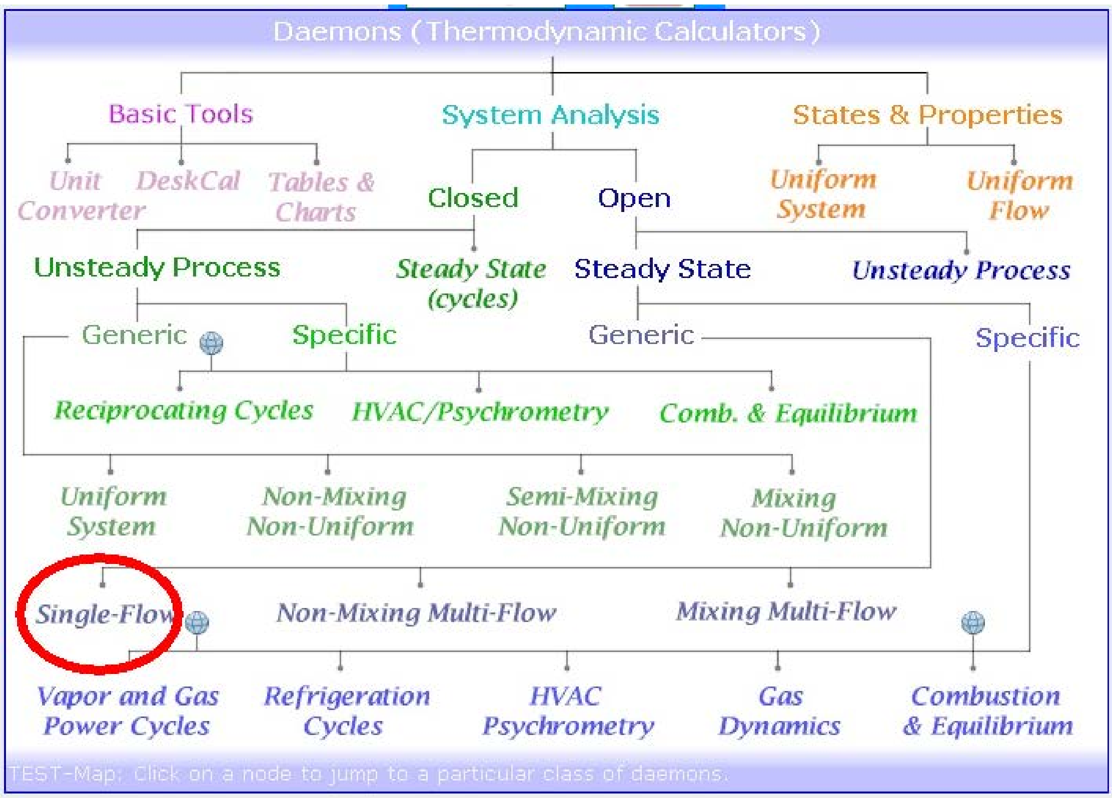
8. From the I/O panel, get the TEST code etc.:

```
#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

#

#	Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.bb05

#-------------------Start of TEST-code -----------------------------------------------------------------------

 States {
		State-1: Air;
		Given: { p1= 100.0 kPa; T1= 25.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; }
		State-2: Air;
		Given: { p2= 1000.0 kPa; T2= 347.0 deg-C; Vel2= 90.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
		}

Analysis {
		Device-A: i-State = State-1; e-State = State-2;
		Given: { Qdot= "-1500/60" kW; Wdot_ext= -250.0 kW; 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	298.2	0.8557	-85.55	0.02	6.887
#	2	1000.0	620.2	0.178	153.86	331.83	6.978
#
#--------Property spreadsheet ends-----------------------------------------------------------------------

# Mass, Energy, and Entropy Analysis Results:

#	Device-A: i-State = State-1; e-State = State-2;
#		Given: Qdot= "-1500/60" kW; Wdot_ext= -250.0 kW; T_B= 298.15 K;
#		Calculated: Sdot_gen= 0.14507116 kW/K; Jdot_net= -225.0 kW; Sdot_net= -0.061220754
kW/K;

=================================================================================
```

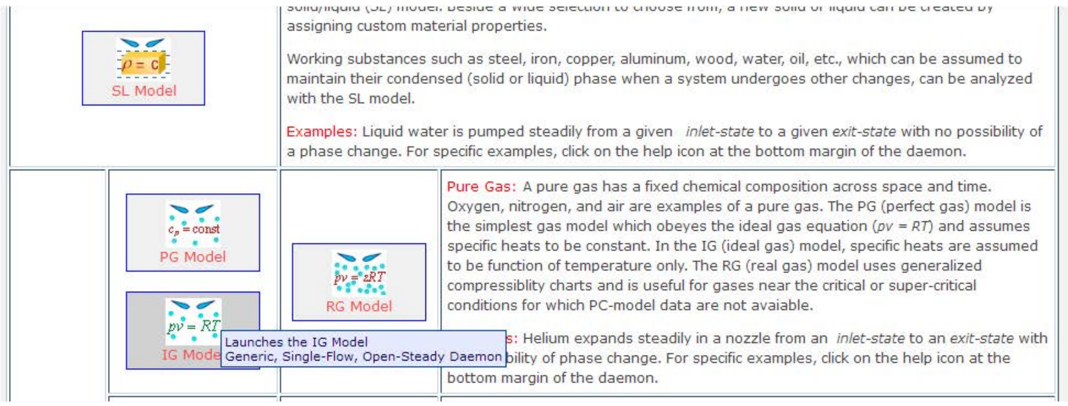
Prob.5.29. A compressor operating at steady state takes in 45 kg/min of methane gas (CH4) at 1 bar, 25 C, 15 m/s, and compresses it with negligible heat transfer to 2 bar, 50 m/s at exit. The power input to the compressor is 110 kW. Using the ideal gas model, determine the temp of the gas at the exit. [Ref. 5]

TEST Solution:

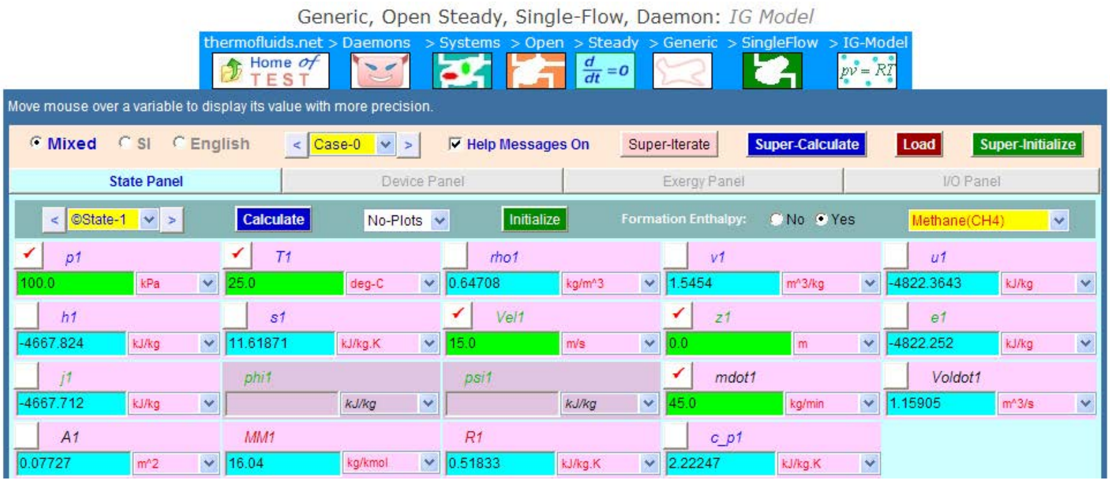
1. Go to System Analysis … Single Flow daemon as shown:



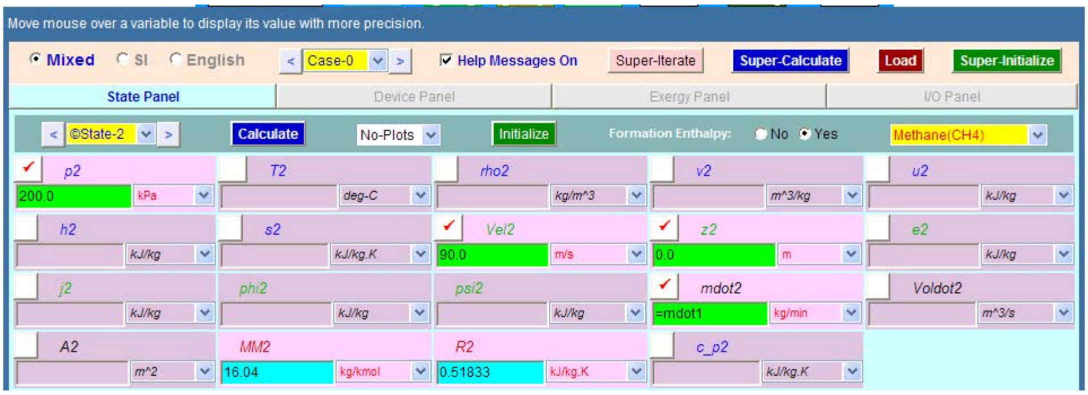
2. Select IG model for Material model:



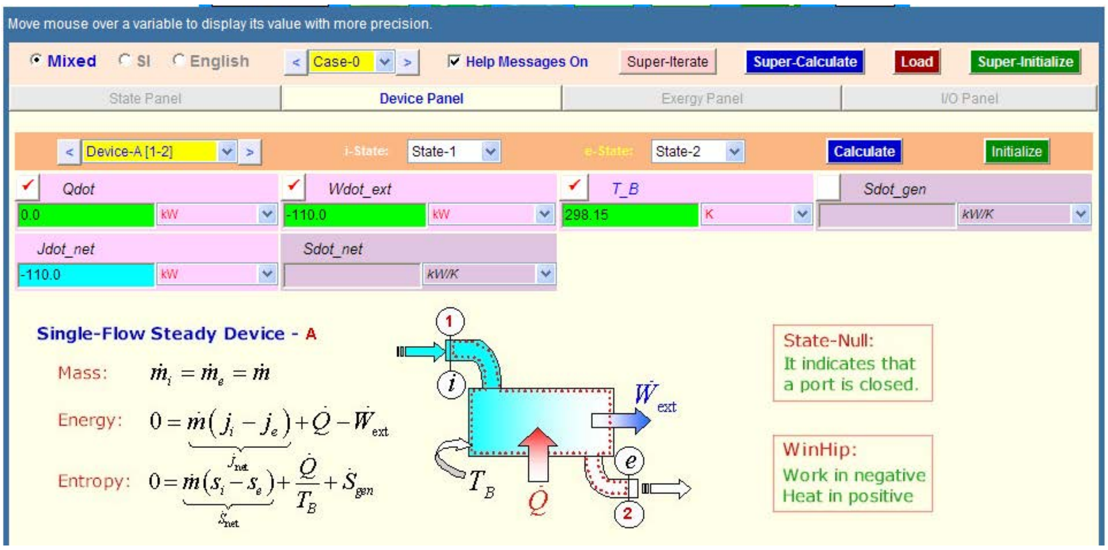
3. Choose Methane (CH4) for working substance, enter data for State 1 (i.e. P1, T1, Vel1 and mdot1), press Enter:



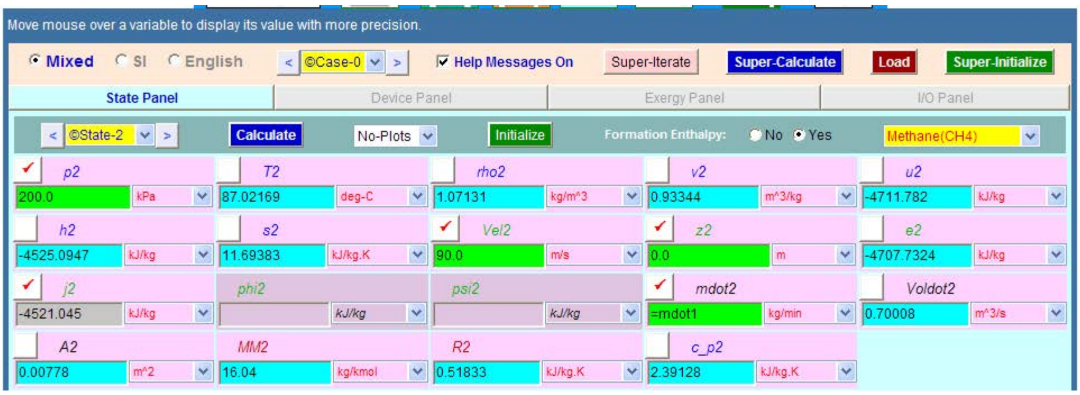
4. Enter data for State 2, (i.e. P2, Vel2 and mdot2), press Enter:



5. Go to Device Panel, enter for b-state and f-state, and also Qdot = 0, Wdot_ext = -110 kW (negative sign since work is done on the system in compressor). Press Enter:

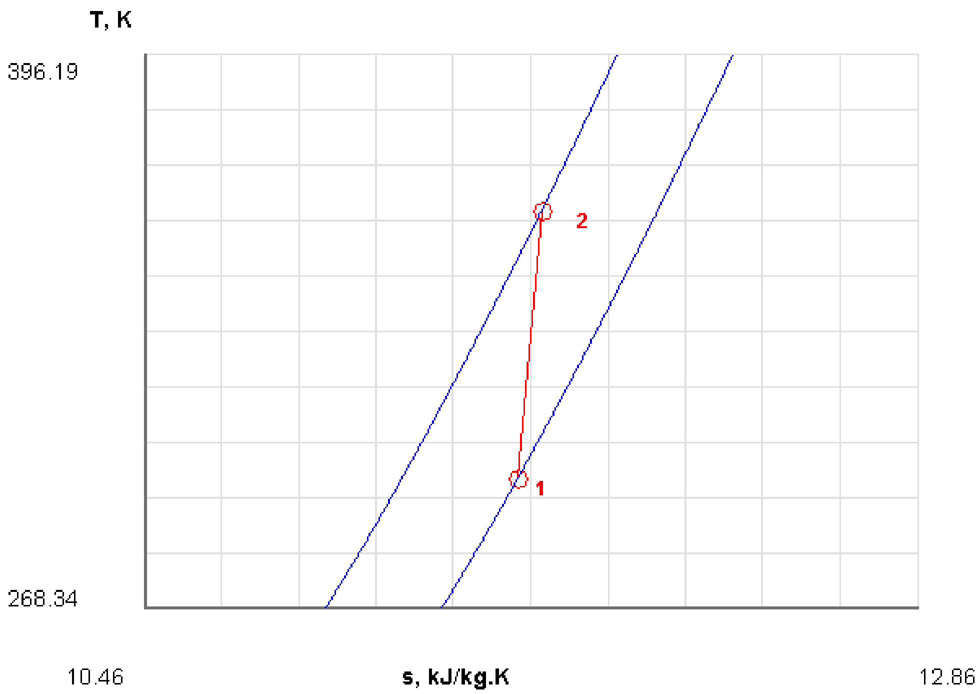


6. Now click on SuperCalculate. Go to State Panel, State 2. We get:



Thus: T2 = 87.02 deg. C … Ans.

7. Indicative T-s diagram is as follows:



8. **I/O panel gives TEST code etc:**

#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE :

 #   Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.ca08

#-------------------Start of TEST-code ---

```
States   {
            State-1: Methane(CH4);
            Given: { p1= 100.0 kPa; T1= 25.0 deg-C; Vel1= 15.0 m/s; z1= 0.0 m; mdot1= 45.0 kg/min; }
            State-2: Methane(CH4);
            Given: { p2= 200.0 kPa; Vel2= 90.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/min; }
            }

Analysis {
            Device-A: i-State = State-1; e-State = State-2;
            Given: { Qdot= 0.0 kW; Wdot_ext= -110.0 kW; 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	298.2	1.5454	-4822.36	-4667.82	11.619
#	2	200.0	360.2	0.9334	-4711.78	-4525.09	11.694

#--------Property spreadsheet ends---

 # Mass, Energy, and Entropy Analysis Results:

Device-A: i-State = State-1; e-State = State-2;

Given: Qdot= 0.0 kW; Wdot_ext= -110.0 kW; T_B= 298.15 K;

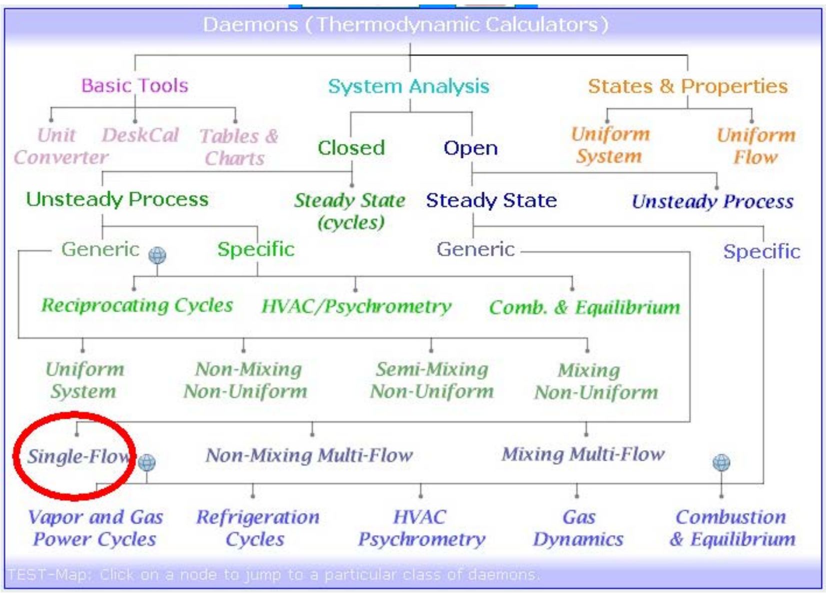
Calculated: Sdot_gen= 0.056342352 kW/K; Jdot_net= -110.00039 kW; Sdot_net= -0.056342352 kW/K;

==

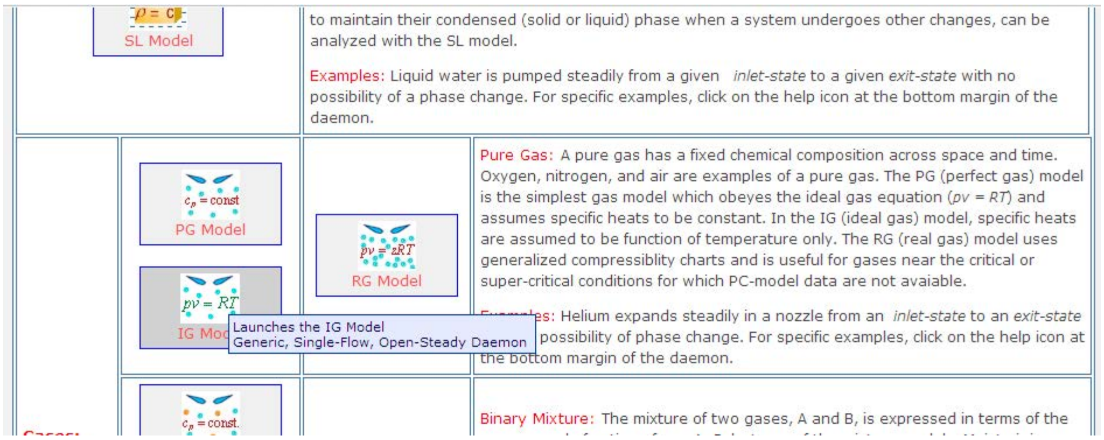
Prob.5.30. Helium is to be compressed from 120 kPa, 310 K to 700 kPa, 430 K. A heat loss of 20 kJ/kg occurs during compression. Neglecting K.E. changes, determine the power input required for a mass flow rate of 90 kg/min. [Ref. 1]

TEST Solution:

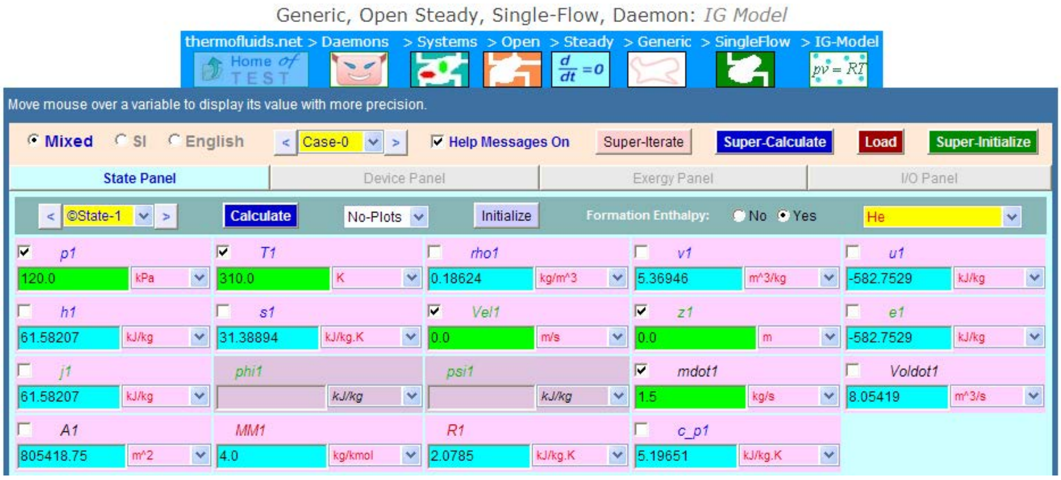
1. Go to System Analysis … Single Flow daemon as shown:



2. Choose the Ideal Gas (IG) model for Material model, since Helium is the working substance:

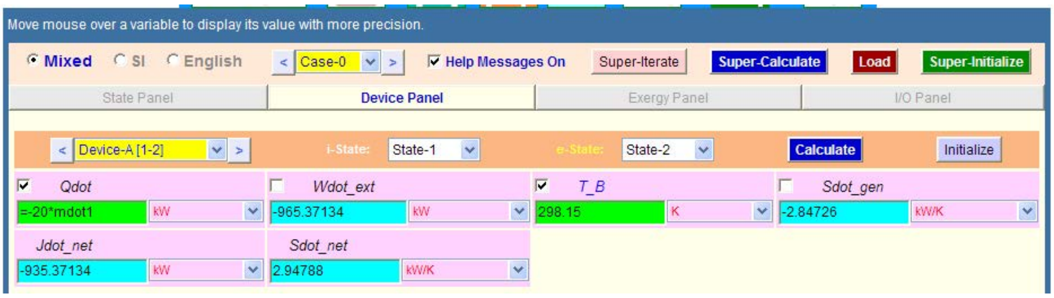


3. Choose He for working substance, enter data for State 1 (i.e. P1, T1, mdot1 = 1.5 kg/s), press Enter. We get:



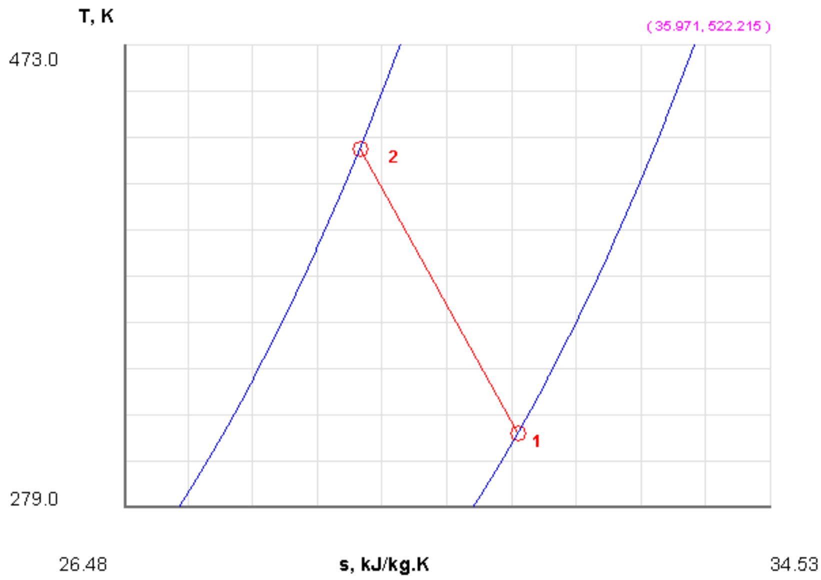
4. Enter data for State 2, i.e. P2, T2, mdot2 = mdot1. Press Enter. We get:

5. Go to Device Panel. Enter Qdot = – 20 * mdot1 and click on Calculate, and SuperCalculate. We get:



Thus: W = – 965.37 kW … Ans. (negative sign, since work is done on the system in compressor)

6. Indicative T-s diagram from Plots tab:



7. I/O panel gives the TEST code and other details:

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

 # Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.bb05

#--------------------Start of TEST-code ---

States {
State-1: He;
Given: { p1= 120.0 kPa; T1= 310.0 K; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.5 kg/s; }
State-2: He;
Given: { p2= 700.0 kPa; T2= 430.0 K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= “mdot1” kg/s; }
}

Analysis {
Device-A: i-State = State-1; e-State = State-2;
Given: { Qdot= “-20*mdot1” kW; 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	120.0	310.0	5.3695	-582.75	61.58	31.389
#	2	700.0	430.0	1.2768	-208.59	685.16	29.424

#--------Property spreadsheet ends--

 # Mass, Energy, and Entropy Analysis Results:

Device-A: i-State = State-1; e-State = State-2;
Given: Qdot= “-20*mdot1” kW; T_B= 298.15 K;
Calculated: **Wdot_ext= -965.37134 kW;** Sdot_gen= -2.8472614 kW/K; Jdot_net= -935.37134 kW; Sdot_net= 2.9478817 kW/K;

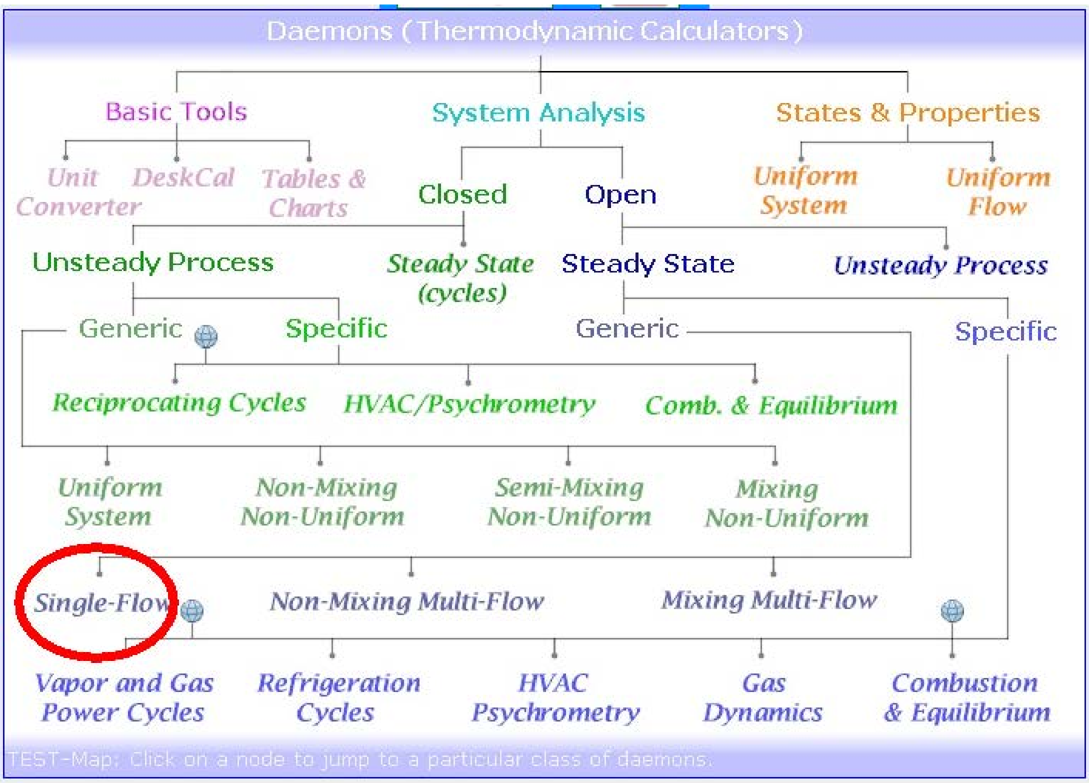
==

Prob.5.31. Refrigerant-134a is throttled from the sat. liquid state at 800 kPa to a temp of -20 C. Determine the pressure of the refrigerant at the final state. [Ref. 1]

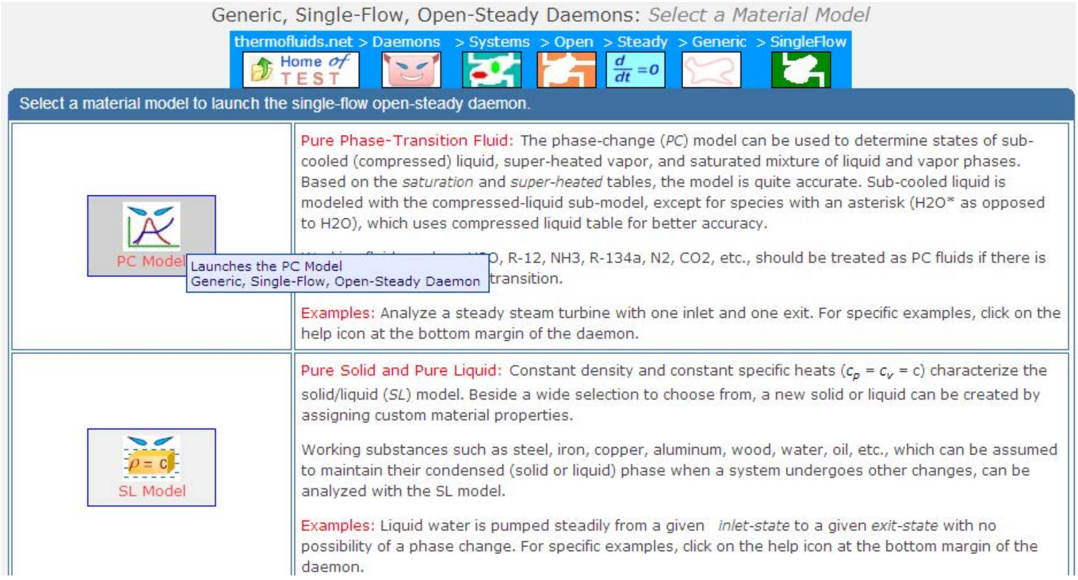
TEST Solution:

Note that this is a problem on throttling. The daemon to be used is still the same as used earlier, viz. Systems>Open>SteadyState>Generic>SingleFlow>IG-Model:

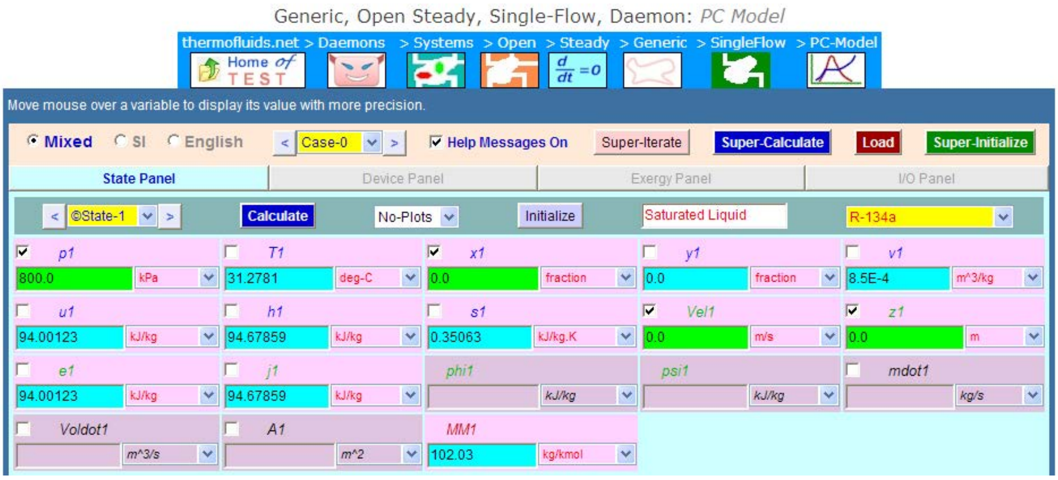
1. Go to System … Single Flow daemon:



2. Choose PC model for material model since R134a is the working substance:



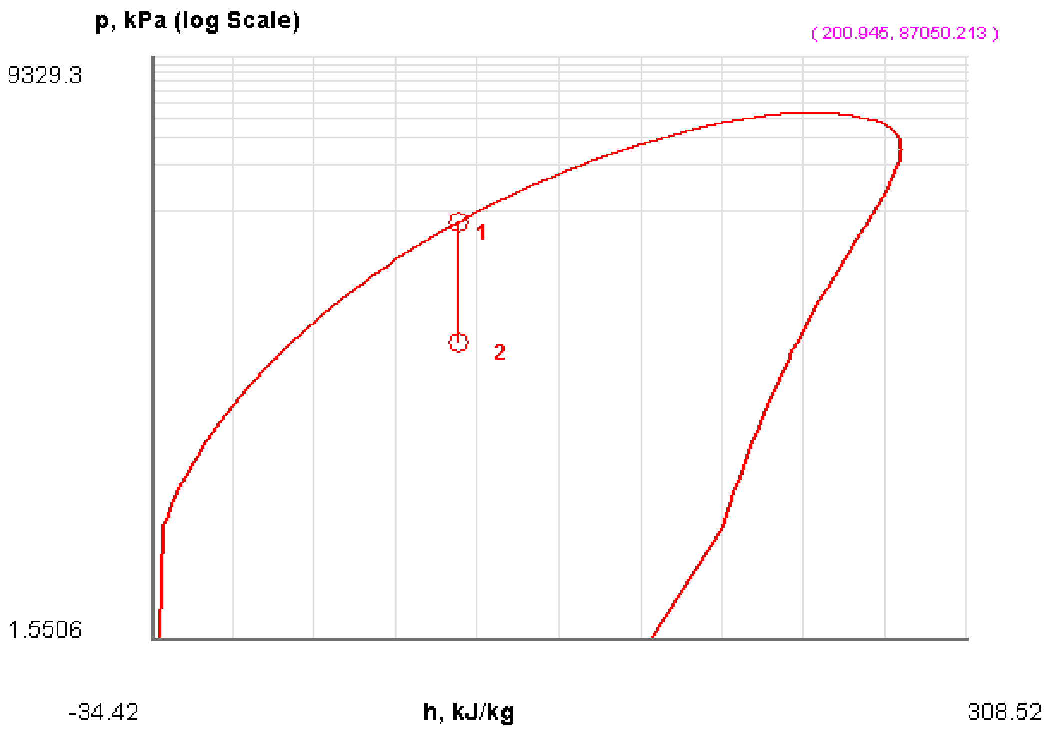
3. Choose R134a for working substance and enter data for State 1, i.e. P1, x1 and press Enter. We get:



4. Enter data for State 2, i.e. T2, and h2 = h1 since it is throttling process. Click on Calculate and SuperCalculate. We get:

Thus: p2 = 133.7 kPa … Ans.

5. Indicative P-h diagram is easily obtained from the Plots tab:



6. I/O panel gives the TEST code etc:

#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.bb06

#-------------------Start of TEST-code --

States {
State-1: R-134a;
Given: { p1= 800.0 kPa; x1= 0.0 fraction; Vel1= 0.0 m/s; z1= 0.0 m; }
State-2: R-134a;
Given: { T2= -20.0 deg-C; h2= “h1” kJ/kg; Vel2= 0.0 m/s; z2= 0.0 m; }
}

#---------------------End of TEST-code --

#--------Property spreadsheet:

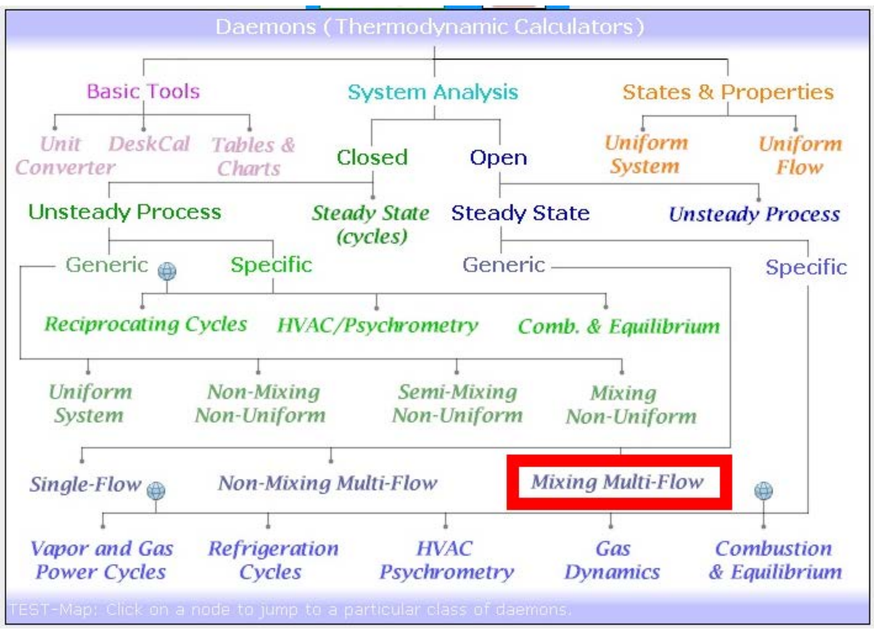
# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	800.0	304.4	0.0	8.0E-4	94.0	94.68	0.351
# 02	133.7	253.2	0.3	0.0487	88.16	94.68	0.378

==

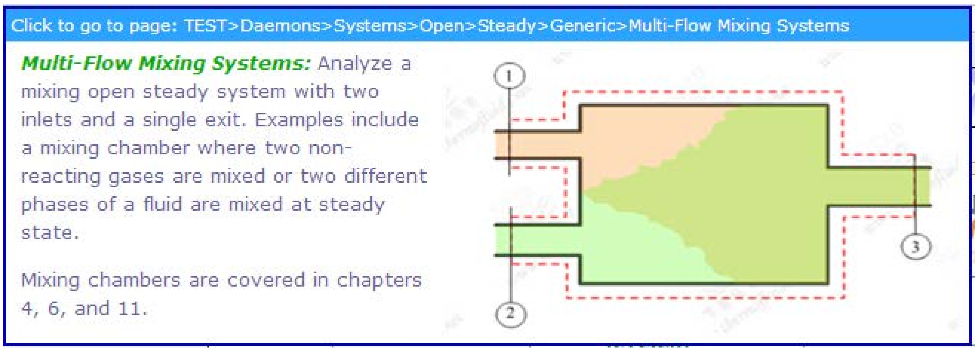
Prob.5.32. A hot water stream at 80 C enters a mixing chamber with a mass flow rate of 0.5 kg/s where it is mixed with a stream of cold water at 20 C. If it is desired that the mixture leave the chamber at 42 C, determine the mass flow rate of the cold water stream. Assume that all the streams are at a pressure of 250 kPa. [Ref. 1]

TEST Solution:

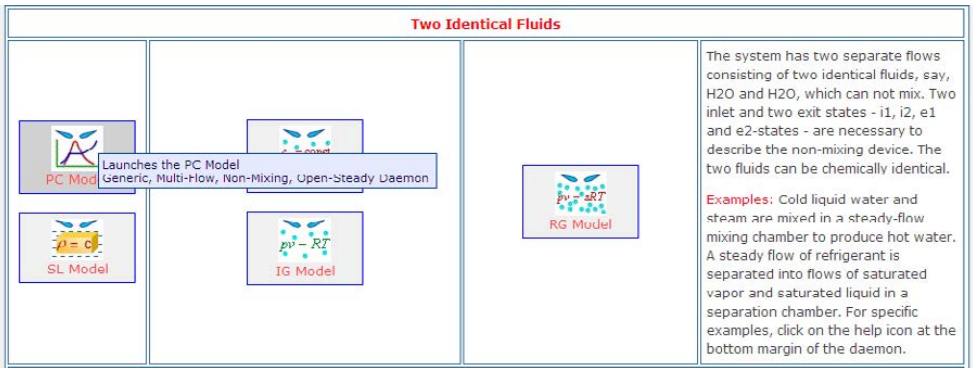
1. This is a problem on mixing chambers. So, choose the appropriate daemon as shown below:



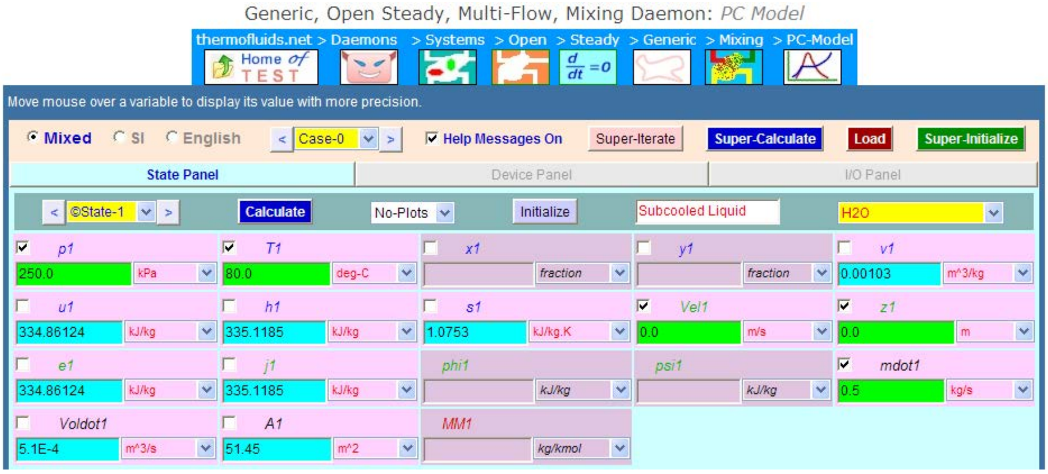
2. Hovering the mouse pointer on Mixing Multi-Flow brings up the following:



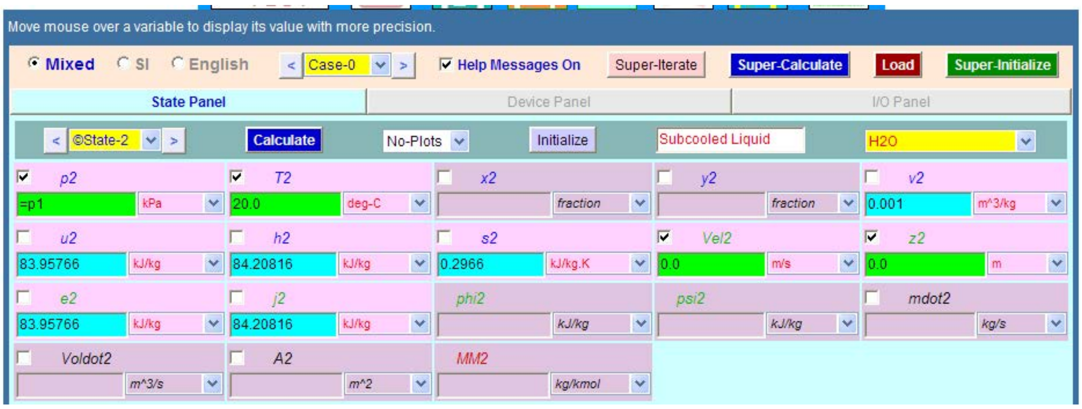
3. Choose Phase Change (PC) model, and choose H2O as working substance:



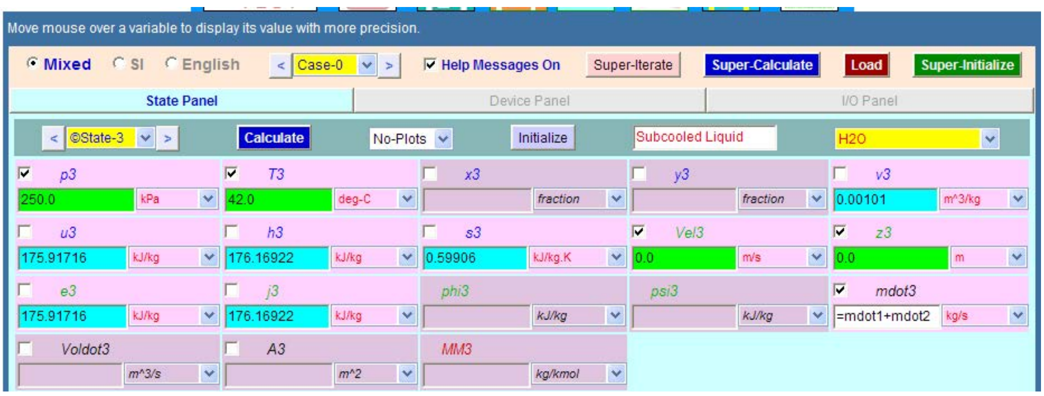
4. Enter data for State 1, i.e. P1, T1, mdot1; click on Calculate (or, press Enter). We get:



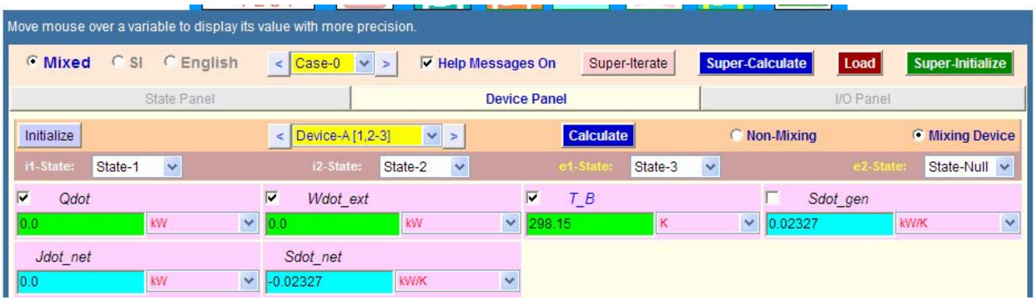
5. Enter data for State 2 (i.e. cold stream entering), i.e, P2 and T2, press Enter:



6. Now, enter data for State 3 (i.e. state after mixing), i. P3, T3, mdot3 (= mdot2 + mdot1), press Enter:



7. Go to Device Panel, enter State 1, State 2 and State 3 for i1-state, i2-state and e1-state respectively. e2-state is maintained as Null-state since there is only one exit.
   Press Enter, and also SuperCalculate:



8. **Now, go to State 2:**

Thus: mdot2 = 0.864 kg/s … Ans.

9. Go to I/O panel to see TEST code etc:

#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

 # Daemon Path: Systems>Open>SteadyState>Generic>MultiFlowMixed>PC-Model; v-10. bb06

#------------------Start of TEST-code ---

States {

State-1: H2O;

Given: { p1= 250.0 kPa; T1= 80.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 0.5 kg/s; }

State-2: H2O;

Given: { p2= "p1" kPa; T2= 20.0 deg-C; Vel2= 0.0 m/s; z2= 0.0 m; }

```
        State-3: H2O;
        Given: { p3= 250.0 kPa; T3= 42.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= "mdot1+mdot2"
        kg/s; }
        }

 Analysis {
        Device-A: i-State = State-1, State-2; e-State = State-3; Mixing: true;
        Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K; }
        }

#----------------------End of TEST-code --------------------------------------------------------------------

#--------Property spreadsheet :
```

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	250.0	353.2		0.001	334.86	335.12	1.075
# 02	250.0	293.2		0.001	83.96	84.21	0.297
# 03	250.0	315.2		0.001	175.92	176.17	0.599

 # Mass, Energy, and Entropy Analysis Results:

Device-A: i-State = State-1, State-2; e-State = State-3; Mixing: true;

Given: Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K;

Calculated: Sdot_gen= 0.023273543 kW/K; Jdot_net= "-2.842171E-14" kW; Sdot_net= -0.023273543 kW/K;

Verify:

#******CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)', '= sqrt(4*A1/PI)', etc.) and press the Enter key)*********

(mdot1*h1+mdot2*h2) = 240.3336599692044
mdot3*h3 = 240.33365996920443

 # i.e. Energy balance is verified.

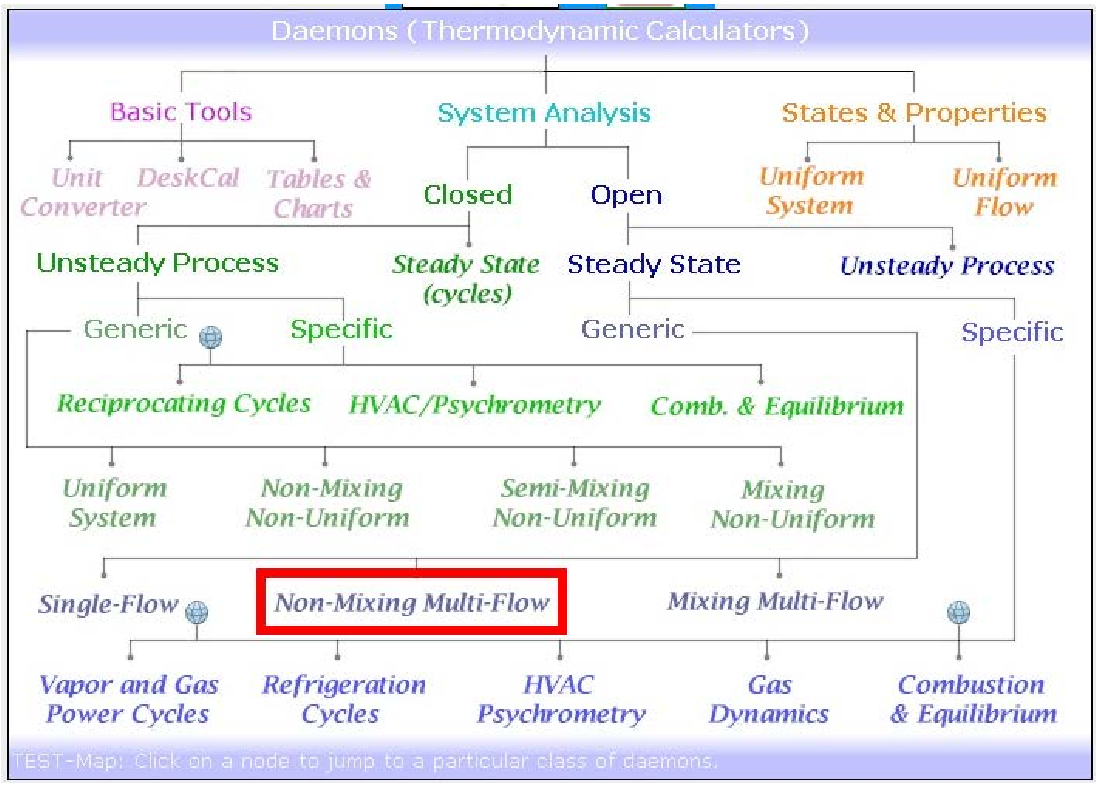
===

Prob. 5.33. Steam enters the condenser of a steam power plant at 20 kPa as sat. vapour with a mass flow rate of 20000 kg/h. It is to be cooled by water from a nearby river, circulating the water through the tubes within the condenser. The river water is not allowed to experience a temp rise above 10 C. If the steam is to leave the condenser as sat. liquid at 20 kPa, determine the mass flow rate of cooling water required. [Ref. 1]

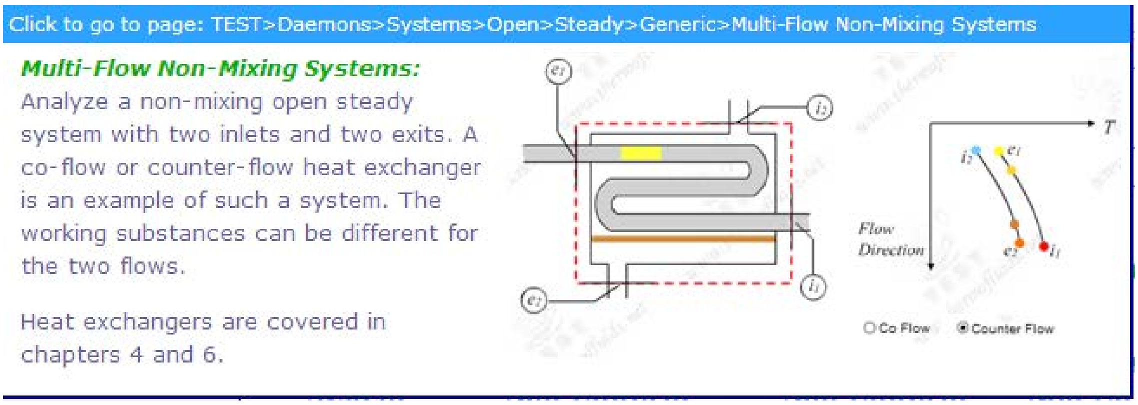
TEST Solution:

This is a **Non-mixing multi-flow** type problem. i.e. the steam and cooling water do not mix.

1. Choose the daemon suitable for Non-mixing, multi-flow problem, as shown below:

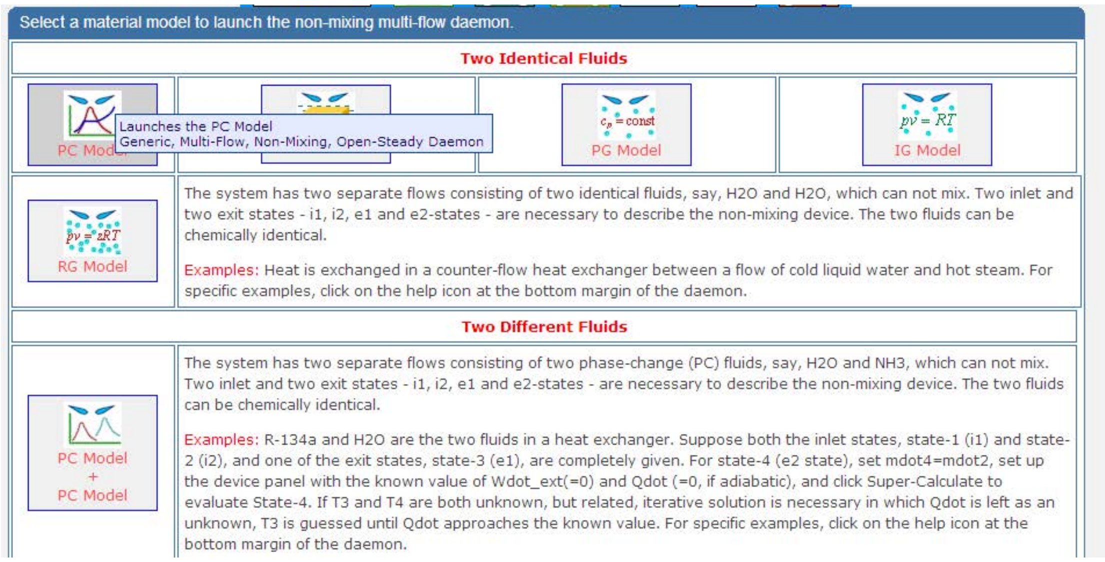


2. Hovering the mouse pointer over "Non-mixing Multi-Flow" gives following window:

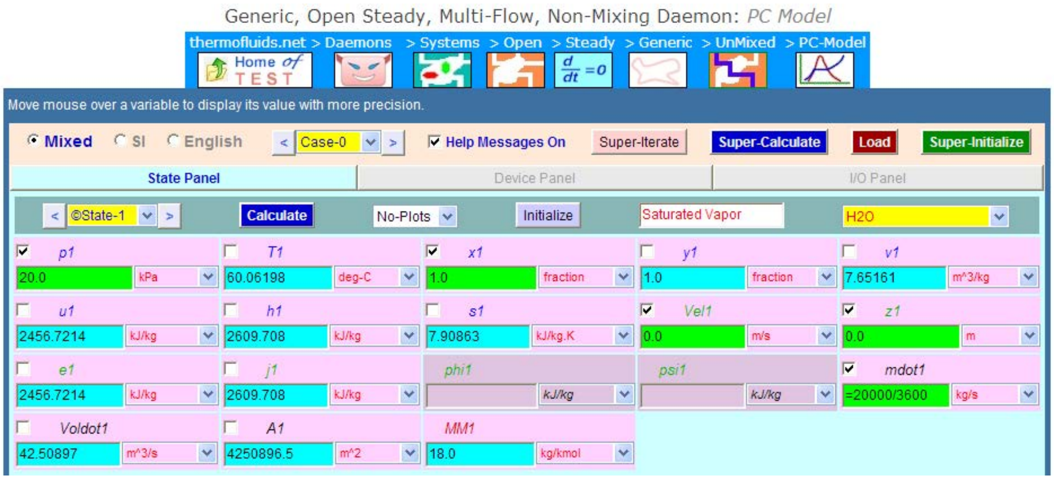


Note that this is the daemon required to solve parallel flow and counter-flow heat exchangers:

3. Choose PC model under **'Two Identical Fluids'** as shown below, since water/steam is the working substance:

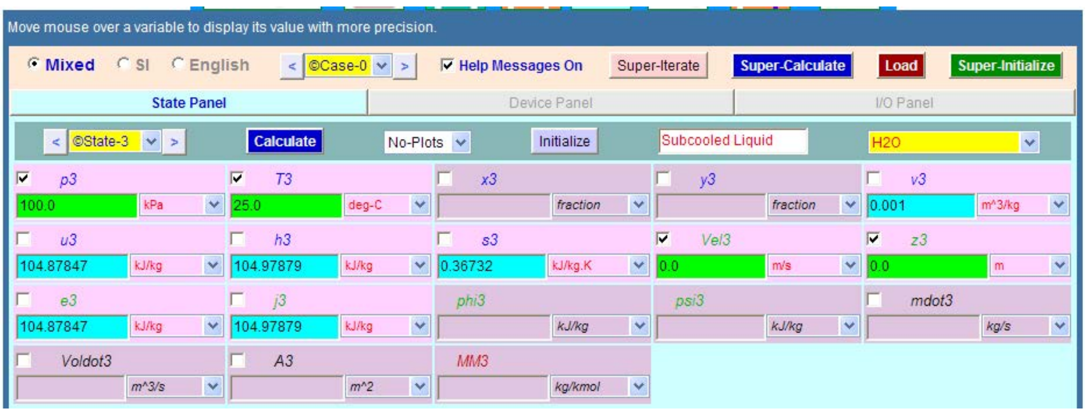


4. After choosing H2O as the working substance, enter data for State 1, i.e. P1, x1 (= 1, since sat. vap. is entering the condenser), and hit Enter:



5. Enter data for State 2 (i.e. sat. liq. leaving the condenser); i.e. enter P2, x2 (=0.0), mdot2 = mdot1. Hit Enter:

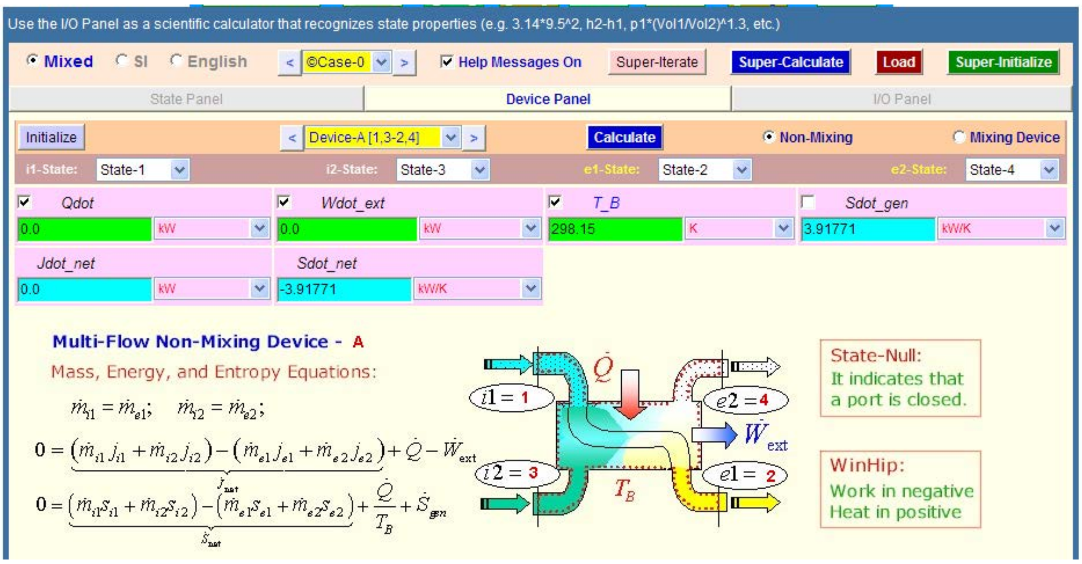
6. For State 3, enter data for river water entering the condenser; hit Enter:



7. State 4 is river water exiting the condenser; enter the data, i.e. P4, T4, mdot4 = mdot3, and hit Enter:

Note that exit temp of cooling (river) water is 10 C above the inlet temp.

8. Now, go to Device Panel, enter i-1 state, i-2 state, e-1 state and e-2 state as shown. Also, Qdot = 0, and Wdot_ext = 0. Press Calculate, and SuperCalculate:



9. Go to State Panel.

See State 3:

We see that: mdot3 = 313.49 kg/s …flow rate of cooling (river) water required… Ans.

10. To see the TEST code etc go to I/O panel:

```
#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE :

#        Daemon Path: Systems>Open>SteadyState>Generic>MultiFlowUnmixed>PC-Model; v-10.
         bb06

#--------------------Start of TEST-code ------------------------------------------------------------------

 States  {
          State-1: H2O;
          Given: { p1= 20.0 kPa; x1= 1.0 fraction; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= "20000/3600" kg/s; }
          State-2: H2O;
          Given: { p2= 20.0 kPa; x2= 0.0 fraction; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
          State-3: H2O;
          Given: { p3= 100.0 kPa; T3= 25.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; }
          State-4: H2O;
          Given: { p4= "p3" kPa; T4= "T3+10" deg-C; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= "mdot3" kg/s; }
          }

 Analysis {
          Device-A: i-State = State-1, State-3; e-State = State-2, State-4; Mixing: false;
          Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K; }
          }

#----------------------End of TEST-code ------------------------------------------------------------------

#******DETAILED OUTPUT:

# Evaluated States:
#         State-1: H2O > Saturated Mixture;
#                  Given: p1= 20.0 kPa; x1= 1.0 fraction; Vel1= 0.0 m/s;
#                         z1= 0.0 m; mdot1= "20000/3600" kg/s;
#                  Calculated: T1= 60.062 deg-C; y1= 1.0 fraction; v1= 7.6516 m^3/kg;
#                         u1= 2456.7214 kJ/kg; h1= 2609.708 kJ/kg; s1= 7.9086 kJ/kg.K;
#                         e1= 2456.7214 kJ/kg; j1= 2609.708 kJ/kg; Voldot1= 42.509 m^3/s;
#                         A1= 4250896.5 m^2; MM1= 18.0 kg/kmol;
#         State-2: H2O > Saturated Mixture;
#                  Given: p2= 20.0 kPa; x2= 0.0 fraction; Vel2= 0.0 m/s;
#                         z2= 0.0 m; mdot2= "mdot1" kg/s;
#                  Calculated: T2= 60.062 deg-C; y2= 0.0 fraction; v2= 0.001 m^3/kg;
#                         u2= 251.3691 kJ/kg; h2= 251.3895 kJ/kg; s2= 0.832 kJ/kg.K;
```

e2= 251.3691 kJ/kg; j2= 251.3895 kJ/kg; Voldot2= 0.0056 m^3/s;
A2= 565.0207 m^2; MM2= 18.0 kg/kmol;
State-3: H2O > Subcooled Liquid;
Given: p3= 100.0 kPa; T3= 25.0 deg-C; Vel3= 0.0 m/s;
z3= 0.0 m;
Calculated: v3= 0.001 m^3/kg; u3= 104.8785 kJ/kg; h3= 104.9788 kJ/kg;
s3= 0.3673 kJ/kg.K; e3= 104.8785 kJ/kg; j3= 104.9788 kJ/kg;
mdot3= 313.4869 kg/s; Voldot3= 0.3145 m^3/s; A3= 31447.955 m^2;
State-4: H2O > Subcooled Liquid;
Given: p4= "p3" kPa; T4= "T3+10" deg-C; Vel4= 0.0 m/s;
z4= 0.0 m; mdot4= "mdot3" kg/s;
Calculated: v4= 0.001 m^3/kg; u4= 146.6718 kJ/kg; h4= 146.7725 kJ/kg;
s4= 0.5052 kJ/kg.K; e4= 146.6718 kJ/kg; j4= 146.7725 kJ/kg;
Voldot4= 0.3154 m^3/s; A4= 31544.615 m^2;

#--------Property spreadsheet starts:

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	20.0	333.2	1.0	7.6516	2456.72	2609.71	7.909
# 02	20.0	333.2	0.0	0.001	251.37	251.39	0.832
# 03	100.0	298.2		0.001	104.88	104.98	0.367
# 04	100.0	308.2		0.001	146.67	146.77	0.505

 # Mass, Energy, and Entropy Analysis Results:

Device-A: i-State = State-1, State-3; e-State = State-2, State-4; Mixing: false;
Given: Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K;
Calculated: Sdot_gen= 3.9177132 kW/K; Jdot_net= 0.0 kW; Sdot_net= -3.9177132 kW/K;

==

Prob.5.34. Air enters an adiabatic horizontal nozzle at 400 C with a velocity of 50 m/s. The inlet area is 240 cm^2. Temp of air at exit is 80 C. Given that the sp. vol. of air at the inlet and exit are respectively 0.2 m^3/kg and 1.02 m^3/kg, find the area of cross-section of the nozzle at the exit. Assume that enthalpy of air is a function of temp only and that cp = 1.005 kJ/kg.K. [VTU-BTD-July 2006:]

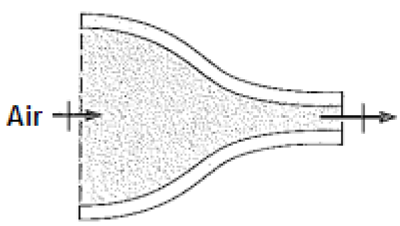
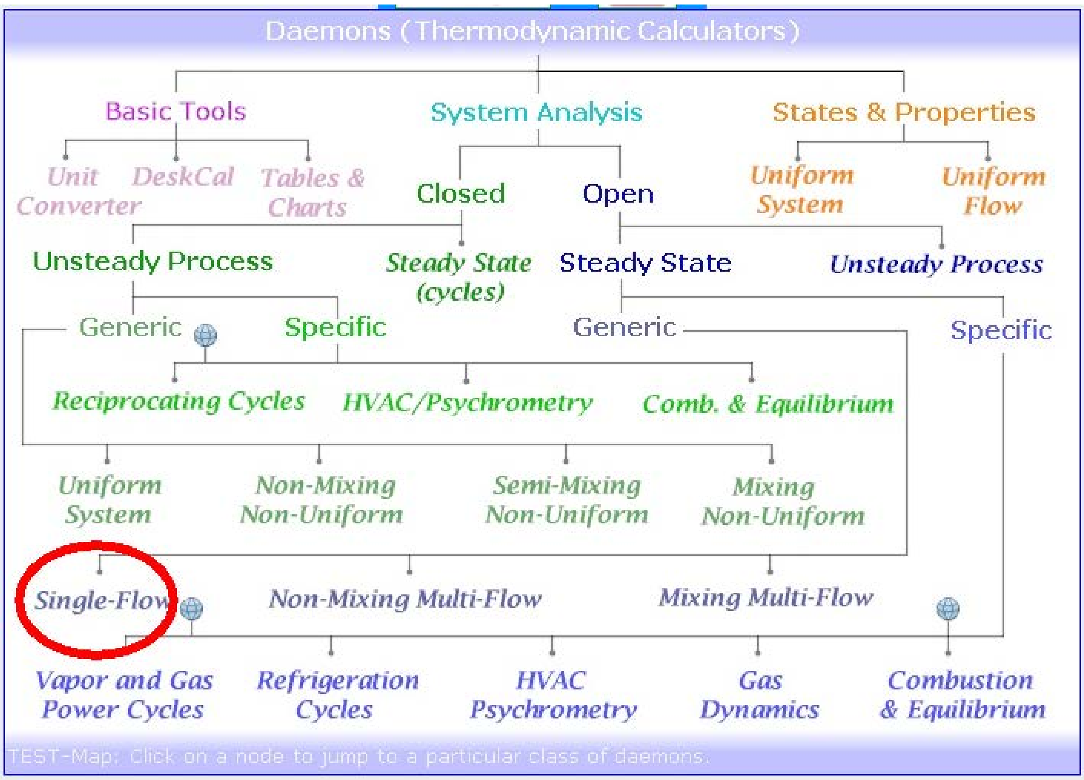


Fig.Prob.5.34

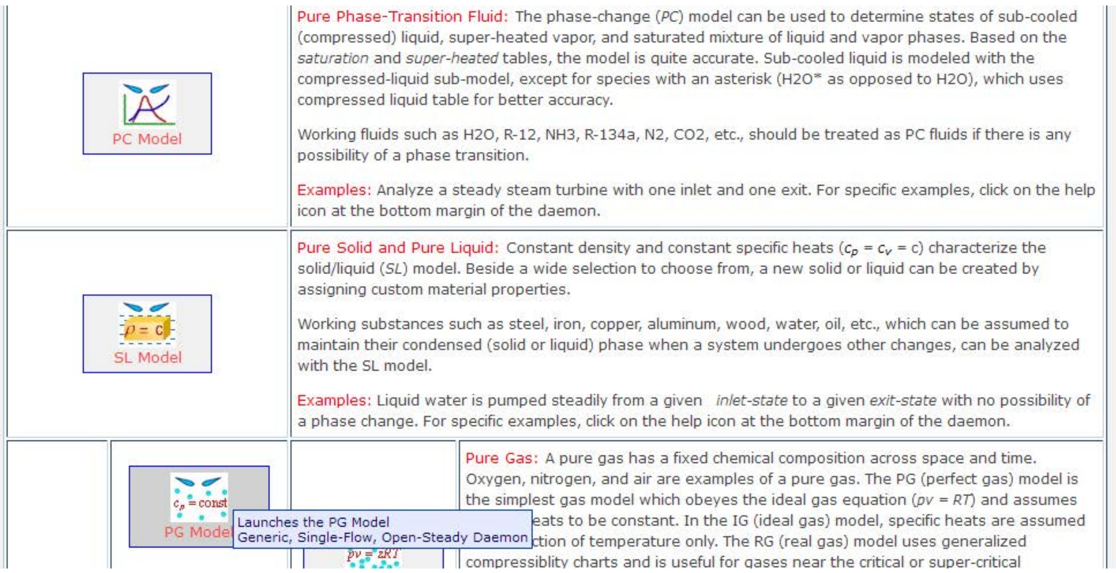
TEST Solution:

This problem is the same as Prob.5.13 which was solved with EES.

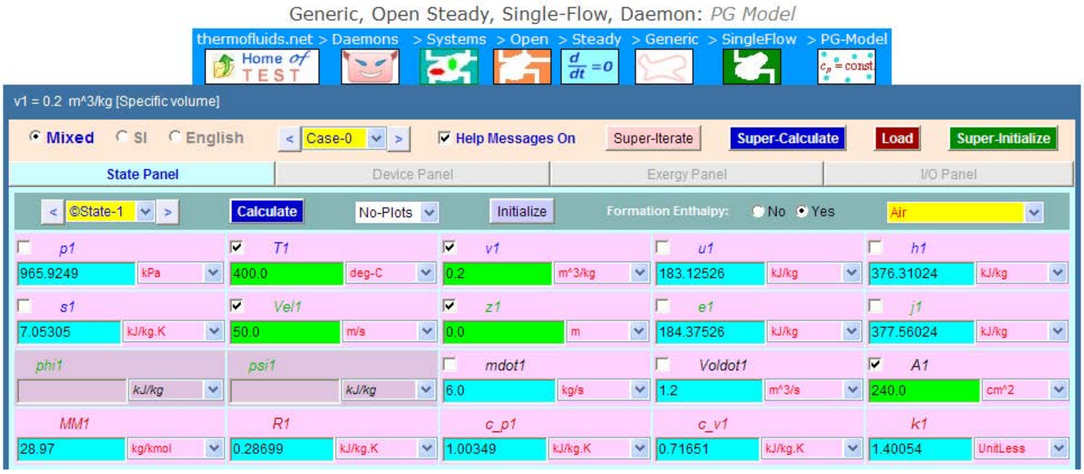
1. Go to the Daemon tree and locate System Analysis – Open – Generic – Single Flow:



2. Select the Perfect Gas (PG) Model (cp = const.) for Material model, since air is the working substance:

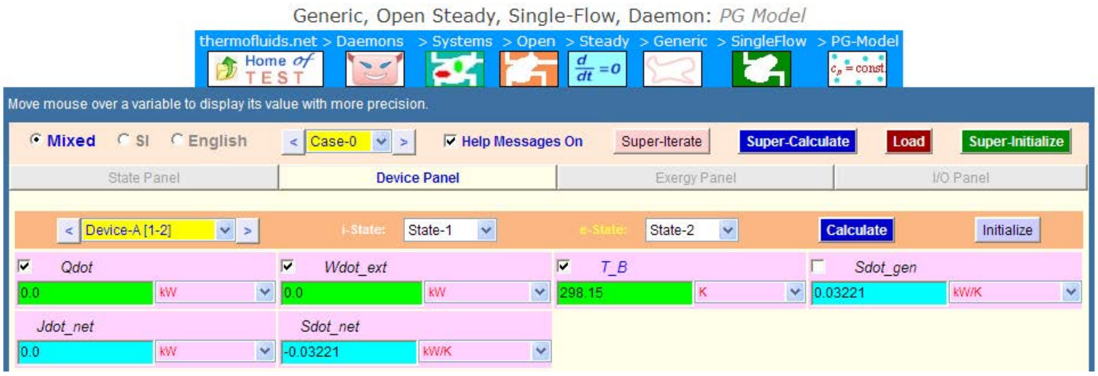


3. We get the following screen after clicking on PG model. Now, choose Air as the Working substance from the drop down menu. Then, enter known values of T1, Vel1, v1 and A1 for State 1. Click on Calculate. We get:



4. Enter data i.e. T2, v2 and mdot2 = mdot1 for State 2, hit Enter:

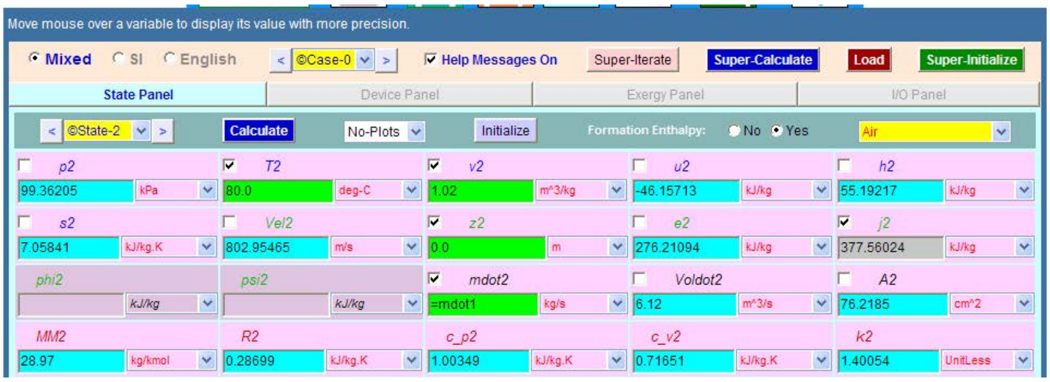
5. Go to Device Panel, enter State 1 and State 2 for i-state and e-state respectively; enter Qdot = 0 and Wdot_ext = 0 for the nozzle and click on Calculate. We get:



6. Now, click on SuperCalculate. Go to State Panel. We get:

State 1:

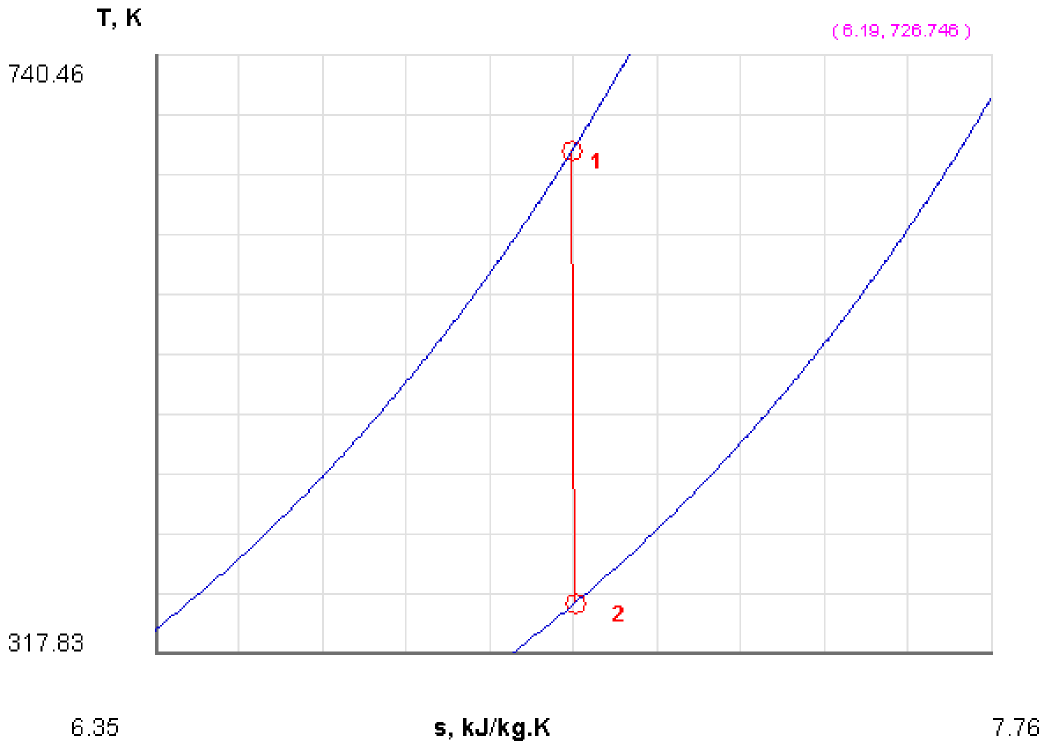
And, State 2:



Thus: A2 = 76.22 cm^2 , Vel2 = 802.95 m/s…. Ans.

Also, p2 = 99.36 kPa, mdot1 = mdot2 = 6 kg/s … Ans.

7. Indicative T-s diagram for Plots tab:



8. I/O panel gives the TEST code etc.:

```
#          Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PG-Model; v-10.bb05

#-------------------Start of TEST-code ---------------------------------------------------------------------

 States   {
            State-1: Air;
            Given: { T1= 400.0 deg-C; v1= 0.2 m^3/kg; Vel1= 50.0 m/s; z1= 0.0 m; A1= 240.0 cm^2; }
            State-2: Air;
            Given: { T2= 80.0 deg-C; v2= 1.02 m^3/kg; z2= 0.0 m; mdot2= "mdot1" kg/s; }
            }

 Analysis {
            Device-A: i-State = State-1; e-State = State-2;
            Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; 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	965.92	673.2	0.2	183.13	376.31	7.053
#	2	99.36	353.2	1.02	-46.16	55.19	7.058
#							

==

Prob.5.35. Steam at 1 MPa and 250 C enters a nozzle with a velocity of 60 m/s and leaves at 10 kPa. Assuming the flow process to be isentropic and the mass flow rate to be 1 kg/s, determine: (i) the exit velocity (ii) the exit diameter. [VTU-BTD-Jan./Feb. 2005]

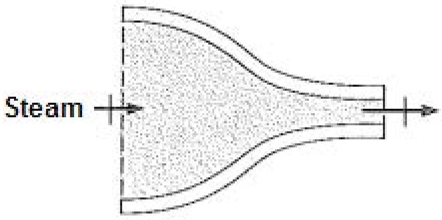
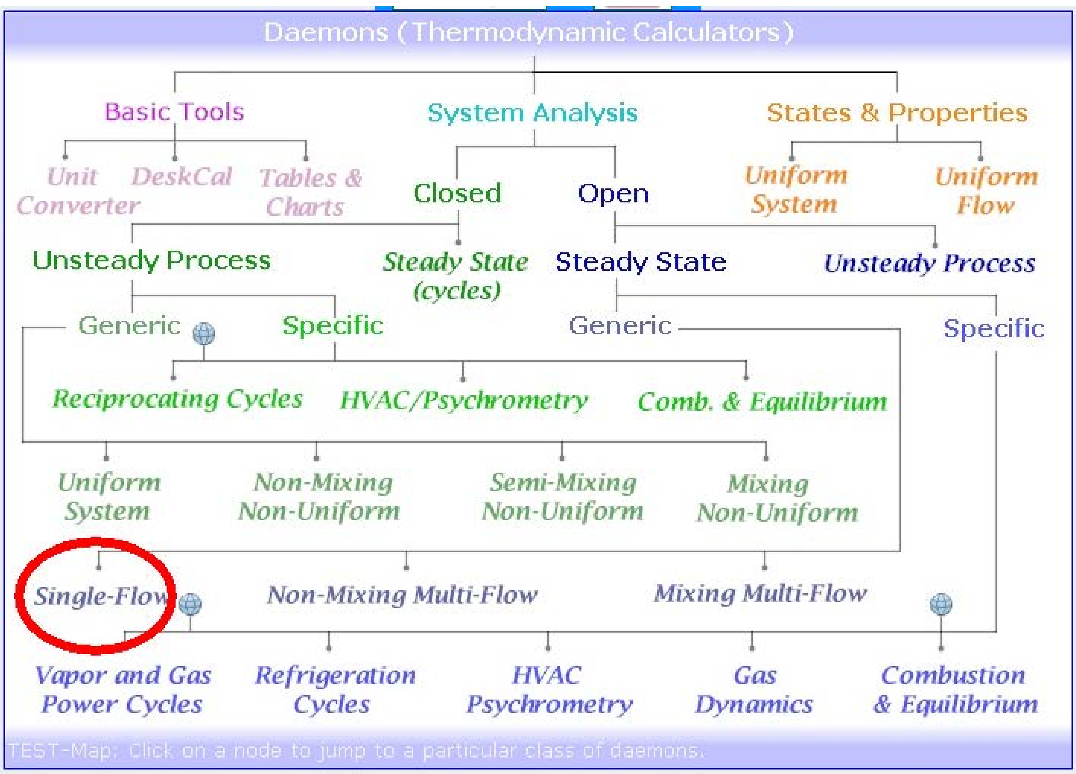


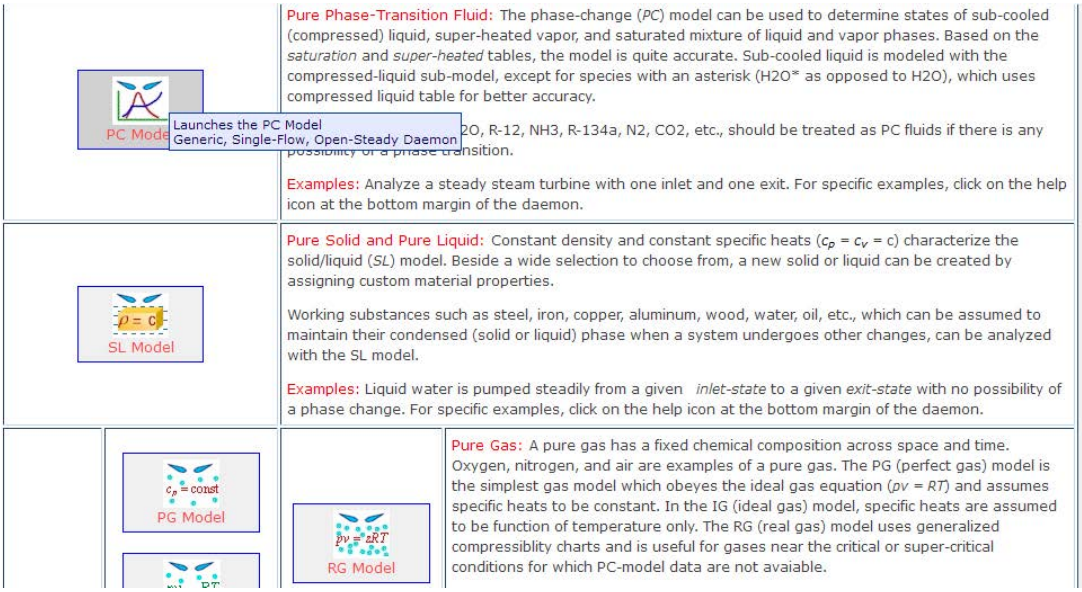
Fig.Prob.5.35

TEST Solution:

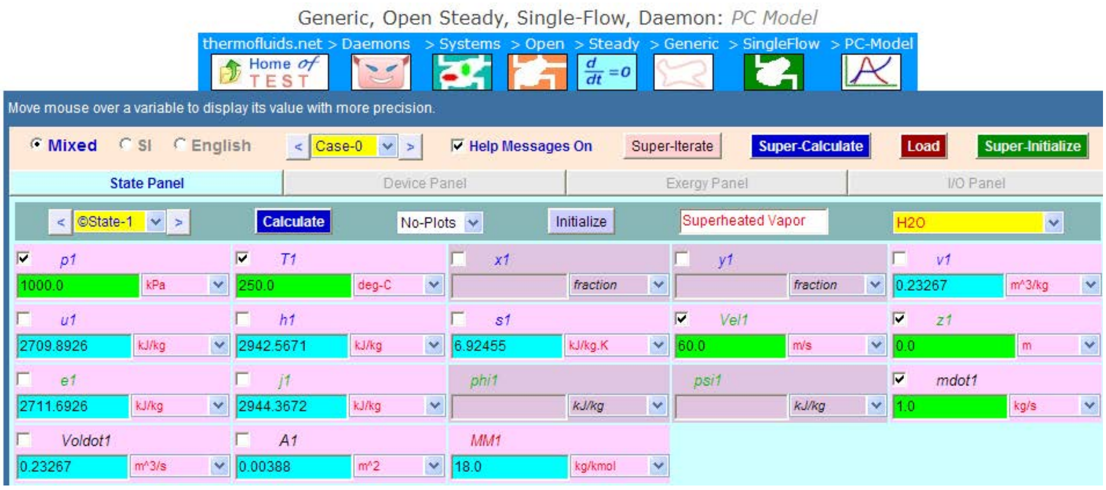
1. Choose the System analysis … Single Flow daemon as shown below:



2. Choose the PC model for Material model:



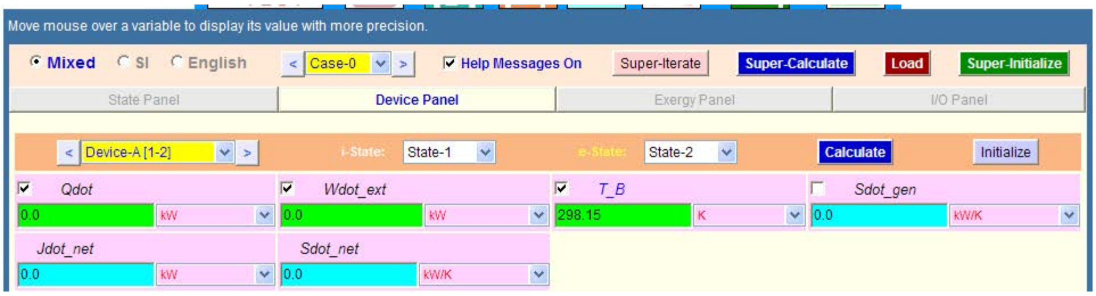
3. Select H2O as working substance. Enter data, i.e. P1, T1, Vel1 and mdot1 for State 1. Hit Enter:



4. Enter P2,s2 = s1 (since isentropic) and mdot2 = mdot1 and hit Enter:

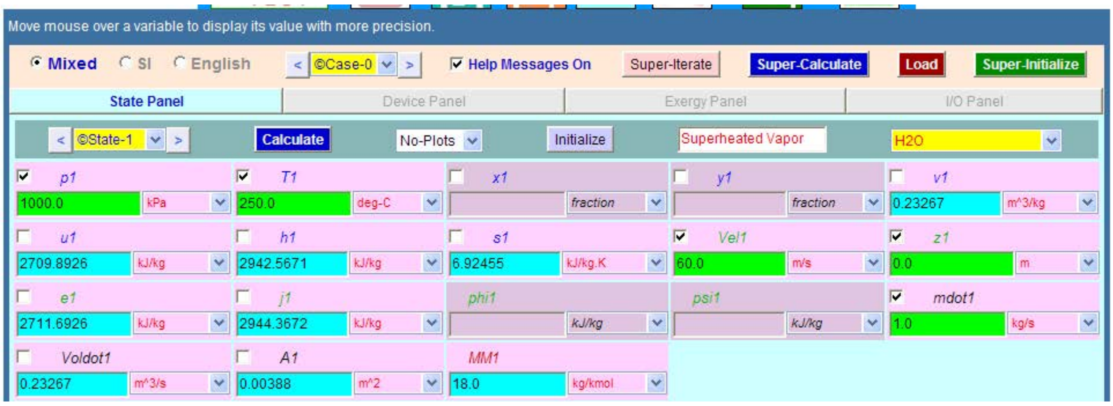
Note in the above screen shot that immediately other parameters for State 2 are calculated.

5. Go to Device Panel, enter State 1 and Styate 2 for i-state and e-state; also, enter Qdot = 0 and Wdot_ext = 0. Hit Enter:



6. Now, click on SuperCalculate. Then, go to State Panel.

See State 1:



And, State 2:

Thus:

exit velocity, Vel2 = 1225.31 m/s,

exit area = 0.01002 m^2 = 100.188 cm^2

Therefore, exit dia = d2 = 11.29 cm

7. I/O panel gives TEST code etc:

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

#        Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.bb06

#--------------------Start of TEST-code ------------------------------------------------------------------------

 States   {
          State-1: H2O;
          Given: { p1= 1000.0 kPa; T1= 250.0 deg-C; Vel1= 60.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }
          State-2: H2O;
          Given: { p2= 10.0 kPa; s2= "s1" kJ/kg.K; z2= 0.0 m; mdot2= "mdot1" kg/s; }
          }

 Analysis {
          Device-A: i-State = State-1; e-State = State-2;
          Given: { Qdot= 0.0 kW; Wdot_ext= 0.0 kW; T_B= 298.15 K; }
          }

#----------------------End of TEST-code ----------------------------------------------------------------------

#--------Property spreadsheet starts:

# State  p(kPa)    T(K)   x     v(m3/kg)   u(kJ/kg)   h(kJ/kg)   s(kJ/kg)
# 01     1000.0    523.2        0.2327     2709.89    2942.57    6.925
# 02     10.0      319.0  0.8   12.2762    2070.91    2193.67    6.925

#******CALCULATE VARIABLES:

         sqrt(A2 * 4 /pi) = 0.11294417026465142 m

#        i.e. d2 = 11.29 cm …Ans.
=====================================================================
```

Prob. 5.36. Air flows steadily through a rotary compressor. At entry the air is at 20 C and 101 kPa. At exit it is at 200 C and 600 kPa. Assuming the flow to be adiabatic, (i) evaluate the work done per unit mass of air if the velocities at inlet and exit are negligible. (ii) what would be the increase in work input if the velocities at inlet and exit are 50 m/s and 110 m/s? [VTU-BTD-Ja./Feb. 2004]

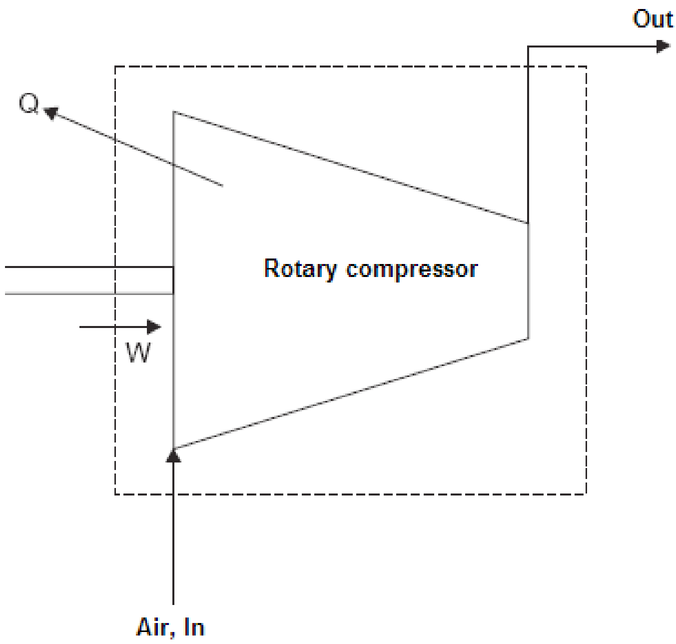
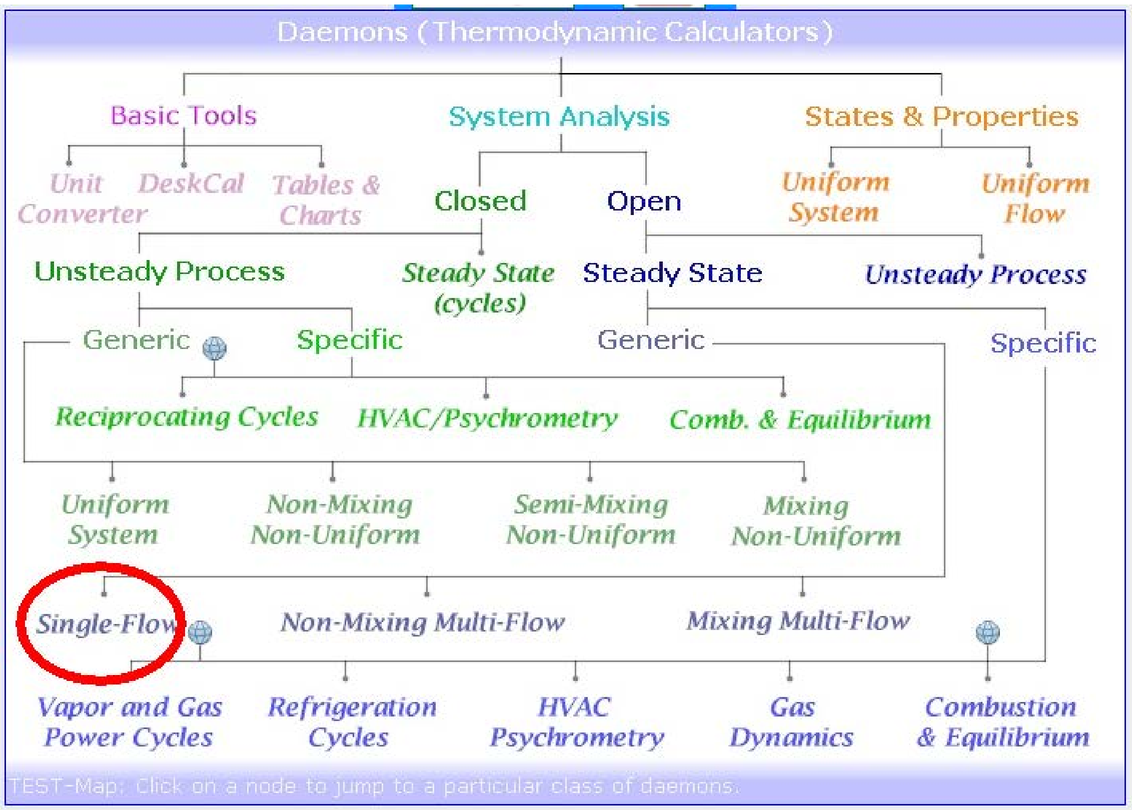


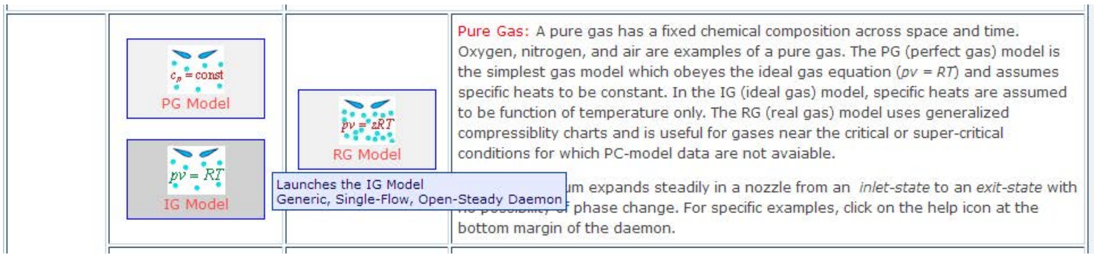
Fig.Prob.5.36

TEST Solution:

1. Choose the System analysis … Single Flow daemon as shown below:

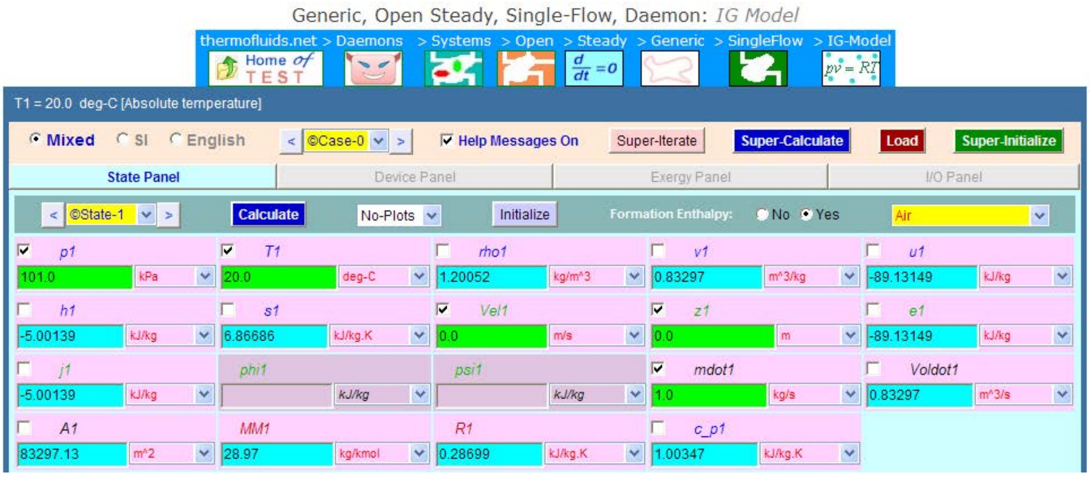


2. Choose the IG model for Material model:

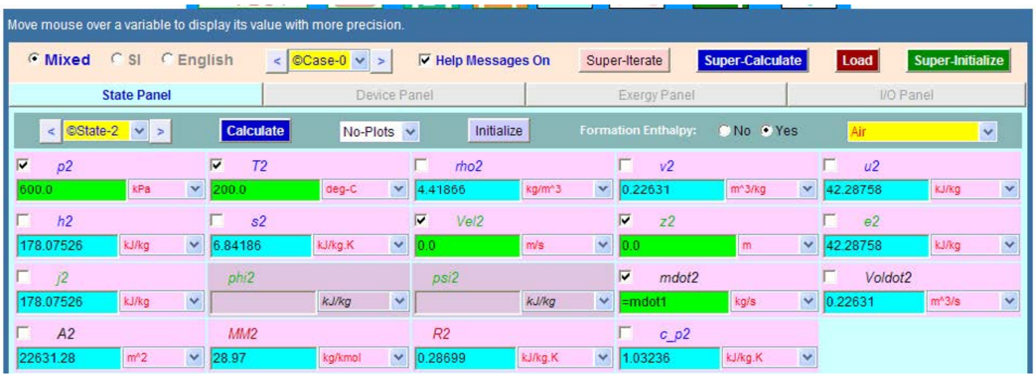


A. **When velocities are negligible:**

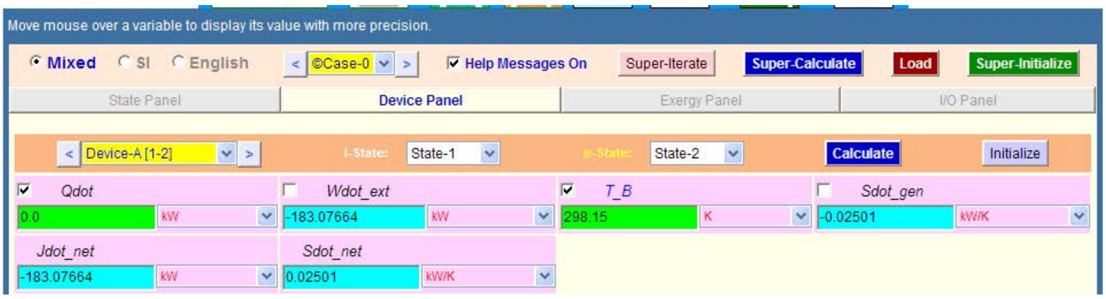
3. Choose Air as working substance. Enter P1, T1, mdot1 for State 1. Vel1 = 0 by default. Hit Enter. We get:



4. Enter P2, T2, mdot2=mdot1 for State 2; press Enter:

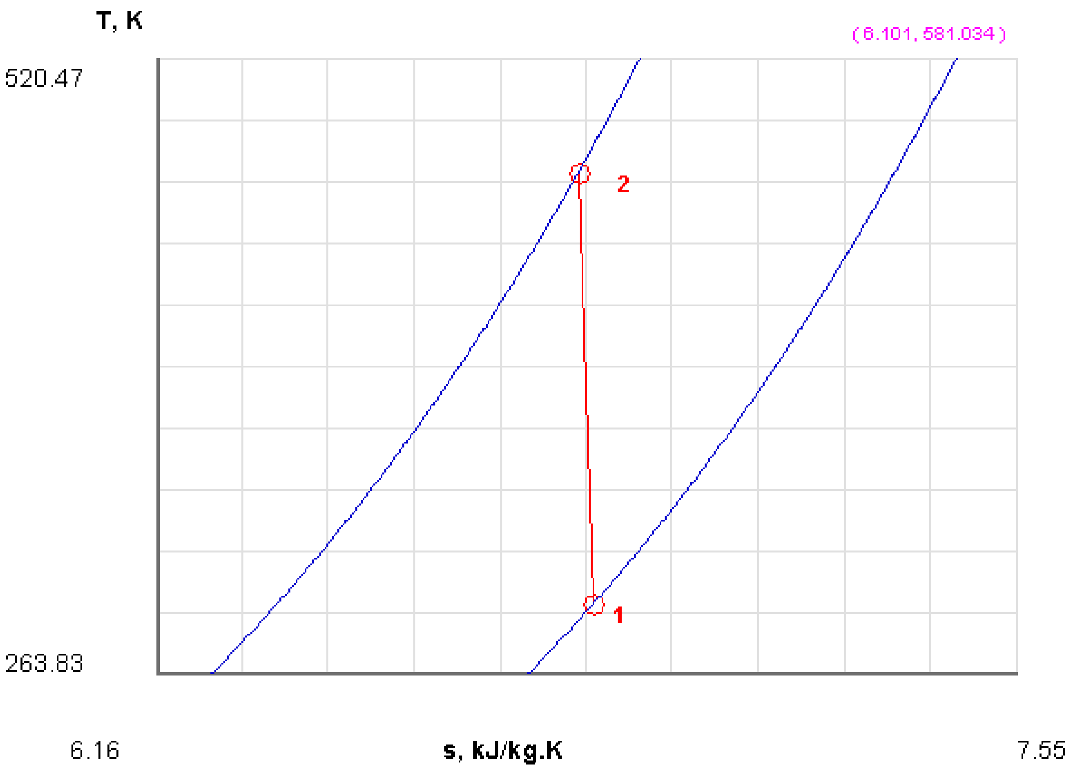


5. Go to Device Panel, enter State 1 and State 2 for i-state and e-state respectively. Also, Qdot = 0, Wdot_ext = 0. Click Calculate, and SuperCalculate. We get:



Thus: Work done on unit mass of air = -183.08 kW….(negative sign indicates work input since it is a compressor)..Ans.

6. Indicative T-s diagram:



7. **I/O panel gives TEST code etc:**

```
#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE :

#        Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.bb05

#--------------------Start of TEST-code -----------------------------------------------------------------------

 States  {
           State-1: Air;
           Given: { p1= 101.0 kPa; T1= 20.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }
           State-2: Air;
           Given: { p2= 600.0 kPa; T2= 200.0 deg-C; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
           }

 Analysis {
           Device-A: i-State = State-1; e-State = State-2;
           Given: { Qdot= 0.0 kW; 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	101.0	293.2	0.833	-89.13	-5.0	6.867
#	2	600.0	473.2	0.2263	42.29	178.08	6.842

==

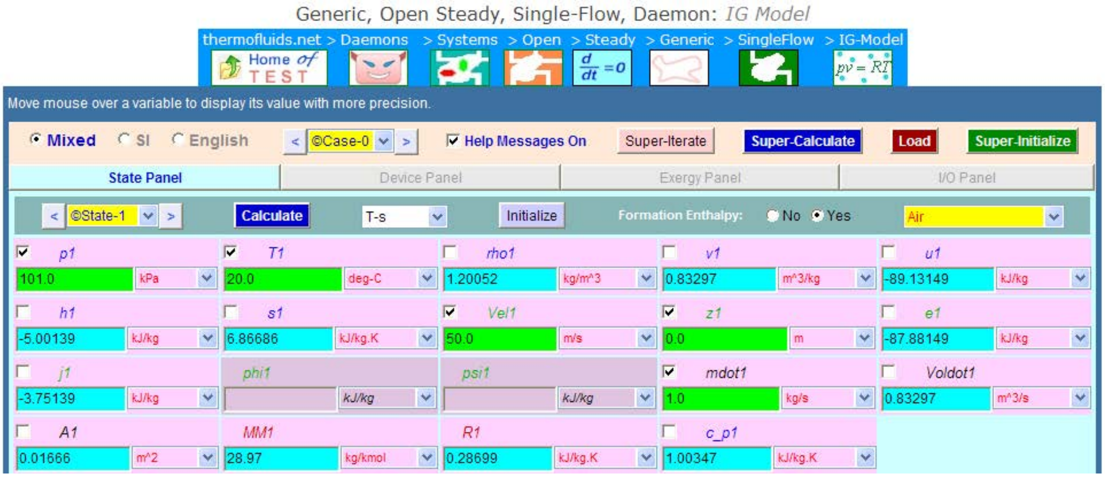
B. **When Vel1 = 50 m/s and Vel2 = 110 m/s:**

The procedure is:

i) **Enter the Vel1 value , Calculate, and**
ii) **enter Vel2 value, Calculate, and then**
iii) **SuperCalculate.**

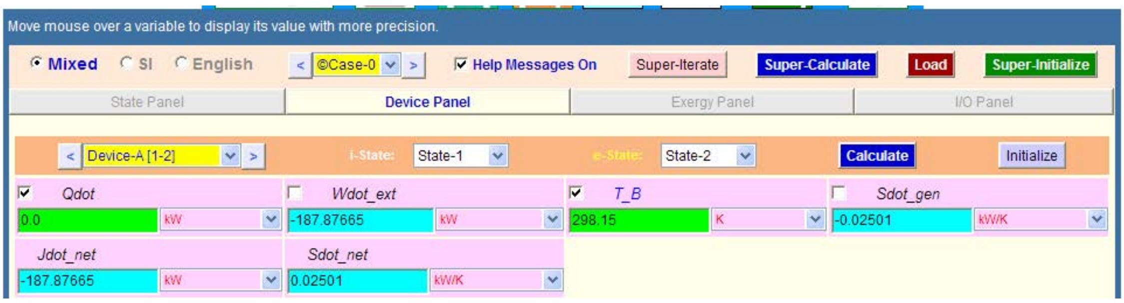
We get:

State 1:



State 2:

Device Panel:



Thus: Work done on unit mass of air = -187.88 kW…when inlet and exit velocities are considered…Ans.

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE #

#        Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>IG-Model; v-10.bb05

#--------------------Start of TEST-code --------------------------------------------------------------------

States   {
         State-1: Air;
         Given: { p1= 101.0 kPa; T1= 20.0 deg-C; Vel1= 50.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }
         State-2: Air;
         Given: { p2= 600.0 kPa; T2= 200.0 deg-C; Vel2= 110.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
         }

Analysis {
         Device-A: i-State = State-1; e-State = State-2;
         Given: { Qdot= 0.0 kW; T_B= 298.15 K; }
         }

#---------------------End of TEST-code ---------------------------------------------------------------------
```

#******DETAILED OUTPUT:

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	101.0	293.2	0.833	-89.13	-5.0	6.867
#	2	600.0	473.2	0.2263	42.29	178.08	6.842

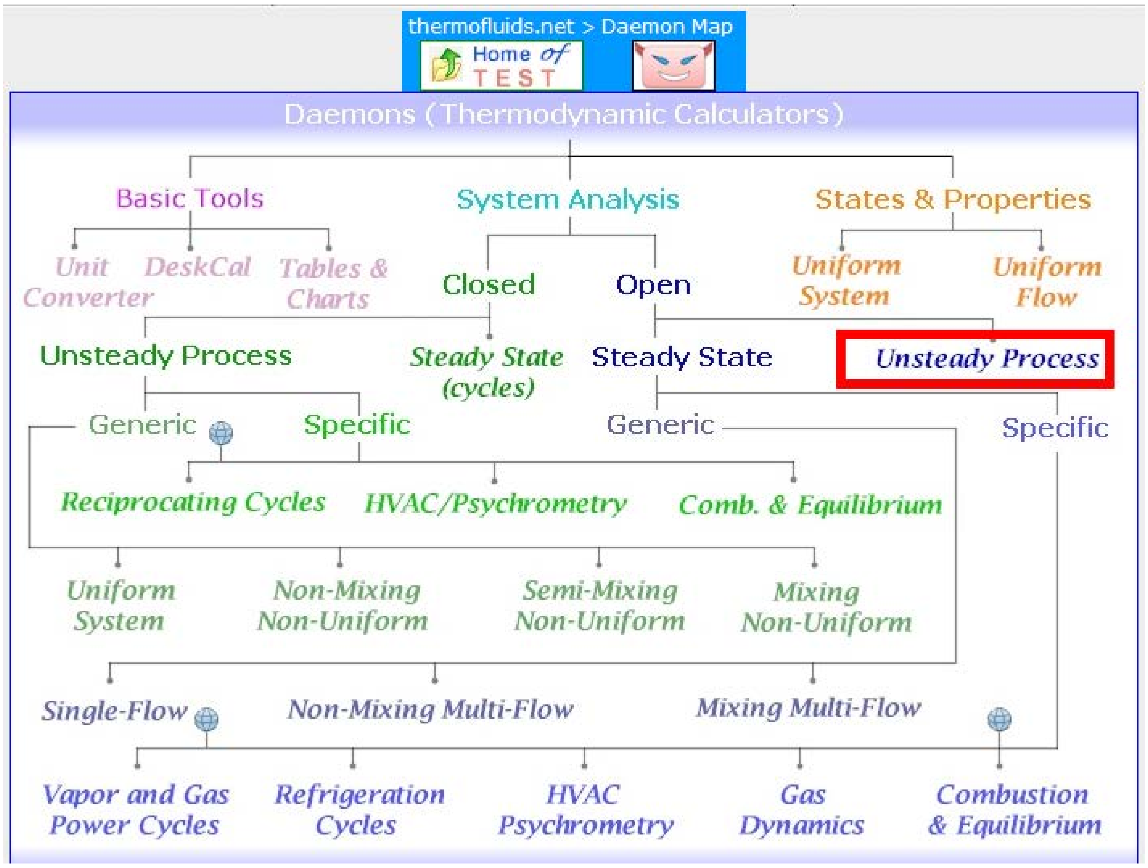
==

Prob. 5.37. Steam at a pressure of 1.4 MPa, 300 C is flowing in a pipe. Connected to this pipe through a valve is an evacuated tank. The valve is opened and the tank fills with steam until the pressure is 1.4 MPa, and then the valve is closed. The process takes place adiabatically and K.E. and P.E. are negligible. Determine the final temp of steam. [Ref. 2]

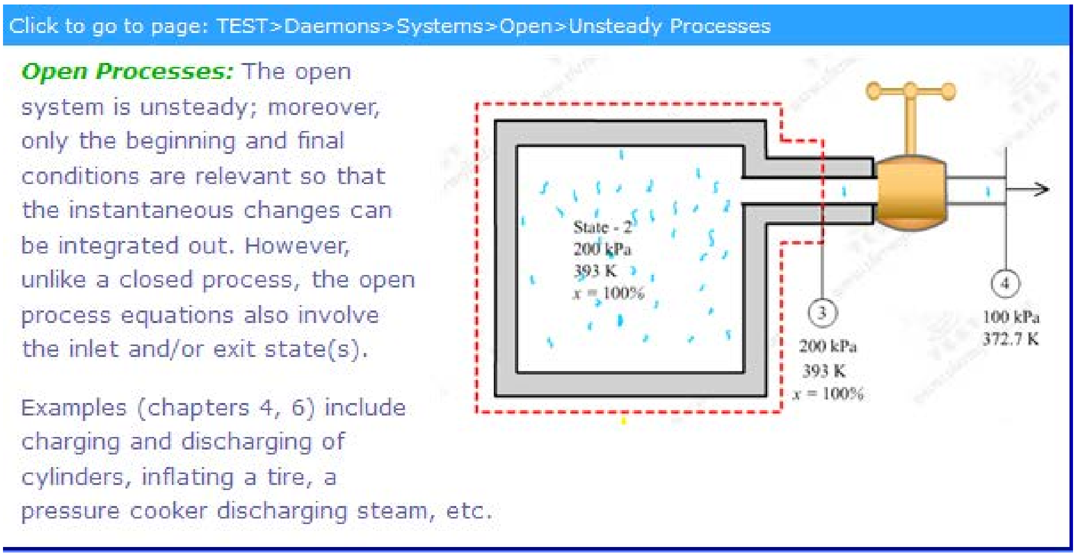
TEST Solution:

This is a problem on charging a tank. i.e. Uniform State, Uniform Flow type of problem. See eqn. 5.14 at the beginning of this chapter.

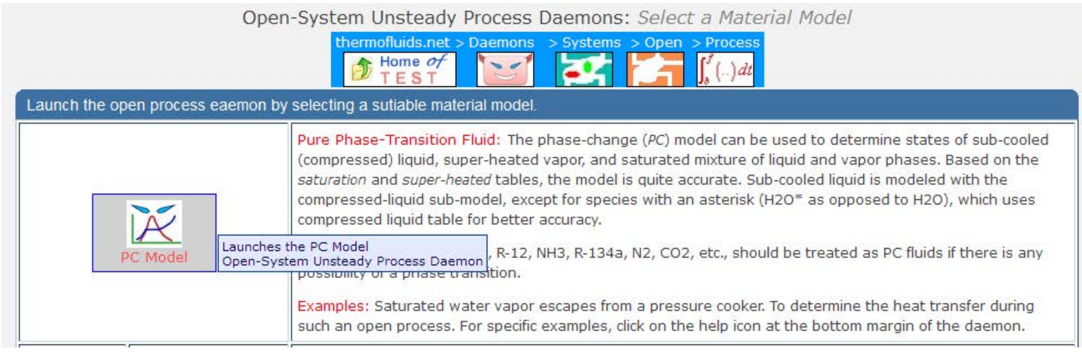
1. Select System Analysis – Open – Unsteady Process daemon as shown below:



2. Hovering the mouse pointer on 'Unsteady Process' brings up the following message window:

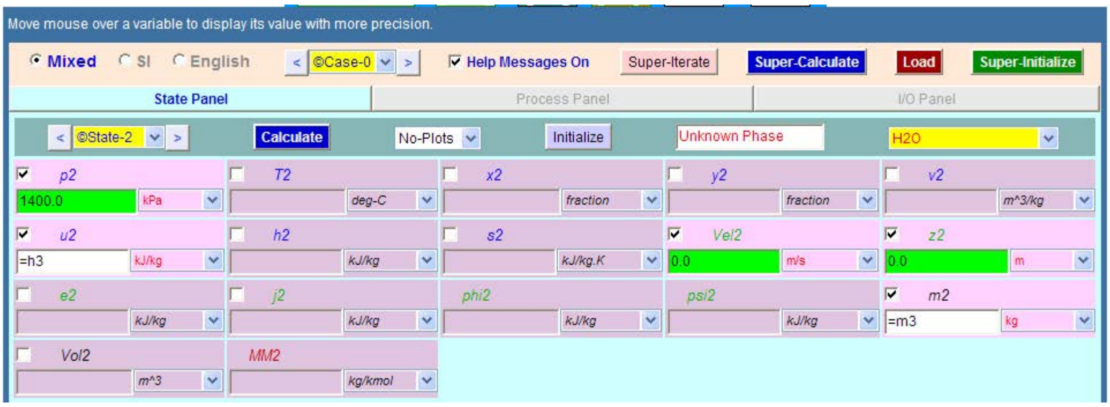


3. Choose PC model for Material model since Steam is the working substance:



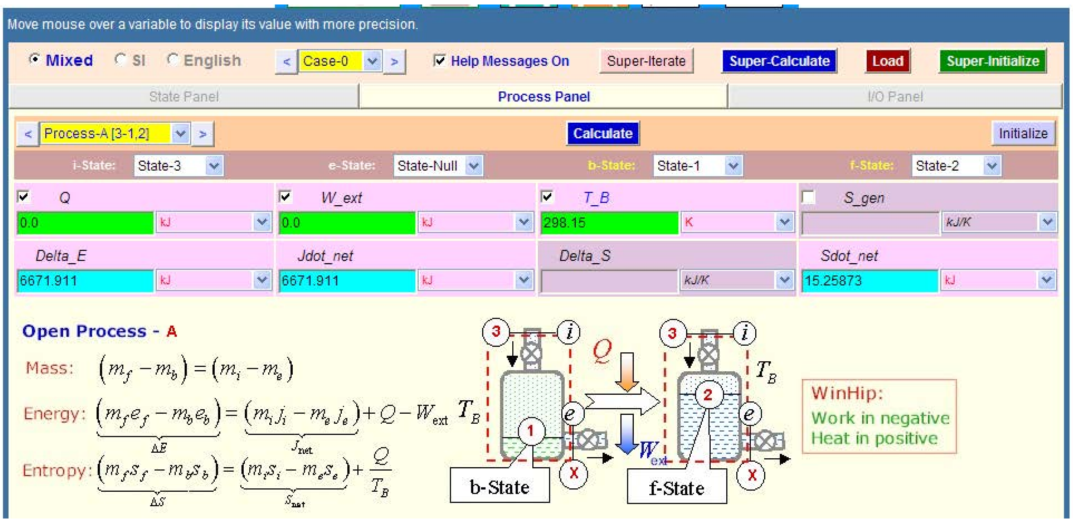
4. Select H2O as the substance and enter data, i.e. P1 = 0, m1 = 0 (since tank is evacuated), and Vol1, for State 1. Press Enter:

5. For State 2, enter P2, and m2 = m3, not known yet. Press Enter:



6. Enter data for State 3, i.e. state of fluid in the pipe, P3, T3 and Vol3 = Vol1. Press Enter:

7. Go to Process Panel, enter i-state = State 3, e-state = Null, and State 1 and State 2 for b-state and f-state respectively, as shown. Also, Q = 0, W_ext = o. Press Enter:



8. **Click on SuperCalculate. Go to State Panel:**

State 2:

Thus, T2 = 452.1 deg. C …. Ans.

9. **I/O panel gives TEST code etc:**

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

 # Daemon Path: Systems>Open>Process>PC-Model; v-10.bb06

#-------------------Start of TEST-code ---

States {
State-1: H2O;
Given: { p1= 0.0 kPa; Vel1= 0.0 m/s; z1= 0.0 m; m1= 0.0 kg; Vol1= 0.4 m^3; }
State-2: H2O;
Given: { p2= 1400.0 kPa; u2= "h3" kJ/kg; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m3" kg; }
State-3: H2O;
Given: { p3= 1400.0 kPa; T3= 300.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; Vol3= "vol1" m^3; }
}

Analysis {
Process-A: ie-State = State-3, State-Null; bf-State = State-1, State-2;
Given: { Q= 0.0 kJ; W_ext= 0.0 kJ; T_B= 298.15 K; }
}

#---------------------End of TEST-code ---

#--------Property spreadsheet:

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	0.0	0.0	0.0	Infinity	0.0	0.0	0.0
# 02	1400.0	725.3		0.2357	3040.33	3370.3	7.459
# 03	1400.0	573.2		0.1823	2785.14	3040.33	6.953

 # Mass, Energy, and Entropy Analysis Results:

Process-A: ie-State = State-3, State-Null; bf-State = State-1, State-2;

Given: Q= 0.0 kJ; W_ext= 0.0 kJ; T_B= 298.15 K;

Calculated: S_gen= 1.1094596 kJ/K; Delta_E= 6671.911 kJ; Jdot_net= 6671.911 kJ; Delta_S= 16.368185 kJ/K;

Sdot_net= 15.258725 kJ;

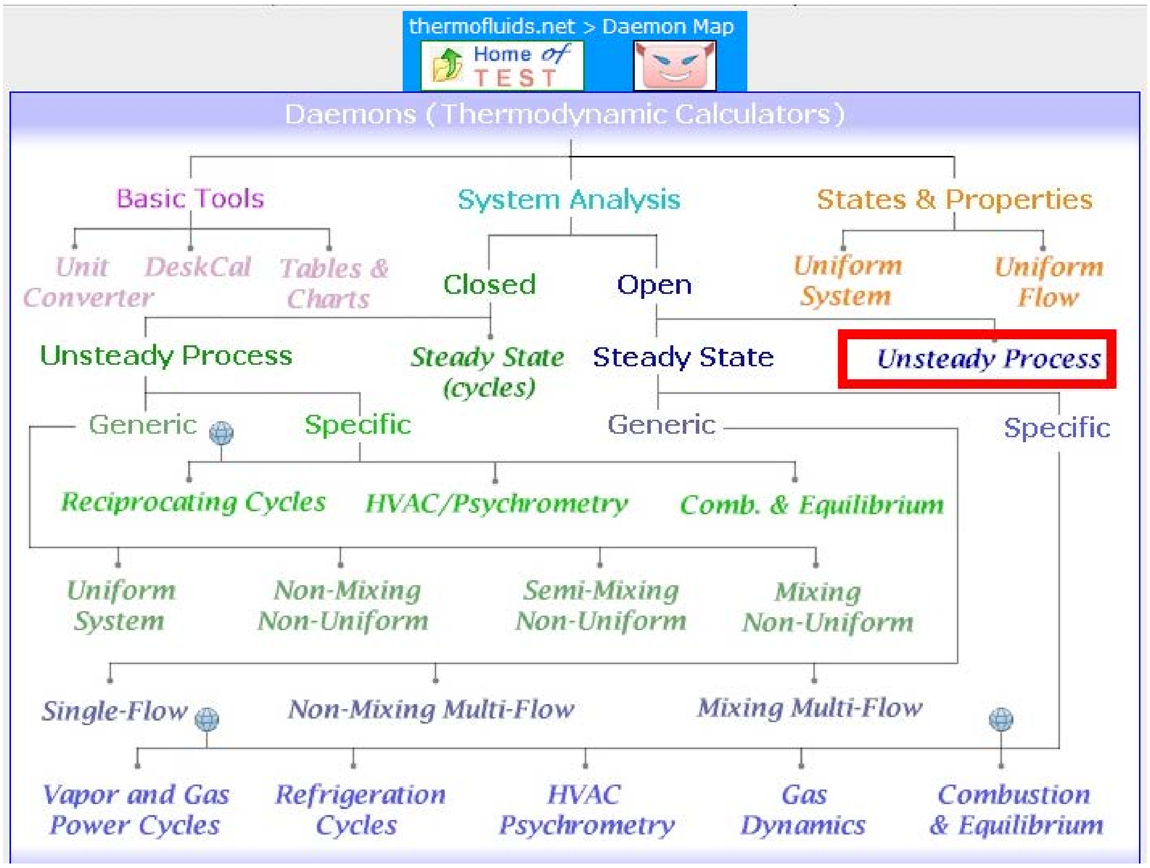
==

Prob.5.38. A 1 m^3 tank contains ammonia at 150 kPa, 25 C. The tank is attached to a line flowing ammonia at 12300 kPa, 60 C. The valve is opened, and mass flows in until the tank is half full of liquid, by volume at 25 C. Calculate the heat transferred from the tank during this process. [Ref. 2]

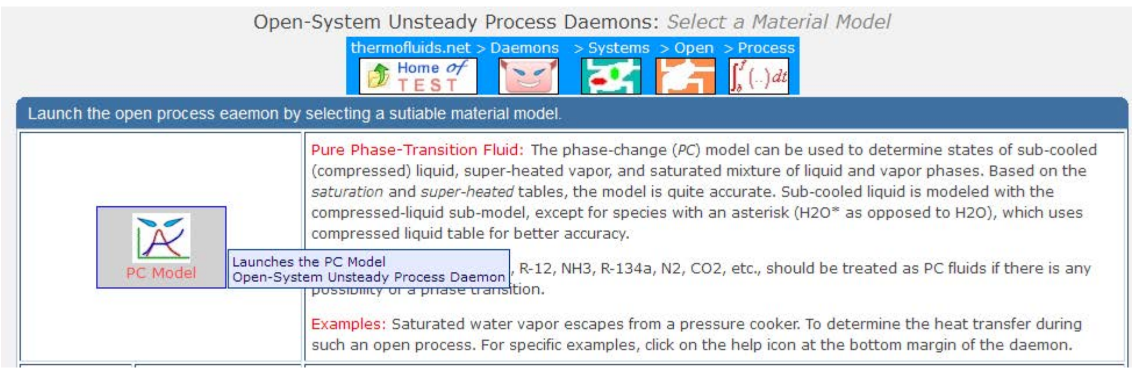
TEST Solution:

This is a problem on charging a tank. i.e. Uniform State, Uniform Flow type of problem. See eqn. 5.14 at the beginning of this chapter.

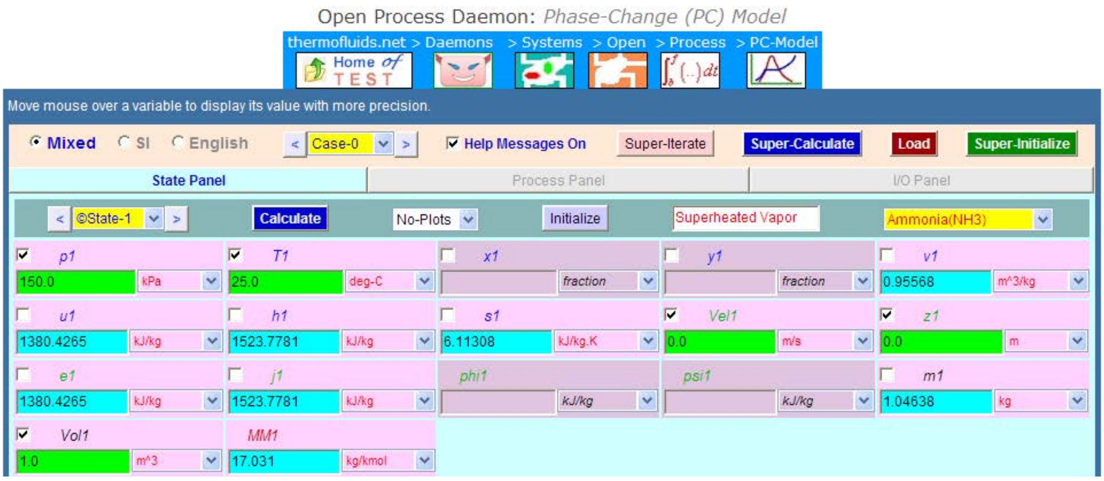
1. Select System Analysis – Open – Unsteady Process daemon as shown below:



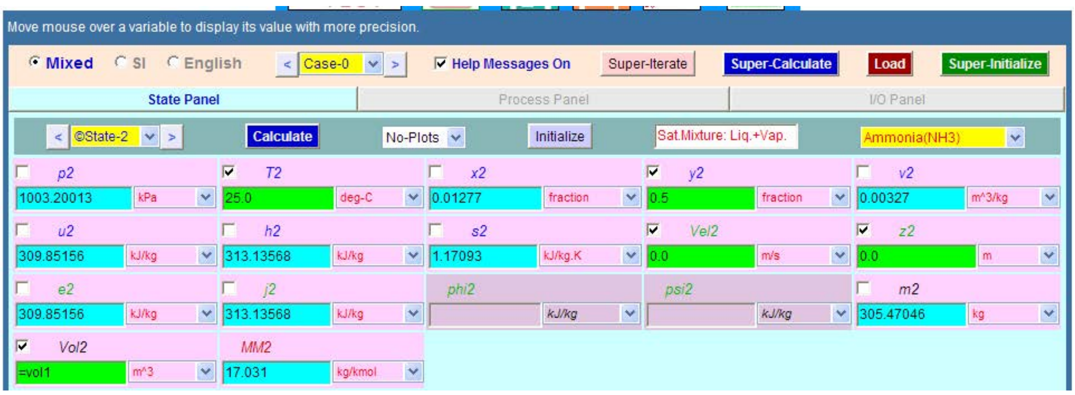
2. Choose PC model for Material model since NH3 is the working substance:



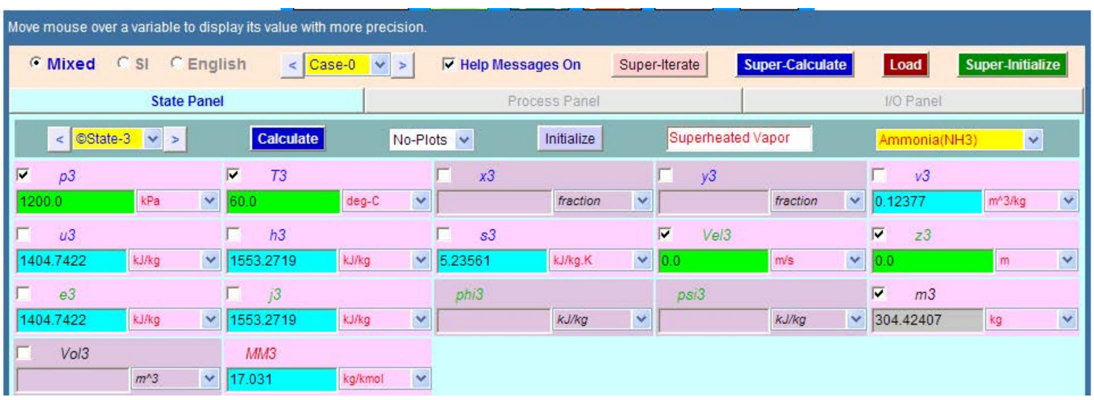
3. Select Ammonia (NH3) as the substance and enter data, i.e. P1, T1and Vol1 for State 1. Press Enter:



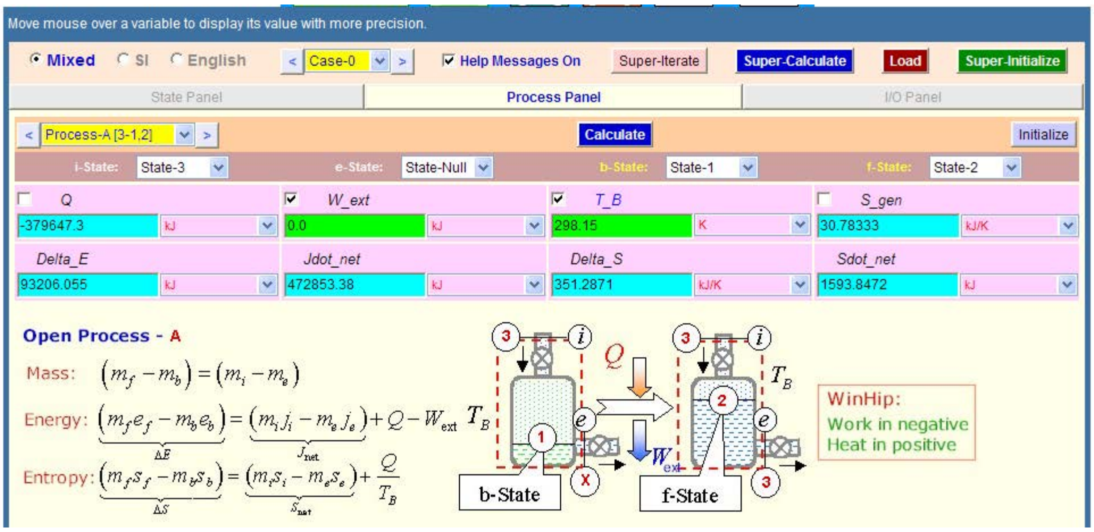
4. Enter the data, viz. T2, Vol2 = Vol1, and y2 = volume fraction = 0.5 for State 2; press Enter:



5. Enter data for State 3 (i.e. fluid flowing in the line), i.e. P3, T3; press Enter:



6. Go to Process panel, enter State 3 for i-state, Null for e-state, and State 1 and State 2 for b-state and f-state respectively. (See the fig. below). Press Enter, and click SuperCalculate:



Thus: Q = -379647.3 kJ …. Ans… (negative sign indicates that heat is rejected).

7. **I/O panel gives TEST code etc:**

#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE :

Daemon Path: Systems>Open>Process>PC-Model; v-10.bb06

#-------------------Start of TEST-code ---

States {
State-1: Ammonia(NH3);
Given: { p1= 150.0 kPa; T1= 25.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 1.0 m^3; }
State-2: Ammonia(NH3);
Given: { T2= 25.0 deg-C; y2= 0.5 fraction; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= "vol1" m^3; }
State-3: Ammonia(NH3);
Given: { p3= 1200.0 kPa; T3= 60.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; }
}

Analysis {
Process-A: ie-State = State-3, State-Null; bf-State = State-1, State-2;
Given: { W_ext= 0.0 kJ; T_B= 298.15 K; }
}
#---------------------End of TEST-code ---

#--------Property spreadsheet starts: ---------------

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	150.0	298.2		0.9557	1380.43	1523.78	6.113
# 02	1003.2	298.2	0.0	0.0033	309.85	313.14	1.171
# 03	1200.0	333.2		0.1238	1404.74	1553.27	5.236

 # Mass, Energy, and Entropy Analysis Results:

Process-A: ie-State = State-3, State-Null; bf-State = State-1, State-2;

Given: W_ext= 0.0 kJ; T_B= 298.15 K;

Calculated: **Q= -379647.3 kJ;** S_gen= 30.783335 kJ/K; Delta_E= 93206.055 kJ; Jdot_net= 472853.38 kJ;

Delta_S= 351.2871 kJ/K; Sdot_net= 1593.847 kJ;

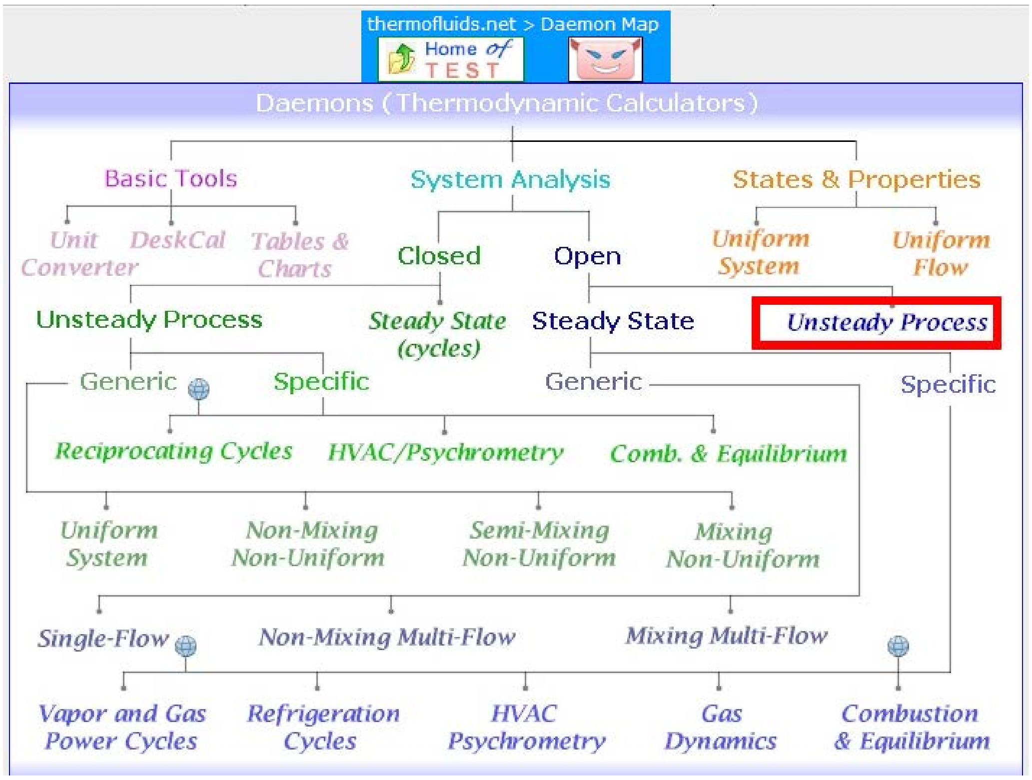
==

Prob. 5.39. A 0.12 m^3 rigid tank initially contains refrigerant R134a at 1 MPa and 100% quality. The tank is connected by a valve to a supply line that carries R134a at 1.2 MPa and 36 C. Now the valve is opened and the refrigerant is allowed to enter the tank. The valve is closed when it is observed that the tank contains sat. liquid at 1.2 MPa. Determine (a) the mass of R134a that has entered the tank (b) the amount of heat transfer [Ref. 1]

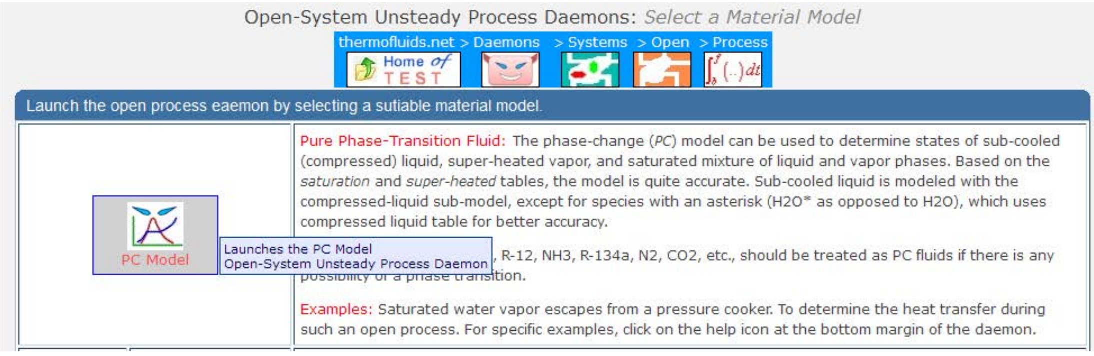
TEST Solution:

This is a problem on charging a tank. i.e. Uniform State, Uniform Flow type of problem. See eqn. 5.14 at the beginning of this chapter.

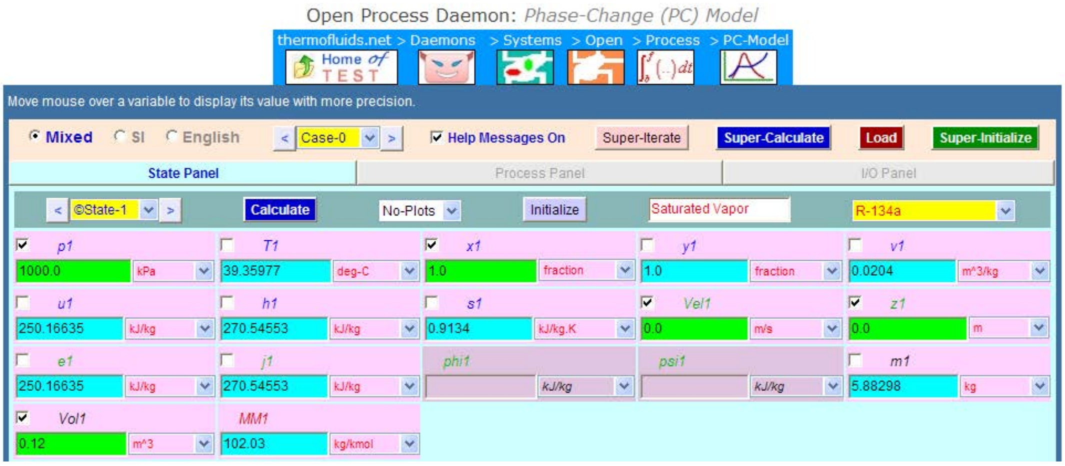
1. Select System Analysis – Open – Unsteady Process daemon as shown below:



2. Choose PC model for Material model since R134a is the working substance:

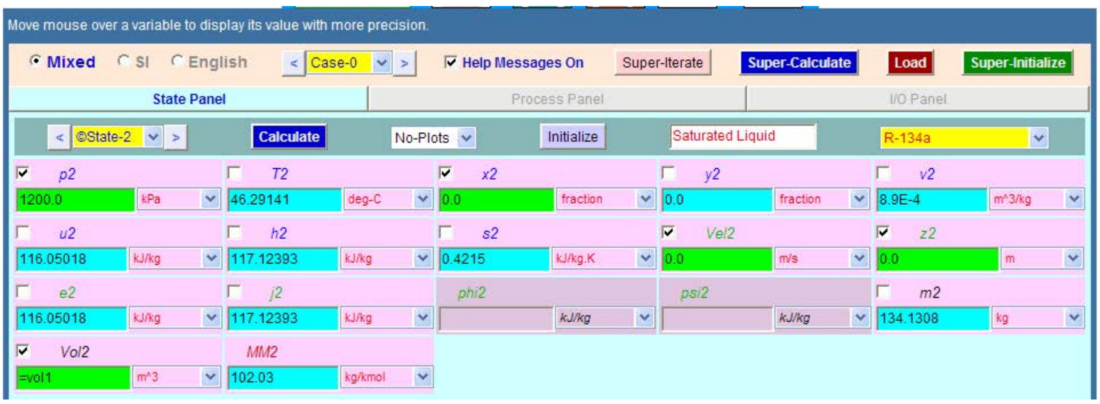


3. Select R134a as the substance and enter data, i.e. P1, x1and Vol1 for State 1. Press Enter:



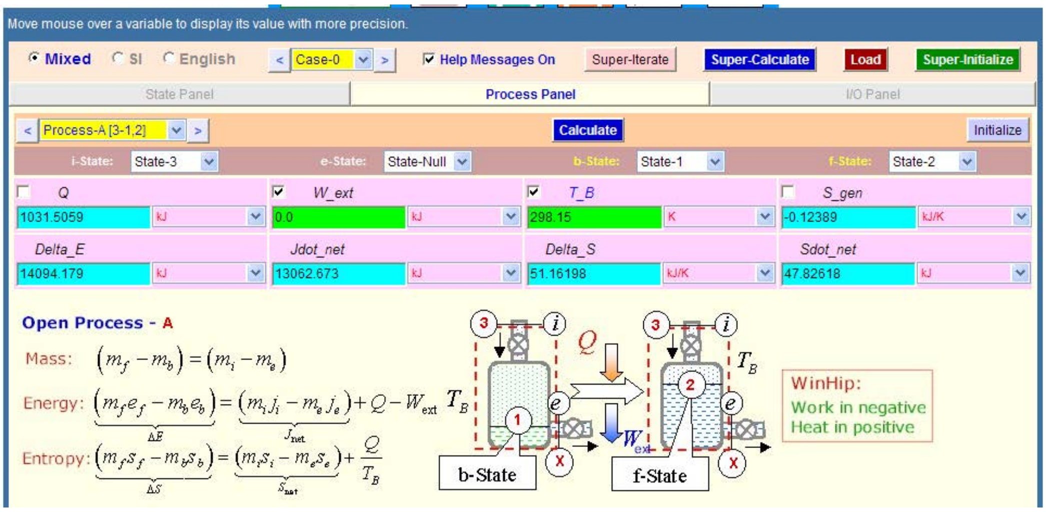
Observe that mass m1 is immediately calculated.

4. Enter P2, x2 and Vol2 = Vol1 for State 2. Press Enter. Immediately, mass m2 is calculated:



5. Enter data i.e. P3, T3 and m3 = (m2-m1) for the State 3, i.e. the R134a flowing in the line. Press Enter:

6. Go to Process panel, enter i-state = State 3, e-state = Null; and enter State 1 and State 2 for b-state and f-state respectively. Also, W_ext = 0, and press Calculate and SuperCalculate. We get:



Thus: Q = 1031.51 kJ (going in to the system), m3 = mi = (m2 – m1) = 128.25 kg …. Ans.

7. Get TEST code etc from the I/O panel:

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

Daemon Path: Systems>Open>Process>PC-Model; v-10.bb06

#-------------------Start of TEST-code ---

States {
State-1: R-134a;
Given: { p1= 1000.0 kPa; x1= 1.0 fraction; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.12 m^3; }
State-2: R-134a;
Given: { p2= 1200.0 kPa; x2= 0.0 fraction; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= "vol1" m^3; }
State-3: R-134a;
Given: { p3= 1200.0 kPa; T3= 36.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m2-m1" kg; }
}

Analysis {
Process-A: ie-State = State-3, State-Null; bf-State = State-1, State-2;
Given: { W_ext= 0.0 kJ; T_B= 298.15 K; }
}

#---------------------End of TEST-code --

#--------Property spreadsheet starts:

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	1000.0	312.5	1.0	0.0204	250.17	270.55	0.913
# 02	1200.0	319.4	0.0	9.0E-4	116.05	117.12	0.421
# 03	1200.0	309.2		9.0E-4	100.82	101.85	0.373

 # Mass, Energy, and Entropy Analysis Results:

Process-A: ie-State = State-3, State-Null; bf-State = State-1, State-2;

Given: W_ext= 0.0 kJ; T_B= 298.15 K;

Calculated: **Q= 1031.5059 kJ;** S_gen= -0.12388586 kJ/K; Delta_E= 14094.179 kJ; Jdot_net= 13062.673 kJ;

Delta_S= 51.161983 kJ/K; Sdot_net= 47.826183 kJ;

==

Prob.5.40. A 100-L rigid tank contains carbon dioxide gas at 1 MPa, 300 K. A valve is cracked open, and carbon dioxide escapes slowly until the tank pressure has dropped to 500 kPa. At this point the valve is closed. The gas remaining inside the tank may be assumed to have undergone a polytropic expansion, with polytropic exponent n =1.15. Find the final mass inside and the heat transferred to the tank during the process. [Ref:2]

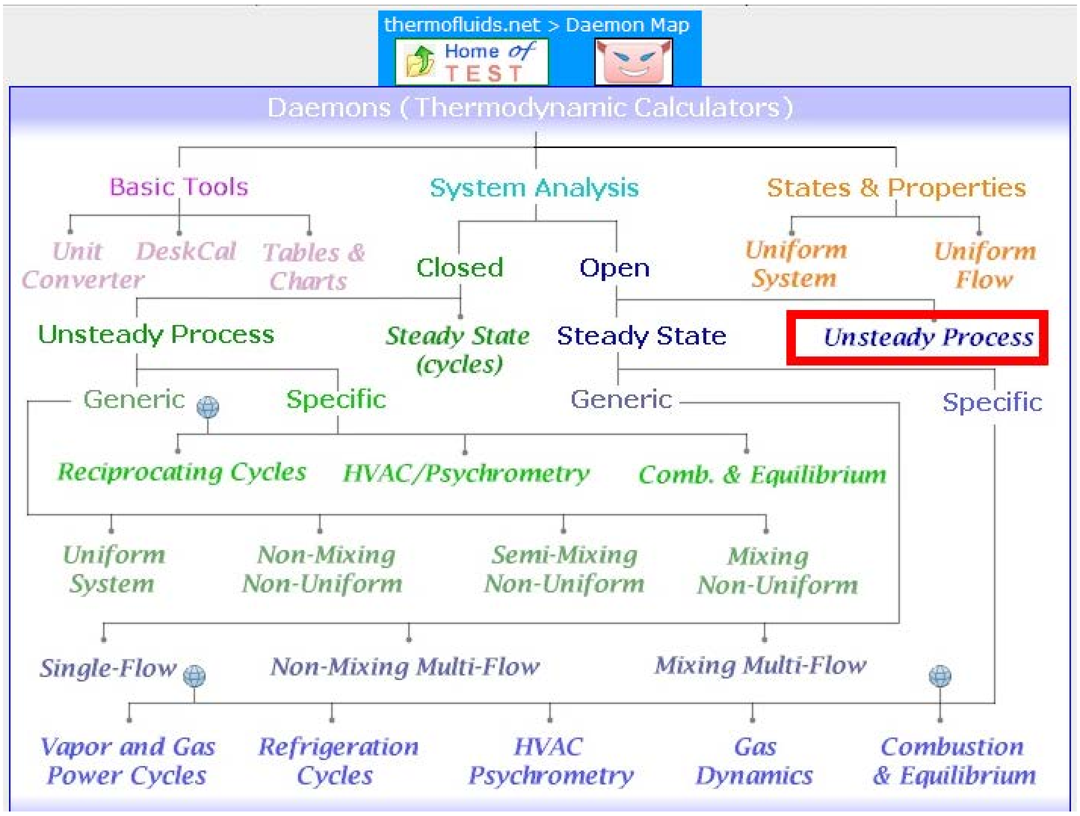
Note that this problem is the same as Prob.5.19, which was solved earlier with EES.

Now, we shall solve it with TEST:

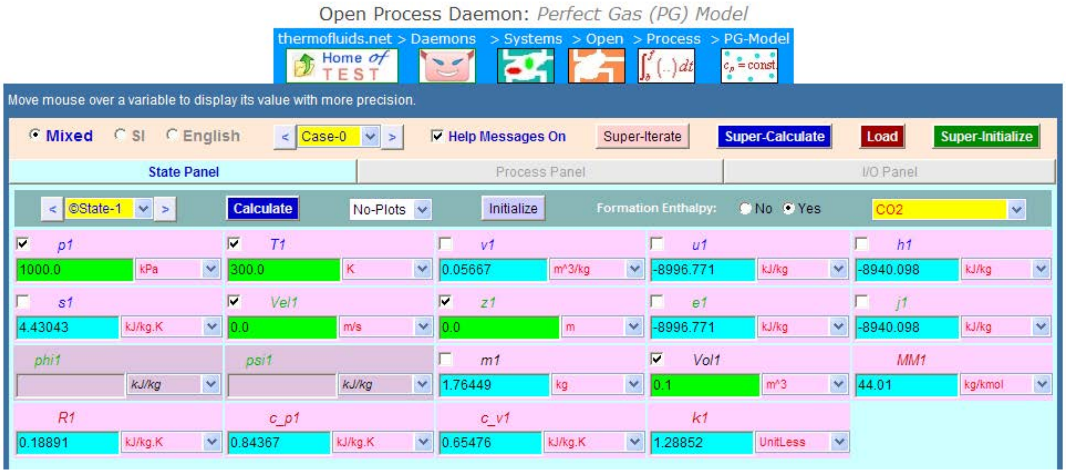
TEST Solution:

This is a problem on discharging a tank. i.e. Uniform State, Uniform Flow type of problem. See eqn. 5.14 at the beginning of this chapter.

1. Select System Analysis – Open – Unsteady Process daemon as shown below:



2. Choose PG model for Material model since CO2 is the working substance. Select CO2 as the working substance and enter data, i.e. P1, T1 and Vol1 for State 1. Press Enter:



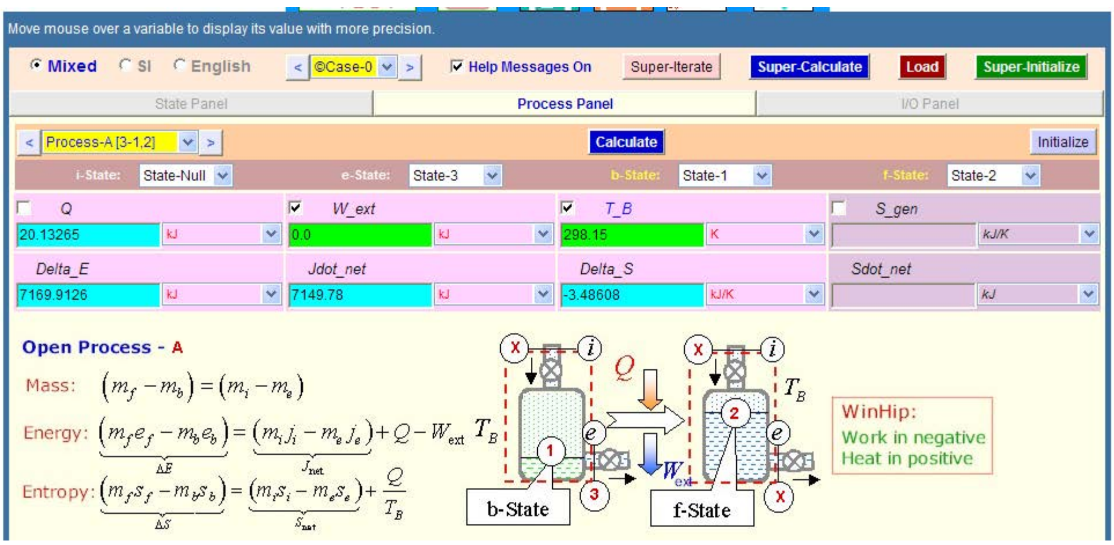
Note that m1 is calculated as 1.76449 kg.

3. Enter P2, T2, Vol2 = Vol1 for State 2; press Enter:

Note that m2 is calculated as 0.96573 kg.

4. State 3 is the state of gas flowing out. Its enthalpy goes on changing during the 'flowing out' process. Let us take the enthalpy as the average of that at the beginning and end of flow, i.e. h3 is average of h1 and h2. And m3 is equal to (m1 – m2). Press Enter:

5. Go to Process panel, enter i-state = Null, e-state = State 3; and enter State 1 and State 2 for b-state and f-state respectively. Also, W_ext = 0. Click on Calculate and SuperCalculate. We get:



Thus: Q = 20.13 kJ (heat transferred in to the tank), m2 = 0.966 kg, T2 = 274.1 K …. Ans.

6. TEST code and other details can be seen in the I/O panel:

```
#~~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

#          Daemon Path: Systems>Open>Process>PG-Model; v-10.bb05

#--------------------Start of TEST-code ---------------------------------------------------------------------

 States  {
            State-1: CO2;
            Given: { p1= 1000.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.1 m^3; }
            State-2: CO2;
            Given: { p2= 500.0 kPa; T2= "T1*(P2/P1)^((1.15 – 1)/1.15)" K; Vel2= 0.0 m/s; z2= 0.0 m;
            Vol2= "Vol1" m^3; }
            State-3: CO2;
            Given: { h3= "(h1+h2)/2" kJ/kg; Vel3= 0.0 m/s; z3= 0.0 m; }
            }

 Analysis {
            Process-A: ie-State = State-Null, State-3; bf-State = State-1, State-2;
            Given: { W_ext= 0.0 kJ; T_B= 298.15 K; }
            }
#----------------------End of TEST-code ---------------------------------------------------------------------
```

#******DETAILED OUTPUT:

Evaluated States:

State-1: CO2 > PG-Model;
Given: p1= 1000.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s;
z1= 0.0 m; Vol1= 0.1 m^3;
Calculated: v1= 0.0567 m^3/kg; u1= -8996.771 kJ/kg; h1= -8940.098 kJ/kg;
s1= 4.4304 kJ/kg.K; e1= -8996.771 kJ/kg; j1= -8940.098 kJ/kg;
m1= 1.7645 kg; MM1= 44.01 kg/kmol; R1= 0.1889 kJ/kg.K;
c_p1= 0.8437 kJ/kg.K; c_v1= 0.6548 kJ/kg.K; k1= 1.2885 UnitLess;
State-2: CO2 > PG-Model;
Given: p2= 500.0 kPa; T2= "T1*(P2/P1)^((1.15 – 1)/1.15)" K; Vel2= 0.0 m/s;
z2= 0.0 m; Vol2= "Vol1" m^3;
Calculated: v2= 0.1036 m^3/kg; u2= -9013.751 kJ/kg; h2= -8961.977 kJ/kg;
s2= 4.4851 kJ/kg.K; e2= -9013.751 kJ/kg; j2= -8961.977 kJ/kg;
m2= 0.9657 kg; MM2= 44.01 kg/kmol; R2= 0.1889 kJ/kg.K;
c_p2= 0.8437 kJ/kg.K; c_v2= 0.6548 kJ/kg.K; k2= 1.2885 UnitLess;
#
State-3: CO2 > PG-Model;
Given: h3= "(h1+h2)/2" kJ/kg; Vel3= 0.0 m/s; z3= 0.0 m;
Calculated: T3= 287.0334 K; u3= -9005.262 kJ/kg; e3= -9005.262 kJ/kg;
j3= -8951.037 kJ/kg; m3= 0.7988 kg; MM3= 44.01 kg/kmol;
R3= 0.1889 kJ/kg.K; c_p3= 0.8437 kJ/kg.K; c_v3= 0.6548 kJ/kg.K;
k3= 1.2885 UnitLess;

#--------Property spreadsheet starts:

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	1000.0	300.0	0.0567	-8996.77	-8940.1	4.43
#	2	500.0	**274.1**	0.1035	-9013.75	-8961.98	4.485
#	3		287.0		-9005.26	-8951.04	

#--------Property spreadsheet ends---

 # Mass, Energy, and Entropy Analysis Results:

Process-A: ie-State = State-Null, State-3; bf-State = State-1, State-2;
Given: W_ext= 0.0 kJ; T_B= 298.15 K;
Calculated: **Q= 20.132648 kJ;** Delta_E= 7169.9126 kJ; Jdot_net= 7149.78 kJ; Delta_S= -3.4860783 kJ/K;

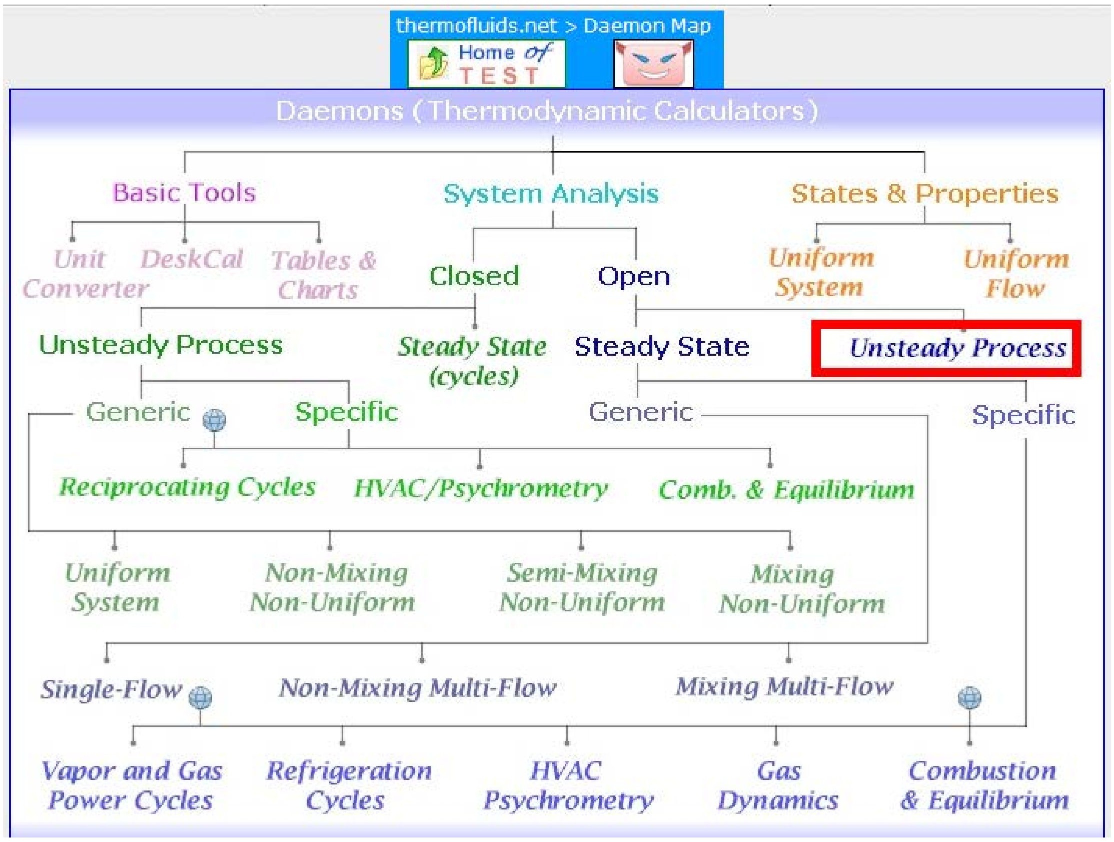
==

Prob.5.41. A rigid tank has a volume of 0.06 m^3 and initially contains two phase liquid-vapour mixture of H2O at a pressure of 15 bar and a quality of 20%. As the tank contents are heated, a pressure regulating valve keeps the pressure constant in the tank by allowing sat. vap. to escape. Neglecting KE and PE changes (a) determine the total mass in the tank, in kg and the amount of heat transfer, in kJ, if heating continues until the final quality is 0.5 (b) plot the total mass in the tank, and the amount of heat transfer versus final quality, x, ranging from x = 0.2 to 1. [Ref. 3]

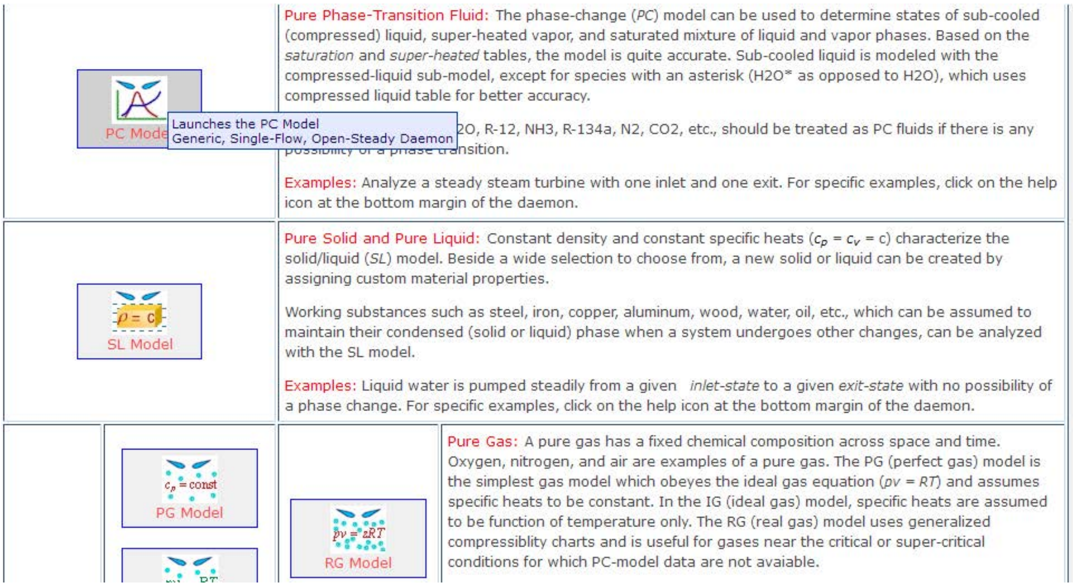
TEST Solution:

This is a problem on discharging a tank. i.e. Uniform State, Uniform Flow type of problem. See eqn. 5.14 at the beginning of this chapter.

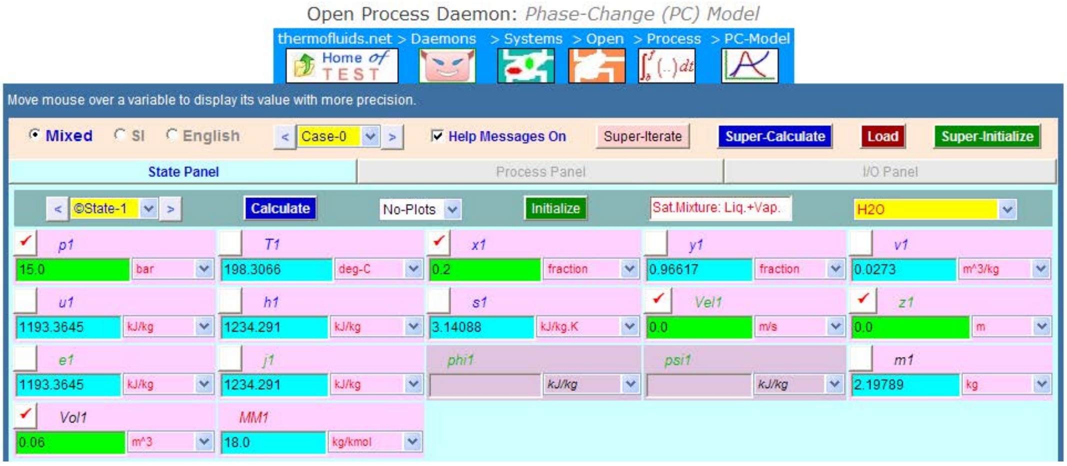
1. Select System Analysis – Open – Unsteady Process daemon as shown below:



2. Choose PC model for Material model since H2O is the working substance.



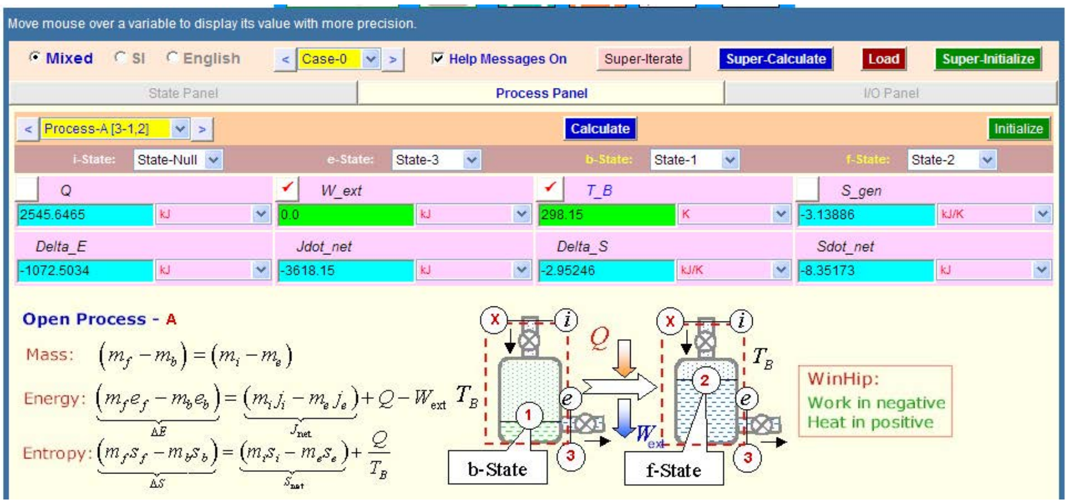
3. Select H2O as the working substance and enter data, i.e. P1, x1 and Vol1 for State 1. Press Enter:



4. Enter P2 = P1, x2 and Vol2=Vol1 for State 2, press Enter:

5. For the fluid flowing out, it is State 3. Enter P3 = P1, x3 = 1 (since, by data, it is sat. vap.) and m3 = (m1-m2). Press Enter:

6. Go to Process panel. Enter i-state = Null, e-state = State 3 (i.e. fluid flowing out). Also, enter States 1 and 2 for b-state and f-state respectively. Enter W_ext = 0. Press Enter. We get:



Note that Q is calculated as: Q = 2545.65 kJ …= heat supplied…. Ans.

7. **Click on SuperCalculate: Go to I/O panel to see TEST code etc:**

#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE :

Daemon Path: Systems>Open>Process>PC-Model; v-10.cb01

#-------------------Start of TEST-code ---

```
States {
    State-1: H2O;
    Given: { p1= 15.0 bar; x1= 0.2 fraction; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.06 m^3; }
    State-2: H2O;
    Given: { p2= "p1" bar; x2= 0.5 fraction; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= "vol1" m^3; }
    State-3: H2O;
    Given: { p3= "p1" bar; x3= 1.0 fraction; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1-m2" kg; }
    }

Analysis {
    Process-A: ie-State = State-Null, State-3; bf-State = State-1, State-2;
    Given: { W_ext= 0.0 kJ; T_B= 298.15 K; }
    }
```

#---------------------End of TEST-code ---

#

```
#******DETAILED OUTPUT:

# Evaluated States:

#       State-1: H2O > Saturated Mixture;
#               Given: p1= 15.0 bar; x1= 0.2 fraction; Vel1= 0.0 m/s;
#                       z1= 0.0 m; Vol1= 0.06 m^3;
#               Calculated: T1= 198.3066 deg-C; y1= 0.9662 fraction; v1= 0.0273 m^3/kg;
#                       u1= 1193.3645 kJ/kg; h1= 1234.291 kJ/kg; s1= 3.1409 kJ/kg.K;
#                       e1= 1193.3645 kJ/kg; j1= 1234.291 kJ/kg; m1= 2.1979 kg;
#                       MM1= 18.0 kg/kmol;
#       State-2: H2O > Saturated Mixture;
#               Given: p2= "p1" bar; x2= 0.5 fraction; Vel2= 0.0 m/s;
#                       z2= 0.0 m; Vol2= "vol1" m^3;
#               Calculated: T2= 198.3066 deg-C; y2= 0.9913 fraction; v2= 0.0665 m^3/kg;
#                       u2= 1718.751 kJ/kg; h2= 1818.4697 kJ/kg; s2= 4.3799 kJ/kg.K;
#                       e2= 1718.751 kJ/kg; j2= 1818.4697 kJ/kg; m2= 0.902 kg;
#                       MM2= 18.0 kg/kmol;
```

```
#        State-3: H2O > Saturated Mixture;
#                 Given: p3= "p1" bar; x3= 1.0 fraction; Vel3= 0.0 m/s;
#                        z3= 0.0 m; m3= "m1-m2" kg;
#                 Calculated: T3= 198.3066 deg-C; y3= 1.0 fraction; v3= 0.1319 m^3/kg;
#                        u3= 2594.395 kJ/kg; h3= 2792.101 kJ/kg; s3= 6.445 kJ/kg.K;
#                        e3= 2594.395 kJ/kg; j3= 2792.101 kJ/kg; Vol3= 0.1709 m^3;
#                        MM3= 18.0 kg/kmol;

#--------Property spreadsheet starts:

# State  p(kPa)     T(K)    x     v(m3/kg)    u(kJ/kg)    h(kJ/kg)    s(kJ/kg)
# 01     1500.0     471.5   0.2    0.0273     1193.36     1234.29      3.141
# 02     1500.0     471.5   0.5   0.0665      1718.75     1818.47      4.38
# 03     1500.0     471.5   1.0   0.1319      2594.4      2792.1       6.445
```

 # Mass, Energy, and Entropy Analysis Results:

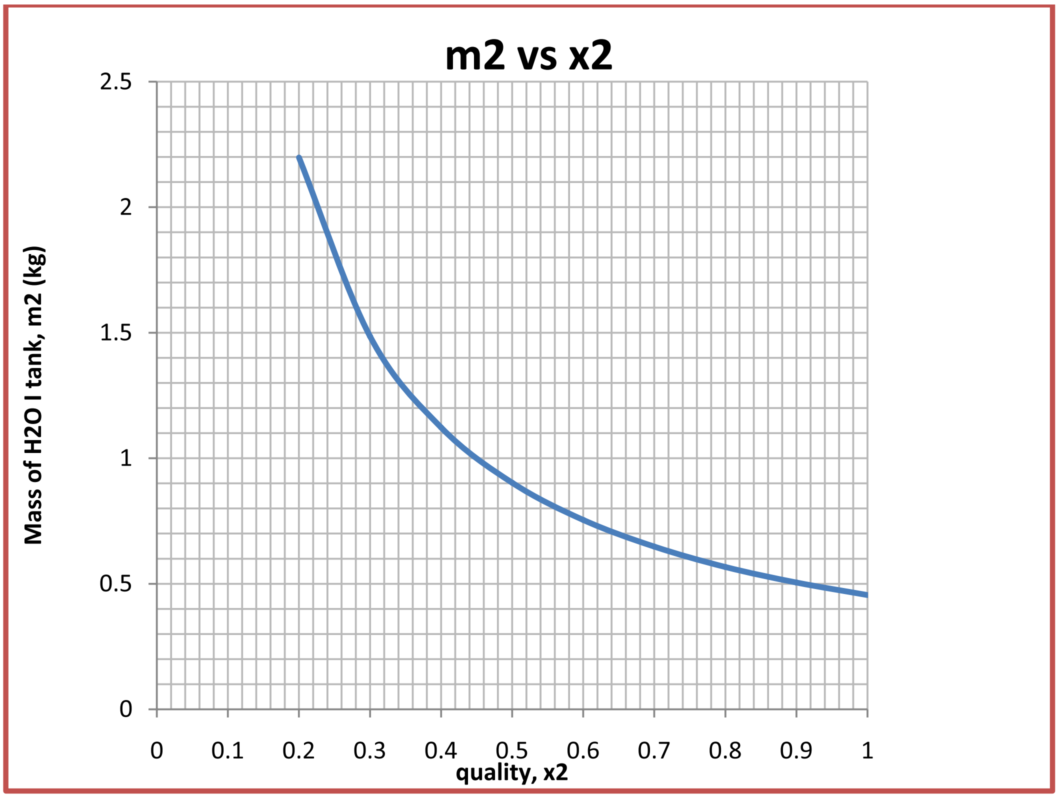
```
#        Process-A: ie-State = State-Null, State-3; bf-State = State-1, State-2;
#                 Given: W_ext= 0.0 kJ; T_B= 298.15 K;
#                 Calculated: Q= 2545.6465 kJ; S_gen= -3.1388645 kJ/K; Delta_E= -1072.5034 kJ; Jdot_
net= -3618.15 kJ;
#                        Delta_S= -2.9524584 kJ/K; Sdot_net= -8.351734 kJ;
```

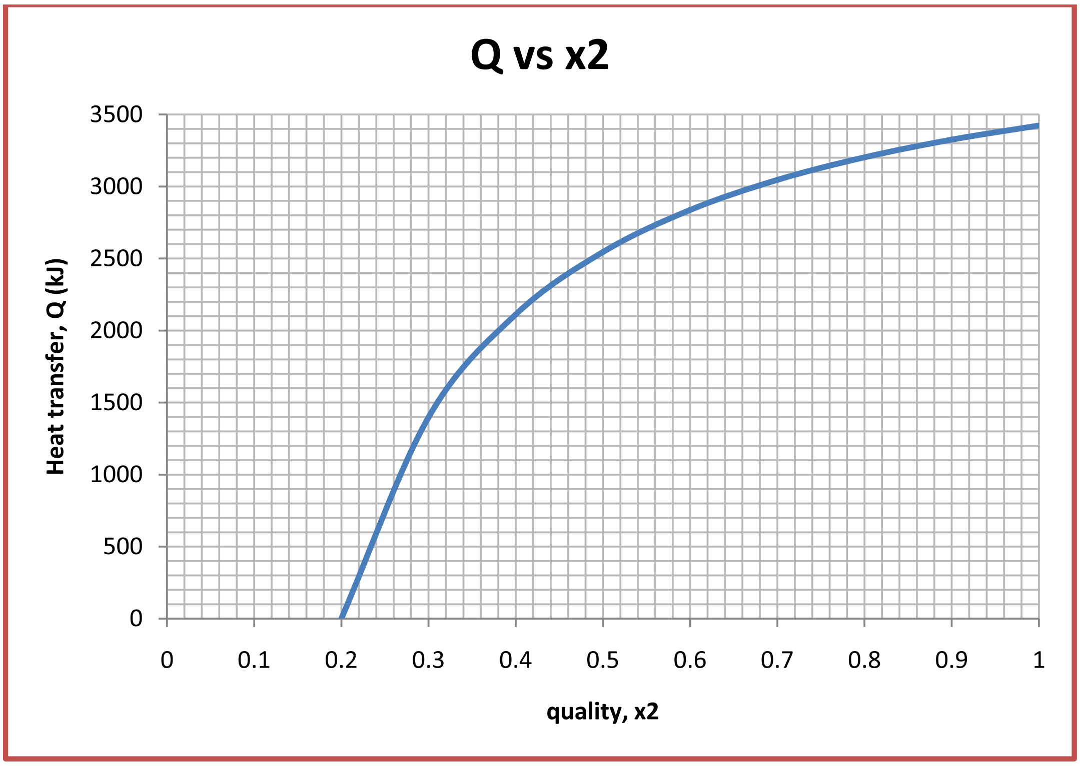
(b) Plot m2, Q against final quality, x2:

The procedure is simple: Go to State 2, change x2 to desired value, press Calculate, and then SuperCalculate. All calculations are immediately up-dated. Read the values of m2 from State 2, and Q from the Process panel. Do this for all desired values of x2 and tabulate as shown below:

x2	m2 (kg)	Q (kJ)
0.2	2.19789	0
0.3	1.486	1398.07
0.4	1.123	2112.21
0.5	0.902	2545.65
0.6	0.754	2836.7
0.7	0.648	3045.63
0.8	0.567	3202.9
0.9	0.505	3325.56
1	0.455	3423.9

Now, plot the results in EXCEL:





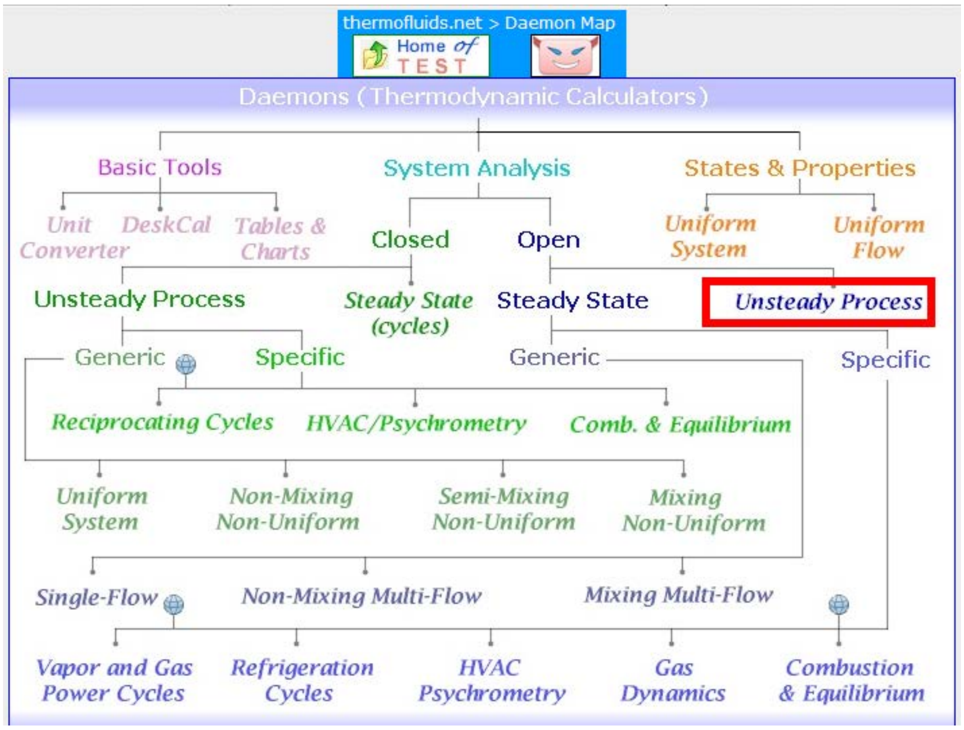
==

Prob.5.42. A well insulated rigid tank of volume 10 m^3 is connected to a large steam line through which steam flows at 15 bar and 280 C. The tank is initially evacuated. Steam is allowed to flow into the tank until the pressure inside is P. (a) Determine the amount of mass in the tank, and the temp in the tank , when P = 15 bar (b) Plot the quantities in part (a) versus P ranging from 0.1 to 15 bar. [Ref. 3]

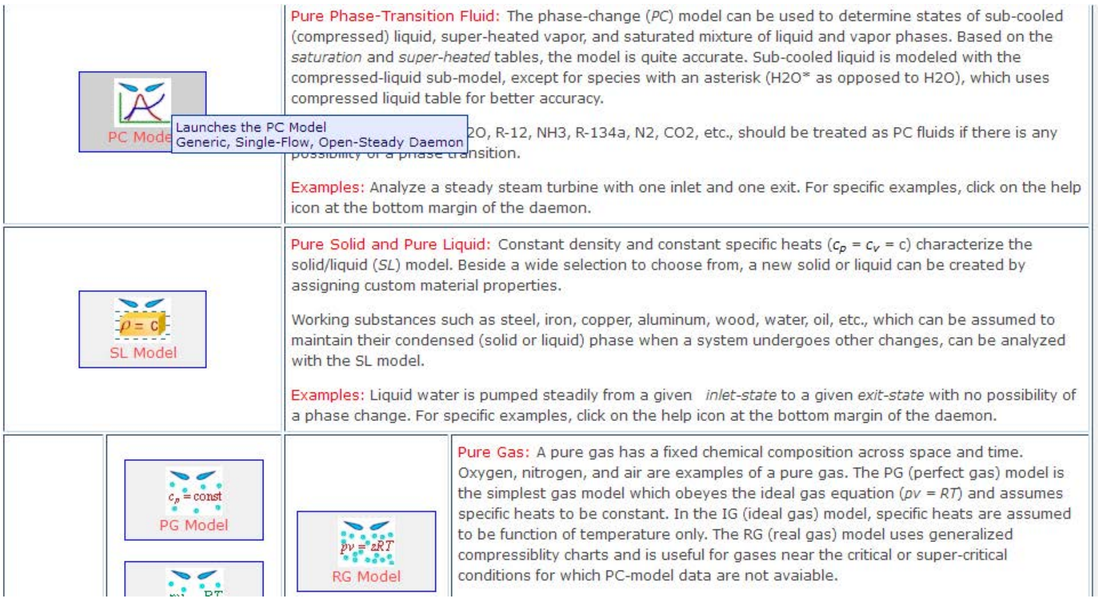
TEST Solution:

This is a problem on charging a tank. i.e. Uniform State, Uniform Flow type of problem. See eqn. 5.14 at the beginning of this chapter.

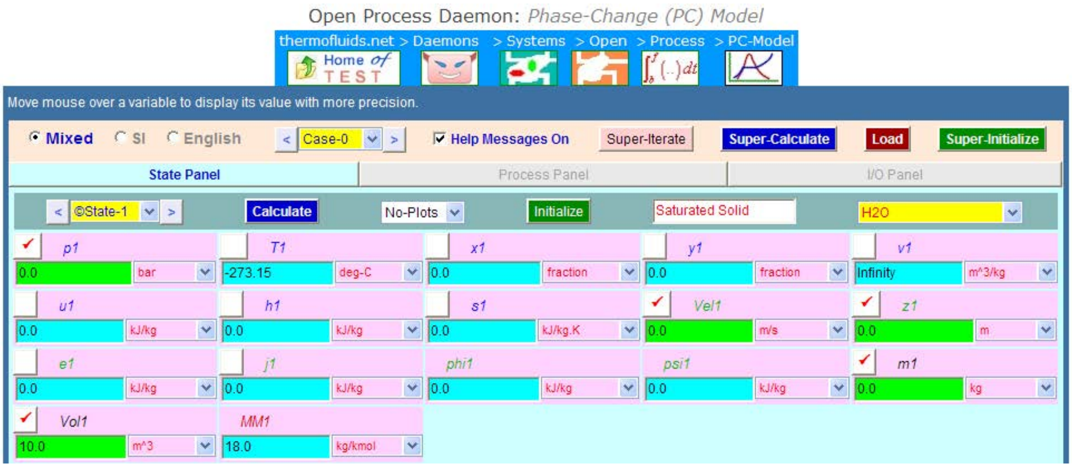
1. Select System Analysis – Open – Unsteady Process daemon as shown below:



2. Choose PC model for Material model since H2O is the working substance.



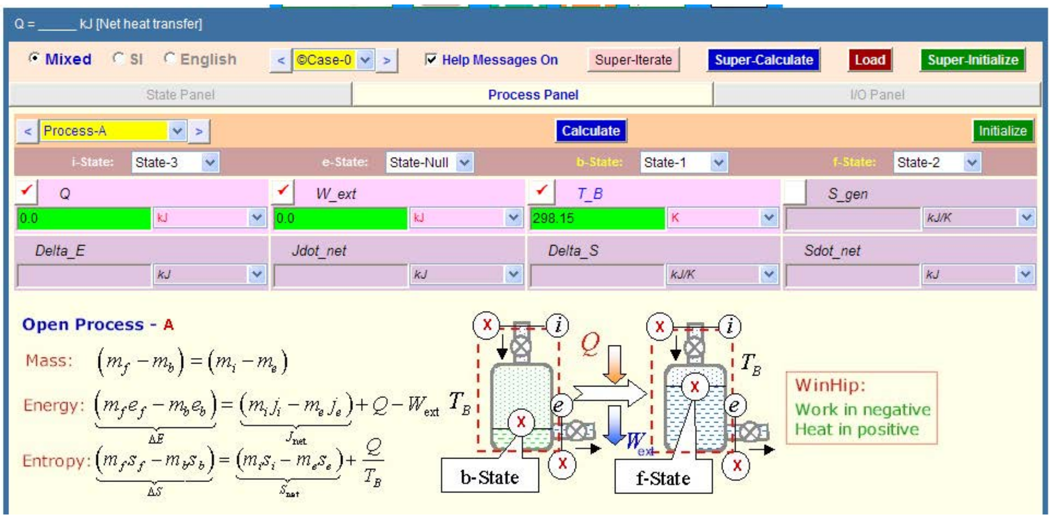
3. Select H2O as the working substance and enter data, i.e. P1= 0, m1= 0 (since evacuated tank), and Vol1 = 10 m^3 for State 1. Press Enter:



4. For State 2, enter P2, Vol2, and u2 = h3 for filling an evacuated tank (see eqn. 5.14 at the beginning of this chapter). Press Enter:

5. State 3 refers to the fluid in the line. Enter P3, T3 and m3 = m2. Press Enter:

6. Now, go to Process Panel. Enter i-state = State 3, e-state = Null, and enter States 1 and 2 for b-state and f-state respectively. Also, enter Q = 0 (since the tank is insulated) and W_ext = 0 (since no external work). Press Calculate:



7. Now, click on SuperCalculate. Go to States panel. We get:

State 1:

State 2:

We see that: T2 = 423.99 C, m2 = 46.46 kg … Ans.

8. **I/O panel gives TEST code etc:**

#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE:

Daemon Path: Systems>Open>Process>PC-Model; v-10.cb01

#--------------------Start of TEST-code ---

```
States {
        State-1: H2O;
        Given: { p1= 0.0 bar; Vel1= 0.0 m/s; z1= 0.0 m; m1= 0.0 kg; Vol1= 10.0 m^3; }
        State-2: H2O;
        Given: { p2= 15.0 bar; u2= "h3" kJ/kg; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= "vol1" m^3; }
        State-3: H2O;
        Given: { p3= 15.0 bar; T3= 280.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m2" kg; }
        }
```

#----------------------End of TEST-code --

#--------Property spreadsheet starts:

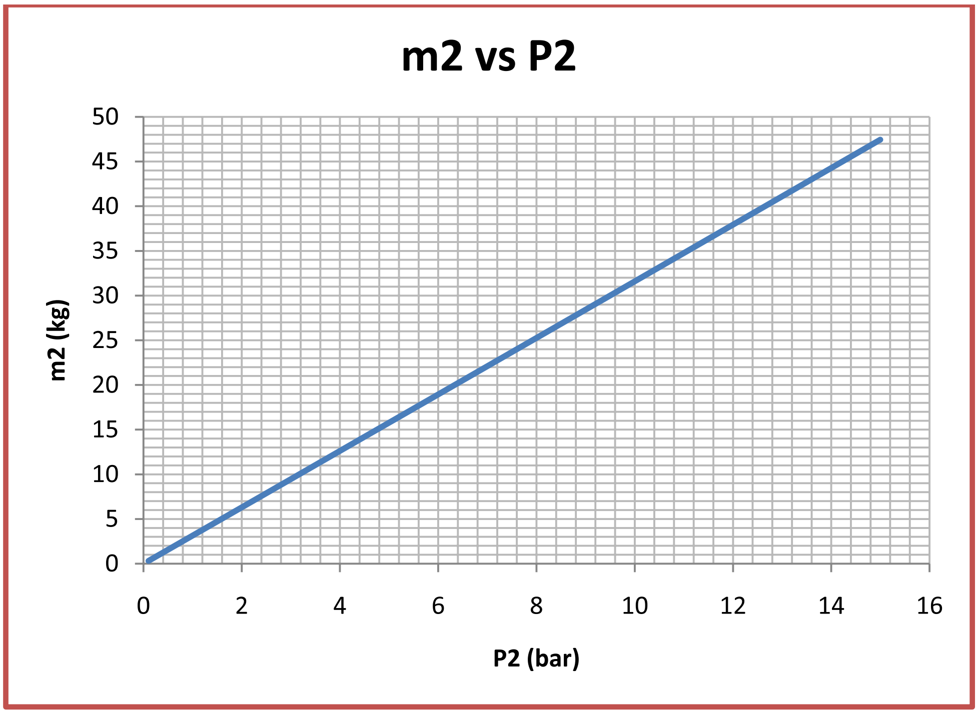
# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	0.0	0.0	0.0	Infinity	0.0	0.0	0.0
# 02	1500.0	697.1		0.2107	2991.81	3307.88	7.341
# 03	1500.0	553.2		0.1626	2747.96	2991.81	6.834

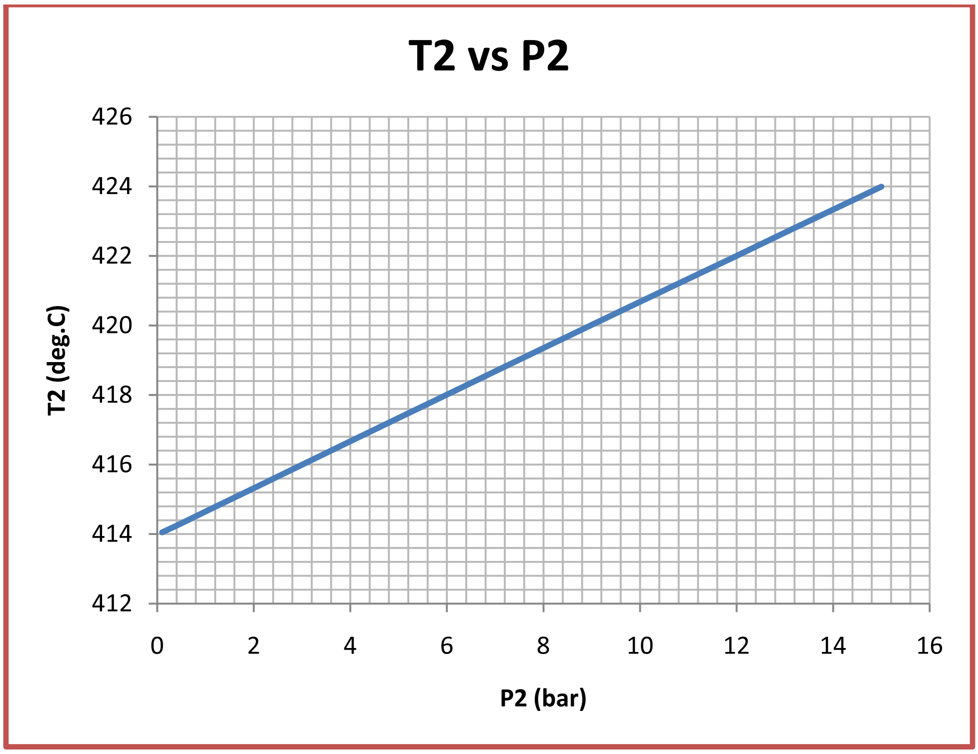
(b) Plot m2, T2 against final pressure P2:

Procedure: Go o State 2, change P2 to desired value, and click on Calculate, and SuperCalculate. Immediately, all calculations are updated. Read the values of T2 and m2. Repeat this procedure for all desired values of P2. Tabulate the results as shown below:

P2(bar)	m2 (kg)	T2 (deg.C)
0.1	0.315	414.05
0.5	1.577	414.31
1	3.154	414.65
2	6.31	415.32
4	12.63	416.67
6	18.95	418.01
8	25.27	419.35
10	31.60	420.68
12	37.94	422.0
13	41.11	422.67
15	47.46	423.99

Now, plot the results in EXCEL:





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5.4 References:

1. *Yunus A. Cengel & Michael A. Boles*, Thermodynamics, An Engineering Approach, 7th Ed. McGraw Hill, 2011.
2. *Sonntag, Borgnakke & Van Wylen*, Fundamentals of Thermodynamics, 6th Ed. John Wiley & Sons, 2005.
3. *Michel J. Moran & Howard N. Shapiro*, Fundamentals of Engineering Thermodynamics, 4th Ed. John Wiley & Sons, 2000.
4. *P.K. Nag*, Engineering Thermodynamics, 2nd Ed. Tata McGraw Hill Publishing Co., 1995.
5. *R.K. Rajput,* A Text Book of Engineering Thermodynamics, Laxmi Publications, New Delhi, 1998.

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