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Basic Thermodynamics: Software Solutions – Part IV

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Availability (or 'Exergy') and Second Law analysis

Basic Thermodynamics: Software Solutions – Part IV
1st edition

ISBN 978-87-403-0704-7

Contents

8 Availability or 'Exergy' and Irreversibility

Learning objectives:

1. First, 'Availability' (or 'Exergy') and its importance in II Law analysis of systems is explained.
2. Available energy referred to a cycle is explained next.
3. Decrease in Available energy when heat is transferred through a finite temperature difference is studied next.
4. Availability in Non-flow systems and Steady flow processes are discussed.
5. Helmholtz and Gibbs Functions are mentioned.
6. Important concept of 'Irreversibility' or 'degradation' or 'dissipation' is explained.
7. 'Effectiveness' of a process with reference to II Law is elaborated.
8. 'Exergy balance' with reference to processes is studied.
9. Concepts of above topics are consolidated with some problems worked out with EES and TEST software.

==

8.1 Definitions, Statements and Formulas used:

8.1.1 'Availability' or 'Available energy' or 'Exergy' [1,5,7]:

Consider a high temp source at temp T_H and the environment (sink) at T_0. Then, a reversible heat engine between the source and the sink will deliver max. work output. However, we also know from II Law that all the heat available can not be converted to work, and some amount of heat is necessarily to be rejected to the sink. So, the amount of heat rejected is the *'unavailable part'* of the energy and the W_{max} obtained is the *'available part'* of the energy.

Thus, by definition: 'A system delivers the max. possible work as it undergoes a reversible process from the specified initial state to the state if its environment, that is, the *'dead state'*. This is the **'useful work potential'** of the system at the specified state and is called **'Exergy'.**

Exergy of heat: If heat Q is supplied at a source temp of T_H and the environment is at T_0, the exergy or the max. work output is:

$$W_{max} = Q \cdot \left(1 - \frac{T_0}{T_H}\right) \quad \text{...eqn. (8.1)}$$

i.e. $$W_{max} = Q - T_0 \cdot \Delta s \quad \text{....eqn. (8.2)}$$

where Δs = entropy change in the process

Also, the unavailable energy (or 'anergy') = T0 .Δs

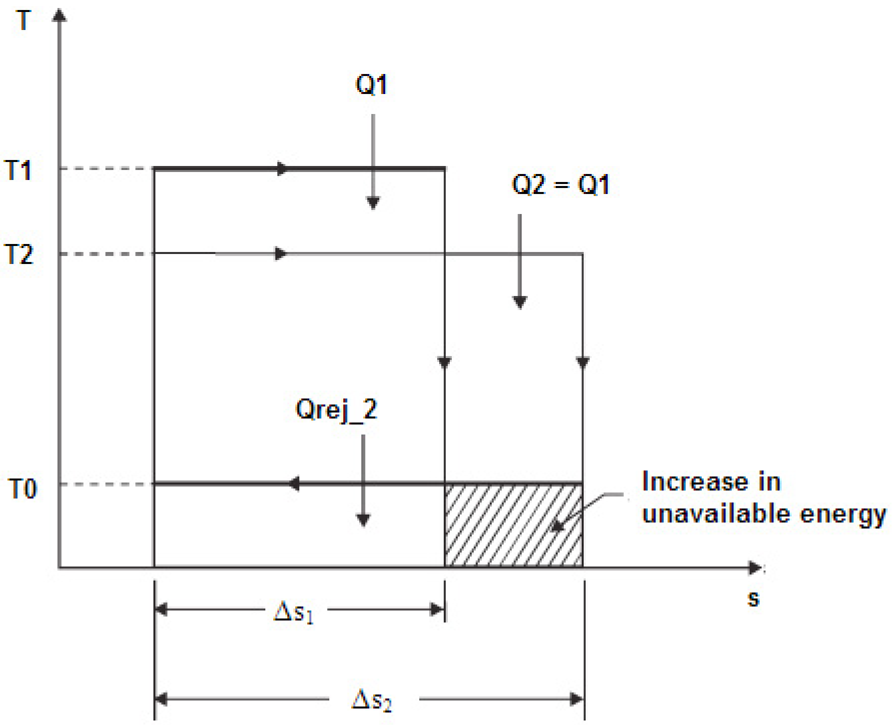
Exergy of Work: Exergy of work is work itself, since there is no Thermodynamic restriction on its availability.

Exergy of Kinetic Energy and Potential Energy: Again, the exergies of K.E. and P.E. are the respective energies themselves.

8.1.2 Decrease in Available energy when heat is transferred through a finite temp. difference:

Whenever heat is transferred through a finite temp difference, there is a decrease in the availability of the energy so transferred.

Consider an amount of heat, Q1, supplied at temp T1, the surrounding being at T0. Then the availability of this heat Q1 supplied at T1 is: $A = W_{max} = (T1 - T0).\ \Delta s_1$



Now, if the *same amount* of heat is supplied from the source at T1 to the engine through a finite temp difference, absorbing heat at a lower temp T2, availability of heat as received by the engine at T2 is calculated as follows:

We have heat supplied: $Q1 = T1\ .\Delta s_1 = Q2 = T2.\Delta s_2$

Since $T2 < T1$, we have: $\Delta s_1 < \Delta s_2$

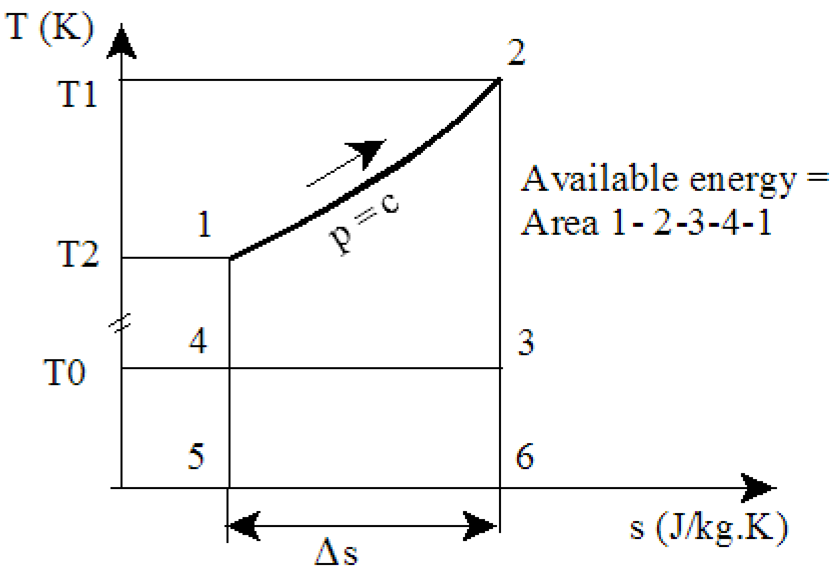
And the heat rejected in the second case: Qrej_2 = T0 . Δs_2 which is more than the heat rejected in the first case, i.e. Qrej_1 = T0 . Δs_1

Therefore, available energy lost = W1 – W2 = T0 . $(\Delta s_2 - \Delta s_1)$ …. Eqn. (8.3)

Note that greater the temp difference (T1 – T2), greater is the heat rejection Qrej_2 and greater is the un-available part of the energy.

If heat is supplied at varying temperatures, i.e. at constant pressure:

Then, Available energy is easily calculated as follows:



Note that:

Heat supplied = cp * (T2 - T1) ....J/kg = Area 1-2-6-5-1

$$\text{Unavailable\_energy} = \text{Area\_4} - 3 - 6 - 5 - 4 = T_0 \cdot \Delta s = T_0 \cdot cp \cdot \ln\left(\frac{T2}{T1}\right) \text{ J/kg}$$

$$\text{Available\_energy} = \text{Area\_1} - 2 - 3 - 4 - 1$$

i.e. Available energy = Area 12651 - Area 43654

i.e. $$\text{Available\_energy} = cp \cdot (T2 - T1) - T_0 \cdot cp \cdot \ln\left(\frac{T2}{T1}\right) \quad \text{J/kg}$$

Note that in the above equations Temp should be in Kelvin.

8.1.3 Availability (or Exergy) in non-flow systems [5]:

Remember that max. useful work or max. available work is the theoretical max. work of the reversible engine ***minus*** the work done on the atmosphere by the expanding boundary.

Let the closed system considered be the fluid behind a piston inside a cylinder, at conditions: p1, T1.

Now, let the state change from State 1 to the ambient or 'dead state' (denoted by p0, T0).

Then, we have:

Max. work *available* = (u1 – u0) – T0 . (s1 – s0) – p0.(v0 – v1) … eqn.(8.4),

where u = int. energy, s = entropy. And p0.(v0 – v1) is the work done on atmosphere.

(Note: when the fluid undergoes a complete cycle, the work done on the atmosphere is zero).

We write eqn. (8.4) as:

$\mathbf{W_{max} = a1 - a0}$ **… eqn. (8.5)**

where, **a = u + p0.v – T0.s** (per unit mass) …. Eqn.(8.6)

is called the ***non-flow availability function***.

Note that '**a**' is a composite property of the system and its environment.

8.1.4 Availability (or Exergy) in steady flow systems [5]:

Let the initial conditions of the flow system be p1, T1, Z1. Let this state be reduced to atmospheric or 'dead state' denoted by p0, T0, Z0 (= 0), through an ideal process. Then,

$$W_{max} = \left(h_1 + \frac{C1^2}{2} + Z1_g\right) - h_0 - T_0 \cdot (s_1 - s_0) \qquad \text{...eqn.(8.7)}$$

In many systems, changes in K.E and P.E. can be considered as negligible. Then,

$$W_{max} = (h_1 - T_0 \cdot s_1) - (h_0 - T_0 \cdot s_0) = b - b_0 \qquad \text{....eqn.(8.8)}$$

where the property, **b = h – T0.s** (per unit mass) is called the ***steady flow availability function***.

Note that '**b**' is a composite property of the system and its environment, and is known as ***Keenan function.***

8.1.5 Helmholtz and Gibbs Functions [5]:

Work in a **non-flow reversible system** is given by:

$$W = Q - (u_0 - u_1) = T \cdot ds - (u_0 - u_1) = T \cdot (s_0 - s_1) - (u_0 - u_1)$$

i.e. $$W = (u_1 - T \cdot s_1) - (u_0 - T \cdot s_0) \qquad \text{....eqn.(8.9)}$$

The term (u – T.s) is known as ***Helmholtz function***.

If the work against atmosphere is p0.(v0 – v1), then:

Max. *available* work =

$$W_{max} = W - p_0 \cdot (v_0 - v_1)$$

But, $$W = (u_1 - T \cdot s_1) - (u_0 - T \cdot s_0)$$

Therefore: $$W_{max} = (h_1 - T \cdot s_1) - (h_0 - T \cdot s_0)$$

i.e. $$W_{max} = g_1 - g_0 \qquad \text{....eqn.(8.10)}$$

where

g = (h – T.s) is known as 'Gibbs function' or 'free energy function'.

Now, max. available work when State changes from 1 to 2, is given by:

$$W_{max} = (g_1 - g_0) - (g_2 - g_0) = g_1 - g_2 \qquad \text{...eqn.(8.11)}$$

Similarly, for steady flow system:

$$W_{max} = (g_1 - g_2) + (KE_1 - KE_2) + (PE_1 - PE_2) \qquad \text{...eqn.(8.12)}$$

Note that Gibbs function, g = (h – T.s) is a property of the system whereas availability function ,i.e. a = (u + p0 . v – T0.s) is a composite property of the system and surroundings.

To summarise:

$$a = u + p_0 \cdot v - T_0 \cdot s$$

$$b = u + p \cdot v - T_0 \cdot s$$

$$g = u + p \cdot v - T \cdot s$$

When State 1 proceeds to 'dead state 0':

$$a = b = g$$

8.1.6 Irreversibility [5]:

***Irreversibility* is defined as:**

$$I = W_{max} - W \quad ..eqn.(8.13)$$

Irreversibility is also known as **'degradation'** or **'dissipation'**.

For a non-flow system, between states 1 and 2, *for unit mass*:

$$I = T_0 \cdot (\Delta s_{sys} + \Delta s_{surr}) = T_0 \cdot \Delta s_{gen} \quad \text{...eqn.(8.14)}$$

i.e. $I \geq 0$

For a steady flow process, *per unit mass*:

$$I = (W_{max} - W) = \left[\left(b_1 + \frac{C_1^2}{2} + g \cdot Z1\right) - \left(b_2 + \frac{C_2^2}{2} + g \cdot Z2\right)\right] - \left[\left(h_1 + \frac{C_1^2}{2} + g \cdot Z1\right) - \left(h_1 + \frac{C_1^2}{2} + g \cdot Z1\right) + Q\right]$$

i.e. $I = T_0 \cdot (\Delta s_{sys} + \Delta s_{surr}) = T_0 \cdot \Delta s_{gen} \quad \text{...eqn.(8.15)}$

Note: Expression for Irreversibility is the same for both the flow and non-flow processes.

8.1.7 Effectiveness [5]:

'Efectiveness' is defined as the ratio of actual useful work to the max. useful work.

Useful output of a system is given by increase of availability of the surroundings.

$$\text{Effectiveness, } \varepsilon = \frac{\text{Increase\_of\_availability\_of\_surroundings}}{\text{Loss\_of\_availability\_of\_the\_system}} \quad \text{...eqn.(8.16)}$$

i.e. $\varepsilon = \dfrac{W_{useful}}{W_{max\_useful}} \quad \text{...eqn.(8.17)}$

Note: Effectiveness of an actual process is always less than unity.

8.1.8 Second Law efficiency, ηII [4]:

Second Law efficiency is defined as:

$$\eta_{II} = \frac{\text{minimum\_exergy\_intake\_to\_perform\_given\_task}}{\text{actual\_exergy\_intake\_to\_perform\_same\_task}}$$

i.e. $\eta_{II} = \dfrac{A_{min}}{A} \quad \text{...eqn.(8.17)}$

where A is the availability or exergy.

A **power plant** converts a fraction of available energy A or W_{max} to useful work. For desired output of W, A_{min} = W and A = W_{max}.

$$\text{Now:} \quad I = W_{max} - W \quad \text{and,} \quad \eta_{II} = \frac{W}{W_{max}} \quad \text{...eqn.(8.18)}$$

Now, I Law efficiency is given by:

$$\eta_I = \frac{W}{Q1} = \frac{W}{W_{max}} \cdot \frac{W_{max}}{Q1} = \eta_{II} \cdot \eta_{carnot} \quad \text{....eqn.(8.19)}$$

$$\text{i.e.} \quad \eta_{II} = \frac{\eta_I}{\eta_{carnot}} \quad \text{...eqn.(8.20)}$$

Remember: If work is involved, A_{min} = W (desired) and,

if heat is involved, A_{min} = Q.(1 – T0/T)

8.1.9 Exergy balance [1]:

For closed systems:

For unit mass:

$$\left(x_{in} - x_{out}\right) - x_{destroyed} = \Delta x_{sys} \quad \text{kJ/kg ...... eqn.(8.24)}$$

where x = exergy

Note that for a reversible process, exergy destroyed = zero.

Also,

$$x_{destroyed} = T_0 \cdot S_{gen} \quad \text{...eqn.(8.25)}$$

For Steady flow systems:

For unit mass:

$$\sum \left(1 - \frac{T_0}{T_k}\right) \cdot q_k - w + \left(\psi_1 - \psi_2\right) - x_{destroyed} = 0 \quad \text{kJ/kg .... eqn.(8.26)}$$

where

heat transfer per unit mass, q = Q/m and

Work transfer per unit mass, w = W/m, and

ψ is flow exergy per unit mass and is given by:

$$\psi = (h - h_0) - T_0 \cdot (s - s_0) + \frac{V^2}{2} + g \cdot z \qquad \text{....eqn.(8.27)}$$

Remember, on unit mass basis:

$$x_{heat} = Q \cdot \left(1 - \frac{T_0}{T}\right) \qquad \text{....exergy of heat}$$

$$x_{work} = w_{useful} \qquad \text{...exergy of work}$$

$$x_{mass} = m \cdot \psi \qquad \text{.....exergy of mass flow}$$

8.1.10 Enthalpy-exergy diagram [6]:

Enthalpy-exergy diagrams are very useful and convenient to make a Second Law analysis of Thermodynamic systems. Exergy is plotted on the y-axis, with enthalpy on the x-axis. So, exergy changes are measured as ordinates in this diagram. Fig. below shows an enthalpy-exergy diagram for helium, drawn by the author, which was used to make an exergy analysis of a helium refrigerator [6].

In the enthalpy-exergy diagram, other lines shown are: const. pressure, constant temp, constant density, and constant entropy lines.

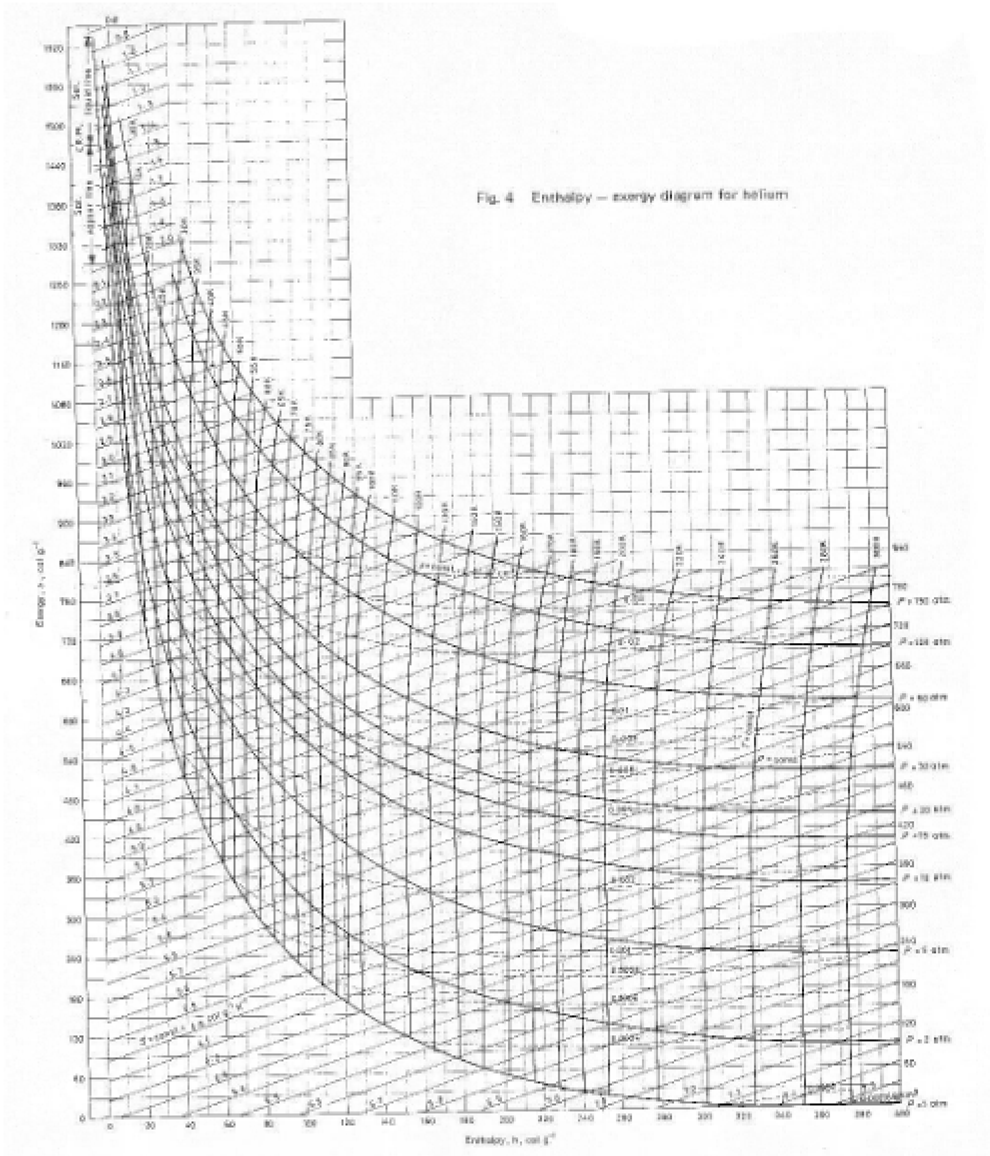


Fig. 4 Enthalpy – exergy diagram for helium

Another way of writing the exergy balance for components of a steady flow system, such as compressors, turbines, throttle valves, heat exchangers etc is as follows[6]:

Remember:

Exergy of heat:

$$e_q = q\cdot\frac{(T - T_0)}{T} = q\cdot\left(1 - \frac{T_0}{T}\right)$$

Exergy of work:

Exergy of work is that itself since there is no thermodynamic restriction on its availability.

Exergy of flow of mass flux:

$$e_{f1} = (h_1 - h_0) - T_0\cdot(s_1 - s_0) \quad \text{kJ/kg...per unit mass}$$

Exergy balance is written as:

$$e_{f1} + e_{q1} + w_1 = e_{f2} + e_{q2} + w_2 + \Delta e \qquad \text{...eqn.(8.28)}$$

where, 1 represents inlets and 2 represents exits, and Δe is the exergy loss.

*As an example, for a **compressor** we can write:.*

$$e_{f1} + w = e_{f2} + \Delta e$$

If the compression is adiabatic: q = 0, and eq =0; and **if it is reversible**, $\Delta e = 0$

Therefore:

$$w = e_{f2} - e_{f1}$$

If the compression is adiabatic, but irreversible, then:

$$w = (e_{f2} - e_{f1}) + \Delta e$$

For an isothermal compression at ambient temp T0, we can write:

$$w = e_{f2} - e_{f1}$$

since though an amount of heat q is evolved during compression, its exergy
eq = 0, compression being at T0.

Similarly:

For an expander, insulated, and with inlet at 3 and exit at 4, we can write:

$$e_3 = e_4 + w + \Delta e_{exp}$$

i.e. $\Delta e_{exp} = (e_3 - e_4) - w$

And, if expansion is isentropic:

$$\Delta e_{exp} = 0$$

==

8.2 Problems solved with EES:

Before we solve problems with EES, let us first write a few useful Functions in EES, which will make it very convenient for us to solve problems:

EES Functions:

1. **To find exergy of heat Q, when heat is supplied at a constant temp. T (ex: condensation, evaporation etc. T0 is the ambient temp.):**

```
$UnitSystem SI Pa C J

FUNCTION ExergyofHeat_ConstTemp(Q,T,T0)

{$ExergyofHeat_constTemp
This function returns the specific availability of a fluid in J/kg as a function of

        Q[J], T [C], T0 (C)

        }

ExergyofHeat_ConstTemp =Q * (1 – (T0 + 273) / (T + 273))

END

"-----------------------------------------------------------------"
```

2. **To find exergy of heat Q, when heat is supplied at a constant pressure (ex: cooling or heating of a fluid between temperatures T and T0, at a constant pressure):**

```
$UnitSystem SI Pa C J

FUNCTION ExergyofHeat_ConstPressure(cp,T,T0)

{$ExergyofHeat_constPressure
This function returns the specific availability of a fluid in J/kg as a function of

       cp[J/kg.C], T [C], T0 (C)

        }

ExergyofHeat_ConstPressure = cp * ( (T – T0) – (T0+273) * ln((T + 273) / (T0 + 273)))

END

"-----------------------------------------------------------------"
```

3. **To find the exergy of mass flow, for an Ideal gas (i.e. enthalpy h is a function of temp only.)**

```
$UnitSystem SI Pa C J

FUNCTION Exergy_massflow_IdealGas(IdealGas$,T, P, V, Z,T0, P0)

{$Exergy_massflow_IdealGas

This function returns the specific availability of IdealGas$ in J/kg as a function of

        T [C], P [Pa], V [m/sec], Z [m], and 'dead state' P0 (Pa), T0 (C)

Ideal gases: Air, Ar, CO, CO2, N2, O2, H2, He, H2O, CH4 etc. See Optios-Function Info-Fluid Props-Ideal gases.

}

g := 9.81 "m/s^2"

h := Enthalpy(IdealGas$, T=T)

s := Entropy(IdealGas$, T=T, P=P)

h0 := Enthalpy(IdealGas$, T=T0)

s0 := Entropy(IdealGas$, T=T0, P=P0)

Exergy_massflow_IdealGas := (h – h0) – (T0+273) * (s – s0) + V^2 / 2 + g * Z

END

"-------------------------------------------------------------"
```

4. **To find the exergy of mass flow, for Real Fluid (i.e. enthalpy h is a function of temp and pressure.)**

```
$UnitSystem SI Pa C J

FUNCTION Exergy_massflow_RealFluid(RealFluid$,T, P, V, Z,T0, P0)

{$Exergy_massflow_RealFluid

This function returns the specific availability of RealFluid$ in J/kg as a function of

    T [C], P [Pa], V [m/sec], Z [m], and 'dead state' P0 (Pa), T0 (C)

RealFluids: Air_ha, Acetone, Ammonia, Argon, R12, R12, R124, R125, R134a, R23, R13, R22, Steam,
Steam_NBS, Steam_IAPWS, Sulphur dioxide, Water, Xenon .. etc.

See Optios-Function Info-Fluid Props-Real Fluids.

    }
```

```
g := 9.81 "m/s^2"

h := Enthalpy(RealFluid$, T=T, P=P)

s := Entropy(RealFluid$, T=T, P=P)

h0 := Enthalpy(RealFluid$, T=T0, P=P0)

s0 := Entropy(RealFluid$, T=T0, P=P0)

Exergy_massflow_RealFluid := (h – h0) – (T0+273) * (s – s0) + V^2 / 2 + g * Z

END

"--------------------------------------------------------------"
```

5. **To find the entropy change for an Ideal gas when the state changes from p1, T1 to p2, T2:**

```
$UnitSystem SI Pa C J

FUNCTION Entropy_change_Idealgas(cp, R, T1,T2, p1, p2)

{$Entropy_change_Idealgas

This function returns the entropy change of an ideal gas as state changes from p1, T1 to p2, T2, in J/kg.K as a function of

        cp[J/kg.C], T [C], p (Pa), R (J/kg.K)

        }

Entropy_change_Idealgas = cp * ln((T2 + 273) / (T1 + 273)) – R * ln (p2 / p1)

END

"----------------------------------------------------------"
```

6. **To find the entropy change for an Ideal gas when the state changes at constant pressure:**

```
$UnitSystem SI Pa C J

FUNCTION Entropy_change_Idealgas_ConstP(cp, T1,T2)

{$Entropy_change_Idealgas_ConstP
This function returns the entropy change of an ideal gas as state changes from T1 to T2, at const. pressure, in J/kg.K as a function of

        cp[J/kg.C], T1, T2 [C], R (J/kg.K)

        }

Entropy_change_Idealgas_ConstP = cp * ln((T2 + 273) / (T1 + 273))

END

"-----------------------------------------------------------------"
```

7. **To find the entropy change for an Ideal gas when the state changes at const. volume:**

```
$UnitSystem SI Pa C J

FUNCTION Entropy_change_Idealgas_ConstV(cv, T1,T2)

{$Entropy_change_Idealgas_ConstV
This function returns the entropy change of an ideal gas as state changes from T1 to T2, at const. volume, in J/kg.K as a function of

        cv[J/kg.C], T1, T2 [C]

        }

Entropy_change_Idealgas_ConstV = cv * ln((T2 + 273) / (T1 + 273))

END

"-------------------------------------------------------"
```

8. **Exergy of a closed system:**

```
$UnitSystem SI Pa C J

FUNCTION Exergy_ClosedSystem_IdealGas(IdealGas$,T, P, T0, P0)

{$Exergy_closedSystem_IdealGas

This function returns the specific availability of IdealGas$ in a closed system, J/kg as a function of

        T [C], P [Pa], and 'dead state' P0 (Pa), T0 (C). Changes in K.E. and P.E. are neglected.

Ideal gases: Air, Ar, CO, CO2, N2, O2, H2, He, H2O, CH4 etc. See Options-Function Info-Fluid Props-Ideal gases.

       }
```

u := IntEnergy(IdealGas$,T=T) "J/kg"

u0 := IntEnergy(IdealGas$,T=T0) "J/kg"

s := Entropy(IdealGas$, T=T, P = P) "J/kg.K"

s0 := Entropy(IdealGas$, T=T0, P = P0)"J/kg.K"

v = Volume(IdealGas$,T= T,P=P) "m^3/kg"

v0 = Volume(IdealGas$,T= T0,P=P0) "m^3/kg"

Exergy_ClosedSystem_IdealGas := (u – u0) – (T0+273) * (s – s0) +p0 * (v – v0) "J/kg"

{W_useful_ClosedSystem_IdealGas := (u – u0) – (T0 + 273) * (s – s0) "J/kg"}

END

===

"**Prob.8.1.** In a certain process, vapours condensing at 400 C transfer heat to water evaporating at 250 C. If the ambient conditions are at 30 C, what is the fraction of available energy lost due to irreversible heat transfer at 250C?"

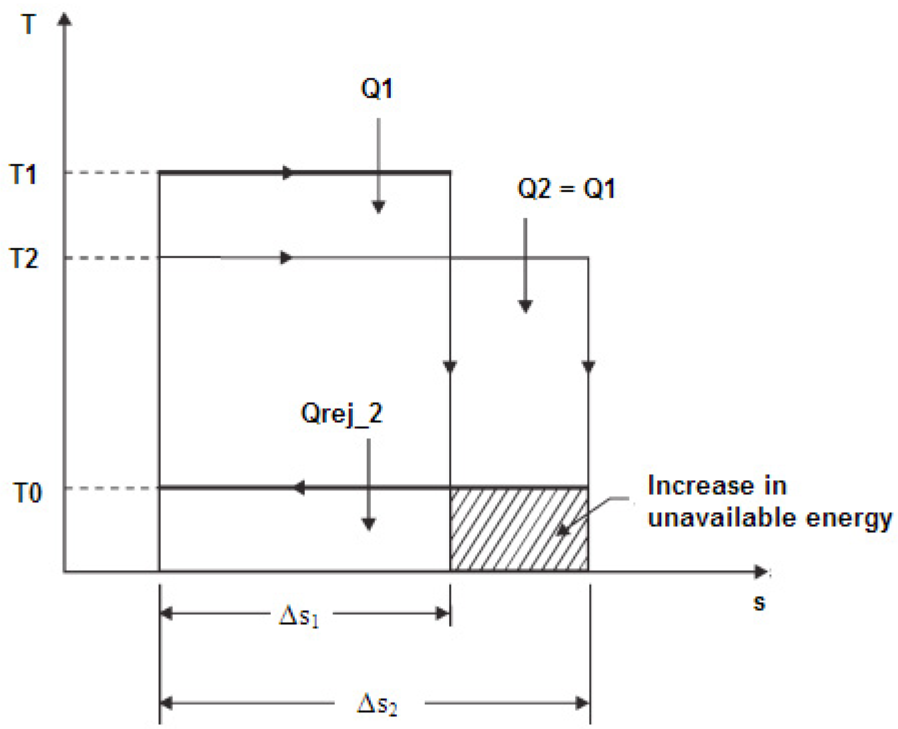


Fig.Prob.8.1

"EES Solution:"

"We shall find out the exergy (or available energy) at 400 C and 250 C, using the Function already written for heat transferred at constant temp. Assume the heat supplied as 100 J and find the difference in exergy:"

"Data:"

Q = 100 "J"

T1 = 400 "C"

T2 = 250 "C"

T0 = 30 "C"

e_q1 = ExergyofHeat_ConstTemp(Q,T1,T0) "J ... exergy of heat supplied at T1"

e_q2 = ExergyofHeat_ConstTemp(Q,T2,T0) "J ... exergy of heat supplied at T2"

Difference = e_q1 – e_q2 "J.... difference in exergies of heat supplied at T1 and T2"

Fraction = Difference / e_q1 "Fraction of difference as compared to exergy of heat supplied at T1"

Results:

Main | ExergyofHeat_ConstTemp

Unit Settings: SI C Pa J mass deg

Difference = 12.91 [J]	e_{q1} = 54.98 [J]	e_{q2} = 42.07 [J]
Fraction = 0.2349	Q = 100 [J]	T0 = 30 [C]
T1 = 400 [C]	T2 = 250 [C]	

Main | ExergyofHeat_ConstTemp

Local variables in Function ExergyofHeat_ConstTemp (2 calls, 0.00 sec)

$\text{ExergyofHeat}_{\text{ConstTemp}}$ =42.07 [J]	Q =100 [J]
T =250 [C]	T0 =30 [C]

Thus,

Fraction of available energy lost due to irreversible heat transfer at 250 C = 0.2349 …Ans.

In addition:

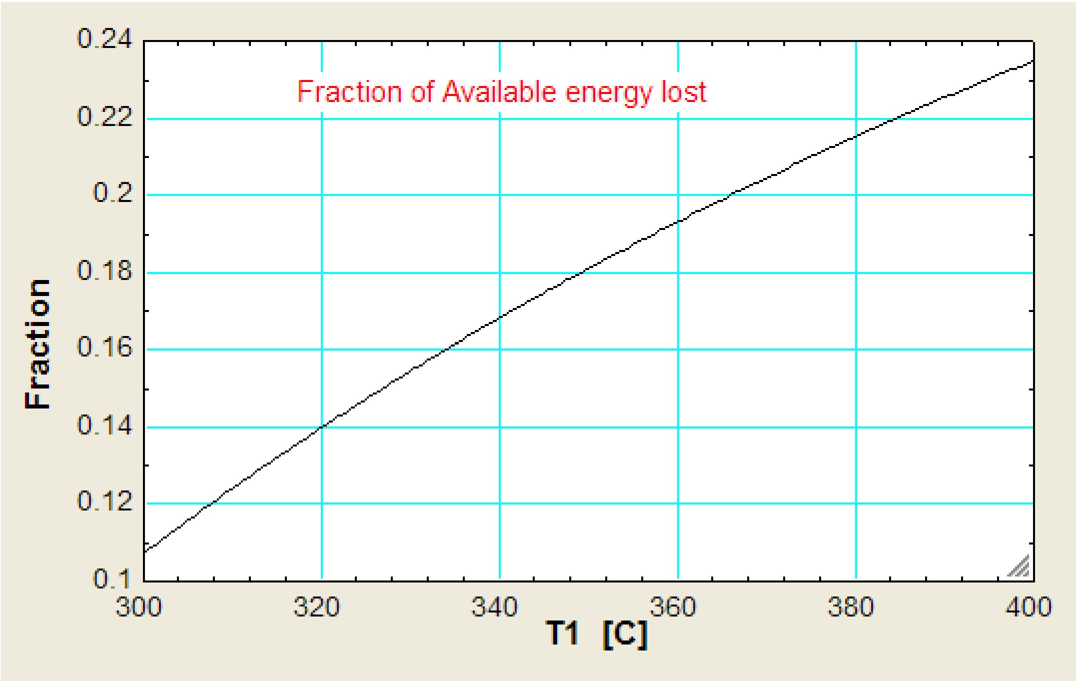
Plot the variation of Fraction as a function of the temp of heat supplied , T1 varies from 300 C to 400 C:

First, compute the Parametric Table:

Table 1

1..11	T1 [C]	Fraction
Run 1	300	0.1073
Run 2	310	0.1241
Run 3	320	0.1398
Run 4	330	0.1545
Run 5	340	0.1682
Run 6	350	0.181
Run 7	360	0.1931
Run 8	370	0.2045
Run 9	380	0.2152
Run 10	390	0.2253
Run 11	400	0.2349

Now, plot the Results:



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"**Prob.8.2.** In a certain process, steam condensing at 106 C transfers heat to increase the temp of 400 kg/min of oil (cp = 3 kJ/kg.K) from 30 C to 80 C. If the ambient conditions are at 7 C, what is the loss in available energy in this heat transfer process?"

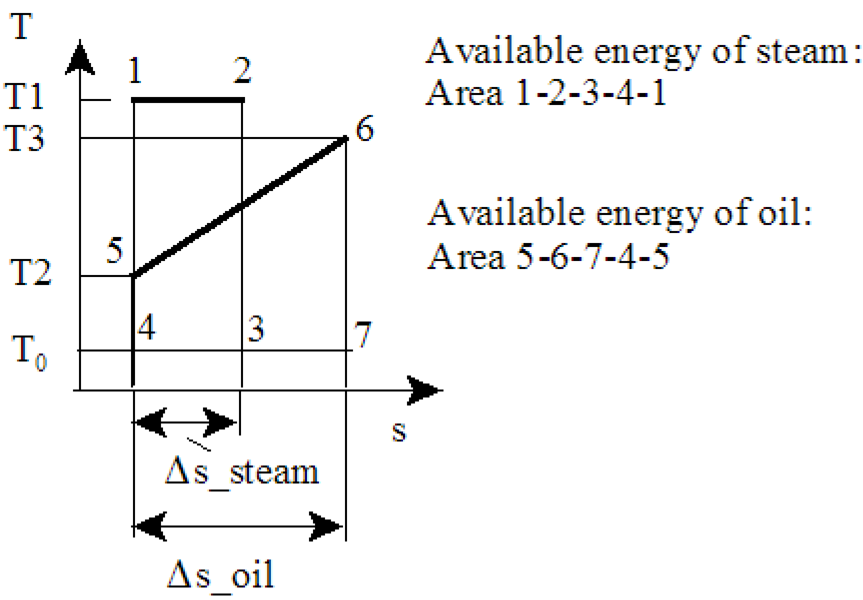


Fig.Prob.8.2

"EES Solution:"

"We shall first, find out the latent heat of steam condensing at 106 C, and then determine the amount of heat required and the amount of steam required to heat 400 kg of oil.

Then, determine exergy (or available energy) of steam at constant temp of 106 C and exergy of oil at constant pressure, using the Functions already written for these cases."

"Data:"

m_oil = 400 "kg/min"

T1 = 106 "C"

h_g = Enthalpy(Steam_NBS,T=T1,x=1)

h_f = Enthalpy(Steam_NBS,T=T1,x=0)

h_fg = (h_g – h_f) "J/kg.... latent heat of steam at 106 C"

cp_oil = 3000 "J/kg.C ... sp. heat of oil"

T2 = 30 "C"

T3 = 80 "C"

T0 = 7 "C"

"Calculations:"

Q = m_oil * cp_oil * (T3 – T2) " J/min...heat gained by oil"

m_steam = Q / h_fg "kg/min ... amount of steam required"

"Method 1: Using the EES Functions written earlier"

e_q_steam = ExergyofHeat_ConstTemp(Q,T1,T0) "J/min ... exergy of heat supplied at T1"

e_q2 = ExergyofHeat_ConstPressure(cp_oil,T2,T0) "J/kg ... exergy of heat supplied at T2"

e_q3 = ExergyofHeat_ConstPressure(cp_oil,T3,T0)"J/kg ... exergy of heat supplied at T3"

"Therefore: exergy change of oil:"

e_q_oil = m_oil * (e_q3 – e_q2) "J/min"

"Therefore: Loss in available energy:"

ExergyLoss = e_q_steam – e_q_oil "J/min"

Results:

Main | ExergyofHeat_ConstTemp | ExergyofHeat_ConstPressure

Unit Settings: SI C Pa J mass deg

cp_{oil} = 3000 [J/kg-K]	ExergyLoss = 6.992E+06 [J/min]
e_{q2} = 2688 [J/kg]	e_{q3} = 24390 [J/kg]
$e_{q,oil}$ = 8.681E+06	$e_{q,steam}$ = 1.567E+07 [J/min]
h_f = 444409 [J/kg]	h_{fg} = 2.241E+06 [J/kg]
h_g = 2.685E+06 [J/kg]	m_{oil} = 400 [kg/min]
m_{steam} = 26.78 [kg/min]	Q = 6.000E+07 [J/min]
T0 = 7 [C]	T1 = 106 [C]
T2 = 30 [C]	T3 = 80 [C]

Main | ExergyofHeat_ConstTemp | ExergyofHeat_ConstPressure

Local variables in Function ExergyofHeat_ConstTemp (1 call, 0.00 sec)

$ExergyofHeat_{ConstTemp}$ =1.567E+07 [J/min]

Q =6.000E+07 [J/min]

T =106 [C]

T0 =7 [C]

Main | ExergyofHeat_ConstTemp | ExergyofHeat_ConstPressure

Local variables in Function ExergyofHeat_ConstPressure (2 calls, 0.00 sec)

cp=3000 [J/kg-K]

$ExergyofHeat_{ConstPressure}$ =24390 [J/kg]

T =80 [C]

T0 =7 [C]

Thus:

Exergy Loss = 6.992E06 J/min …. Ans.

Alternative method:

Find out the Total Entropy change of the system (i.e. steam + oil) = DELTA_S_tot.

Then, Exergy loss = Irreversibility = T0 * DELTA_S_tot

Following is the EES program to do this:

"Data:"

m_oil = 400 "kg/min"

T1 = 106 "C"

h_g = Enthalpy(Steam_NBS,T=T1,x=1)

h_f = Enthalpy(Steam_NBS,T=T1,x=0)

h_fg = (h_g – h_f) "J/kg.... latent heat of steam at 106 C"

cp_oil = 3000 "J/kg.C ... sp. heat og oil"

T2 = 30 "C"

T3 = 80 "C"

T0 = 7 "C"

"Calculations:"

Q = m_oil * cp_oil * (T3 – T2) " J/min...heat gained by oil"

m_steam = Q / h_fg "kg/min ... amount of steam required"

"Method 2:"

"Entropy change of steam:"

DELTA_S_steam = – Q/(T1+273) "J/K ... entropy decrease of steam"

"Entropy change of oil:"

DELTA_S_oil = m_oil * cp_oil * ln ((T3+273) / (T2 + 273)) "J/K.. entropy increase of oil"

"Therefore:"

DELTA_S_tot = DELTA_S_steam + DELTA_S_oil "J/K ... entropy change of (oil + steam)"

"Then: Increase in unavailable energy: or, Loss in exergy:"

ExergyLoss = (T0 + 273) * DELTA_S_tot "J ...Loss in Available energy"

Results:

Unit Settings: SI C Pa J mass deg

cp_{oil} = 3000 [J/kg-K]	$\Delta s_{,oil}$ = 183282 [J/K]
$\Delta s_{,steam}$ = -158311 [J/K]	$\Delta s_{,tot}$ = 24971 [J/K]
ExergyLoss = 6.992E+06 [J/min]	h_f = 444409 [J/kg]
h_{fg} = 2.241E+06 [J/kg]	h_g = 2.685E+06 [J/kg]
m_{oil} = 400 [kg/min]	m_{steam} = 26.78 [kg/min]
Q = 6.000E+07 [J/min]	T0 = 7 [C]
T1 = 106 [C]	T2 = 30 [C]
T3 = 80 [C]	

Thus:

Exergy Loss = 6.992E06 J/min …. Ans.

Note that Exergy loss is the same by both the methods, as it should be.

However, Method 2 is easier.

===

"**Prob.8.3.** 450 kJ of heat from a large source at 900 K is supplied to 2 kg of a gas initially at 2 bar and 350 K in a closed tank. cv = 0.86 kJ/kg.K for the gas. Find the loss in available energy of the system. Surrounding temp = 300 K."

"EES Solution:"

"Data:"

Q = 450E03"J"

T_source = 900 "K"

m_gas = 2 "kg"

P1 = 2E05 "Pa"

T1 = 350 "K"

cv = 860 "J/kg.K"

T0 = 300 "K"

"Calculations:"

"Final temp of gas, T2:"

"Applying I Law to the closed system:

Q = dU + W.

Here W = 0 since vol is const. and dU = cv * (T2 – T1).

Therefore:"

Q = m_gas * cv * (T2 – T1) "...finds T2, in Kelvin"

"We shall calculate the entropy decrease in the Source and entropy increase of the gas. Then, find net entropy increase, and then find loss in availability from: Loss = T0 * dS_net"

"Entropy decrease for Source:"

dS_source = – Q / T_source "J/K .... negative, since heat is leaving the source"

"Entropy increase for gas:"

dS_gas = m_gas * cv * ln (T2/T1) "J.K ... entropy increase of gas"

"Therefore, dS_net:"

dS_net = dS_source + dS_gas "J/K... net entropy change of (source + gas)"

"Therefore: Loss in availability:"

Loss = T0 * dS_net "J ....Loss in Availability"

Results:

Unit Settings: SI C Pa J mass deg

cv = 860 [J/kg.K]	dS_{gas} = 960.1 [J/K]	dS_{net} = 460.1 [J/K]
dS_{source} = -500 [J/K]	Loss = 138027 [J]	m_{gas} = 2 [kg]
P1 = 200000 [Pa]	Q = 450000 [J]	T0 = 300 [K]
T1 = 350 [K]	T2 = 611.6 [K]	T_{source} = 900 [K]

Thus:

Loss in Availability = 138.027 kJ …. Ans.

In addition:

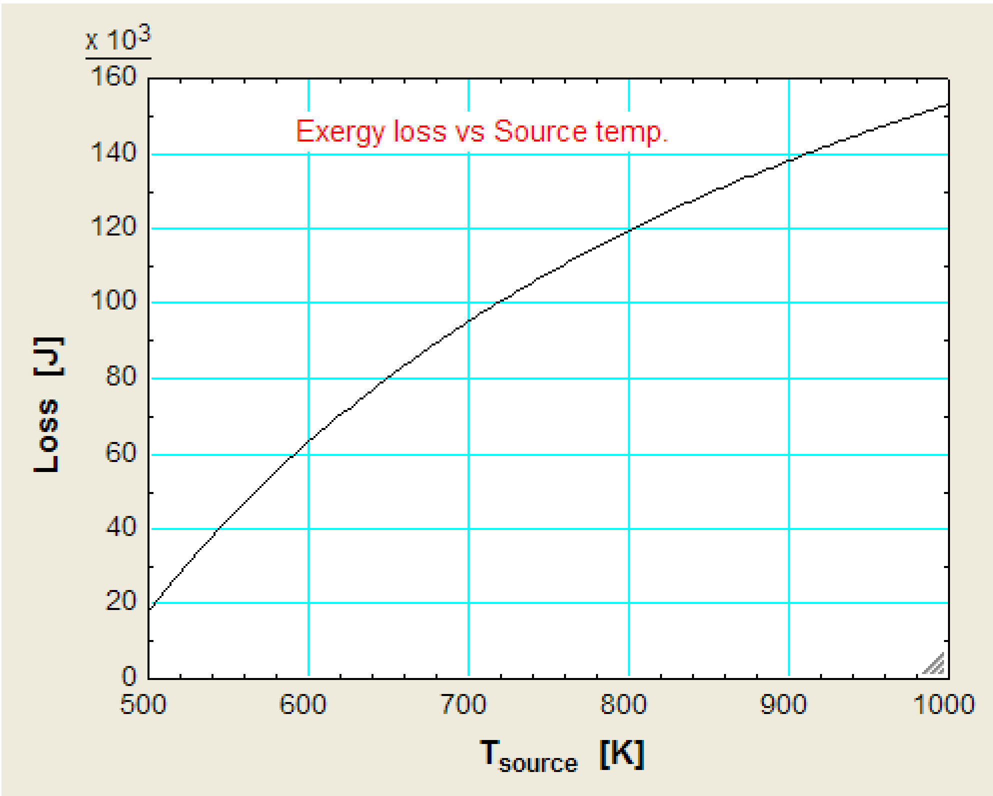
Plot the variation of Loss in exergy as the source temp varies from 500 K to 1000 K, the amount of heat Q remaining constant:

First, compute the Parametric Table:

Table 1

1..11	T_{source} [K]	Loss [J]
Run 1	500	18027
Run 2	550	42572
Run 3	600	63027
Run 4	650	80334
Run 5	700	95169
Run 6	750	108027
Run 7	800	119277
Run 8	850	129203
Run 9	900	138027
Run 10	950	145921
Run 11	1000	153027

Now, plot the Results:



==

"**Prob.8.4.** A system at 500 K receives 7200 kJ/min from a source at 1000 K. The temp of atmosphere is 300 K. Assuming that the temp of the system and source remain constant during heat transfer, find out: (i) the change in entropy during heat transfer (ii) the decrease in available energy after heat transfer. [VTU – BTD – June–July 2008]"

"EES Solution:"

"Data:"

Q = 7200E03"J/min"

T_source = 1000 "K"

T_system = 500 "K"

T0 = 300 "K"

"Calculations:"

"Entropy decrease of Source:"

dS_source = – Q / T_source "J/K per min"

"Entropy increase of system:"

dS_system = Q / T_system "J/K per min"

"Net increase of entropy:"

dS_net = dS_source + dS_system "J/K per min"

"Loss in Availability:"

Loss = T0 * dS_net "J/min"

Results:

Unit Settings: SI C Pa J mass deg

dS_{net} = 7200 [J/K-min]	dS_{source} = -7200 [J/K-min]
dS_{system} = 14400 [J/K-min]	Loss = 2.160E+06 [J/min]
Q = 7.200E+06 [J/min]	T0 = 300 [K]
T_{source} = 1000 [K]	T_{system} = 500 [K]

Thus:

Net change of entropy = dS_net = 7200 J/K per min….. Ans.

Loss in availability = 2.16E06 J/min …. Ans.

==

"**Prob.8.5.** Two kg of air at 5 bar, 80 C expands adiabatically in a closed system until its volume is doubled and its temp becomes equal to that of the surroundings which is at 1 bar and 5 C. Determine: (i) Max work (ii) change in Availability (iii) Irreversibility. [VTU – BTD-June–July 2009]"

"EES Solution:"

"Data:"

m_air = 2 "kg"

T1 = 80 + 273 "K"

P1 = 5E05 "Pa"

P2 = 1E05 "Pa"

T2 = T0 "....by data"

P0 = 1E05 "Pa .... atm. pressure"

V2 = 2 * V1

T0 = 5 + 273 "K"

R_air = 287 "J/kg.K .... Gas constant for Air"

gamma = 1.4 " = (cp/cv) for air"

"Calculations:"

"Initial Volume, V1:"

P1 * V1 = m_air * R_air * T1 "....finds Volume V1"

"Applying I Law to Closed system:

Q = dU + W"

"Here Q = 0 since adiabatic and dU = cv * (T2 – T1).

Therefore:"

cv = R_air / (gamma – 1) "...finds cv, sp. heat at const. vol.....since R = (cp – cv)"

dU = m_air * cv * (T2 – T1) "...finds change in Int. energy"

"To find change in entropy of air:"

dS_air = m_air * (cv * ln (T2/T1) + R_air * ln (V2/V1))"J/K"

"Change in entropy of surroundings:"

dS_surr = 0 "...since adiabatic"

"Net increase in entropy:"

dS_net = dS_air + dS_surr "J.K...net increase in entropy"

"Therefore: W_max:"

"W_max = (U1 – U2) – T0 * (S1 – S2)...from definition of max. work or availability"

W_max = -dU – (- T0 * dS_air) "J ..Max. work"

"Change in Availability:"

"Change_in_availability = (U1 – U2) – T0 * (S1 – S2) + P0 * (V1 – V2)"

Change_availability = -dU – T0 * (-dS_air) + P0 * (V1 – V2) "J"

"Irreversibility:"

Irreversibility = T0 * dS_net "J ... Irreversibility for the process"

Results:

Unit Settings: SI C Pa J mass deg

$Change_{availability}$ = 82424 [J]

dS_{air} = 55.12 [J/K]

dS_{surr} = 0 [J/K]

γ = 1.4

m_{air} = 2 [kg]

P1 = 500000 [Pa]

R_{air} = 287 [J/kg-K]

T1 = 353 [K]

V1 = 0.4052 [m^3]

W_{max} = 122949 [J]

cv = 717.5 [J/kg-K]

dS_{net} = 55.12 [J/K]

dU = -107625 [J]

Irreversibility = 15324 [J]

P0 = 100000 [Pa]

P2 = 100000 [Pa]

T0 = 278 [K]

T2 = 278 [K]

V2 = 0.8105 [m^3]

Thus:

Max. work = W_max = 122.949 kJ … Ans.

Change in Availability = 82.424 kJ … Ans.

Irreversibility = 15.324 kJ … Ans.

==

"**Prob.8.6.** Calculate the available energy of 30 kg of water at 85 C with respect to the surroundings at 15 C, pressure being 1 atm."

"EES Solution:"

"Water may be considered as being brought to ambient conditions in very large no. of steps, heat rejected in each step being supplied to a Carnot engine, which rejects heat to a sink at the ambient temp.

We will use the EES Function written earlier, viz.

FUNCTION ExergyofHeat_ConstPressure(cp,T,T0)

This function returns the specific availability of a fluid in J/kg as a function of

cp[J/kg.C], T [C], T0 (C)

"

"Data:"

T = 85 "C"

T0 = 15 "C"

cp = 4180 "J/kg.K"

m_water = 30 "kg"

Exergy = m_water * ExergyofHeat_ConstPressure(cp,T,T0) "J"

Results:

Main | ExergyofHeat_ConstPressure

Unit Settings: SI C Pa J mass deg

cp = 4180 [J/kg-K]   Exergy = 920325 [J] m_{water} = 30 [kg]

T = 85 [C]   T0 = 15 [C]

Main | ExergyofHeat_ConstPressure

Local variables in Function ExergyofHeat_ConstPressure (1 call, 0.00 sec)

cp=4180 [J/kg-K]

$ExergyofHeat_{ConstPressure}$ =30678 [J/kg]

T =85 [C]

T0 =15 [C]

Thus:

Available energy (i.e. exergy) of 30 kg of water at 85 C, with respect to ambient at 15 C is:

Exergy = 920.325 kJ …. Ans.

===

"**Prob.8.7**. Four kg of Iron ingot at 900 C is dropped in to an oil bath at 65 C containing 20 kg of oil. cp of iron and oil are 0.4 and 2 kJ/kg.K respectively. If the atmospheric temp is 27 C, determine the loss in availability after the materials reach an equilibrium temp."

"EES Solution:"

"Data:"

m_iron = 4 "kg"

T1_iron = 900 "C"

m_oil = 20 "kg"

T1_oil = 65 "C"

T_0 = 27 "C .... temp of ambient"

cp_iron = 400 "J/kg.K"

cp_oil = 2000 "J/kg.K"

"Calculations:"

"Find the final temp, T_f after equilibrium is reached:"

(m_iron * cp_iron * T1_iron) + (m_oil * cp_oil * T1_oil) = (m_iron * cp_iron + m_oil * cp_oil) * T_f
"..determines final temp, T_f"

"Entropy decrease of iron:"

dS_iron = m_iron * cp_iron * ln ((T_f + 273) / (T1_iron + 273)) "J/K"

"Entropy increase of oil:"

dS_oil = m_oil * cp_oil * ln ((T_f + 273) / (T1_oil + 273)) "J/K"

"Net increase of entropy:"

dS_net = dS_iron + dS_oil "J/K"

"Loss in availability:"

Loss = (T_0 + 273) * dS_net "J "

Results:

Unit Settings: SI C Pa J mass deg

cp_{iron} = 400 [J/kg-C]	cp_{oil} = 2000 [J/kg-C]	dS_{iron} = -1846 [J/K]
dS_{net} = 1785 [J/K]	dS_{oil} = 3631 [J/K]	Loss = 535545 [J]
m_{iron} = 4 [kg]	m_{oil} = 20 [kg]	$T1_{iron}$ = 900
$T1_{oil}$ = 65 [C]	T_0 = 27 [C]	T_f = 97.12 [C]

Thus:

Final temp = T_f = 97.12 C … Ans.

Exergy loss = 535.545 kJ …. Ans.

Alternatively:

Apply the Exergy balance before mixing and after mixing:

Following is the EES program:

```
"Data:"

m_iron = 4 "kg"

T1_iron = 900 "C"

m_oil = 20 "kg"

T1_oil = 65 "C"

T_0 = 27 "C .... temp of ambient"

cp_iron = 400 "J/kg.K"

cp_oil = 2000 "J/kg.K"

"Calculations:"

"Find the final temp, T_f after equilibrium is reached:"

(m_iron * cp_iron * T1_iron) + (m_oil * cp_oil * T1_oil) = (m_iron * cp_iron + m_oil * cp_oil) * T_f "..determines final temp, T_f"

"Initial exergy of iron:"

e_1_iron = m_iron * ExergyofHeat_ConstPressure(cp_iron,T1_iron,T_0) "J …. Using the EES Function already written"

"Initial exergy of oil:"

e_1_oil = m_oil * ExergyofHeat_ConstPressure(cp_oil,T1_oil,T_0) "J ……. Using the EES Function already written "

"Therefore, Total initial exergy:"

e_1_total = e_1_iron + e_1_oil "J"
```

"Final exergy of iron:"

e_2_iron = m_iron * ExergyofHeat_ConstPressure(cp_iron,T_f,T_0) "J"

"Final exergy of oil:"

e_2_oil = m_oil * ExergyofHeat_ConstPressure(cp_oil,T_f,T_0) "J"

"Therefore, Total final exergy:"

e_2_total = e_2_iron + e_2_oil "J"

"Now, from an exergy balance:

Total initial exergy = Total final exergy + Losses"

"Therefore:"

e_1_total = e_2_total + e_losses **"....by an exergy balance..finds exergy losses"**

Results:

Main | ExergyofHeat_ConstPressure

Unit Settings: SI C Pa J mass deg

cp_{iron} = 400 [J/kg-C]	cp_{oil} = 2000 [J/kg-C]	$e_{1,iron}$ = 742302
$e_{1,oil}$ = 88839 [J]	$e_{1,total}$ = 831141 [J]	$e_{2,iron}$ = 11369 [J]
$e_{2,oil}$ = 284227 [J]	$e_{2,total}$ = 295596 [J]	e_{losses} = 535545 [J]
m_{iron} = 4 [kg]	m_{oil} = 20 [kg]	$T1_{iron}$ = 900 [C]
$T1_{oil}$ = 65 [C]	T_0 = 27 [C]	T_f = 97.12 [C]

Main | ExergyofHeat_ConstPressure

Local variables in Function ExergyofHeat_ConstPressure (4 calls, 0.00 sec)

cp=2000 [J/kg-C]

$ExergyofHeat_{ConstPressure}$ =14211 [J/kg]

T =97.12 [C]

T0 =27 [C]

Thus, we see that:

Final temp T_f = 97.12 C … Ans.

Exergy Losses = 535.545 kJ … Ans.

Note that exergy losses are the same by both the methods .

==

"**Prob.8.8.** One kg of O2 at 1 bar and 450 K is mixed with 1 kg of H2 at 1 bar and 450 K by removing the partition, which separated the gases in the chamber. Determine the loss of availability if the ambient is at 300 K. Given: Gas constant, R for O2 and H2 are: 270 J/kg.K and 4160 J/kg.K respectively."

"EES Solution:"

"Data:"

m_O2 = 1 "kg"

T1_O2 = 450 "K"

m_H2= 1 "kg"

T1_H2 = 450 "K"

T_0 = 300 "K .... temp of ambient"

R_O2 = 270 "J/kg.K"

R_H2 = 4160 "J/kg.K"

p = 1E05 "Pa"

"Calculations:"

"Initial volume of O2:"

v_O2 = R_O2 * T1_O2 / p "m^3 ....initial vol. of O2"

"Initial volume of H2:"

v_H2 = R_H2 * T1_H2 / p "m^3 ....initial vol. of H2"

"Therefore: final volume after mixing is the sum of initial volumes. Final volume is the same for both O2 and H2"

v_final = v_O2 + v_H2 "m^3 ... final volume"

"Entropy changes:"

"Entropy change for O2:"

dS_O2 = m_O2 * R_O2 * ln (v_final / v_O2) "J/K"

"Entropy change for H2:"

dS_H2 = m_H2 * R_H2 * ln (v_final / v_H2) "J/K"

"Therefore: total entropy change:"

dS_net = dS_O2 + dS_H2 "J/K .... net entropy change"

"Therefore: Loss in available energy (or exergy):"

Losses = T_0 * dS_net "J .... exergy losses"

Results:

Unit Settings: SI C Pa J mass deg

dS_{H2} = 261.6 [J/K]	dS_{net} = 1017 [J/K]	dS_{O2} = 755.4 [J/K]
Losses = 305096 [J]	m_{H2} = 1 [kg]	m_{O2} = 1 [kg]
p = 100000 [Pa]	R_{H2} = 4160 [J/kg-K]	R_{O2} = 270
$T1_{H2}$ = 450 [K]	$T1_{O2}$ = 450 [K]	T_0 = 300 [K]
V_{final} = 19.94 [m³]	V_{H2} = 18.72 [m³]	V_{O2} = 1.215 [m³]

Thus:

Loss in exergy due to mixing = 305.096 kJ … Ans.

==

"**Prob.8.9**. A closed cylinder contains 10 kg of air at 1MPa and 60 C. Determine the work potential of this air if the environmental conditions are 100 kPa and 27 C."

"EES Solution:"

"We have to simply find the Exergy of air at the stated condition.

Let us use the EES Function for Exergy of a closed system, written earlier."

"Data:"

IdealGas$ = 'Air'

m_air = 10 "kg"

P = 1E06 "Pa"

T = 60 "C"

P0 = 1E05 "Pa"

T0 = 27 "C"

Exergy = m_air * Exergy_ClosedSystem_IdealGas(IdealGas$,T, P, T0, P0)

Results:

Main | Exergy_ClosedSystem_IdealGas

Unit Settings: SI C Pa J mass deg

Exergy = 1.139E+06 [J]	IdealGas$ = 'Air'	m_{air} = 10 [kg]
P = 1000000 [Pa]	p0 = 100000 [Pa]	T = 60 [C]
T0 = 27 [C]		

Main | Exergy_ClosedSystem_IdealGas

Local variables in Function Exergy_ClosedSystem_IdealGas (1 call, 0.00 sec)

$Exergy_{ClosedSystem,IdealGas}$=113889 [J/kg]	IdealGas$='Air'
P =1000000 [Pa]	P0 =100000 [Pa]
s=5150 [J/kg-K]	s0=5706 [J/kg-K]
T =60 [C]	T0 =27 [C]
u=238143 [J/kg]	u0=214429 [J/kg]
v=0.09562 [m^3/kg]	v0=0.8615 [m^3/kg]

Thus:

Work potential or Exergy of Air = 1139kJ … Ans.

==

"**Prob.8.10.** In a parallel flow heat exchanger, 1 kg/s of oil (cp = 2.5 kJ/kg.C) is cooled from 260 C to 90C, thus heating the water stream from 60 C to 85 C. Temp of surroundings is 27 C. Determine the loss in availability."

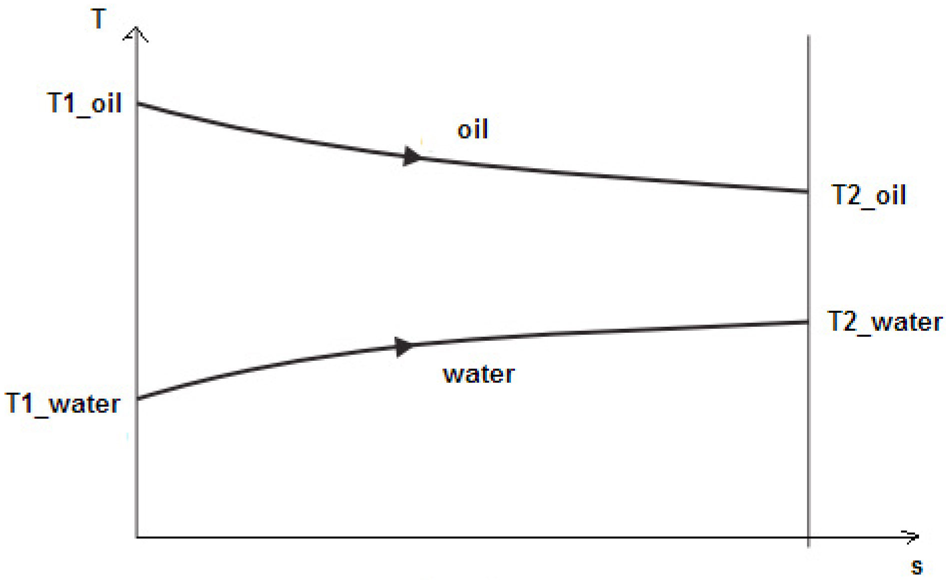


Fig.Prob.8.10

"EES Solution:"

"Data:"

m_oil = 1 "kg/s"

T1_oil = 260 "C"

T2_oil = 90 "C"

T1_water = 60 "C"

T2_water = 85 "C"

T_0 = 27 "C"

cp_oil = 2500 "J/kg.C"

cp_water = 4180 "J/kg.C"

"Calculations:"

"Find the flow rate of water by heat balance:"

m_oil * cp_oil * (T1_oil – T2_oil) = m_water * cp_water * (T2_water – T1_water) "....finds the mass flow rate of water"

"Decrease in entropy of oil:"

dS_oil = cp_oil * ln ((T2_oil+273)/(T1_oil+273)) "J/kg.K"

"Increase in entropy of water:"

dS_water = cp_water * ln ((T2_water+273)/(T1_water+273)) "J/kg.K"

"Change in availability of oil:"

e_oil = m_oil * (cp_oil * (T2_oil – T1_oil) – (T_0 +273)* dS_oil)"J/s"

"Change in availability of water:"

e_water = m_water * (cp_water * (T2_water – T1_water) – (T_0 + 273) * dS_water)"J/s"

"Therefore: Loss in availability:"

Loss = e_oil + e_water "J/s"

Results:

Unit Settings: SI C Pa J mass deg

cp_{oil} = 2500 [J/kg-K]	cp_{water} = 4180 [J/kg-K]	dS_{oil} = -960.3 [J/kg-K]
dS_{water} = 302.6 [J/kg-K]	e_{oil} = -136911 [J/s]	e_{water} = 55808 [J/s]
Loss = -81103 [J/s]	m_{oil} = 1 [kg/s]	m_{water} = 4.067 [kg/s]
$T1_{oil}$ = 260 [C]	$T1_{water}$ = 60 [C]	$T2_{oil}$ = 90 [C]
$T2_{water}$ = 85 [C]	T_0 = 27 [C]	

Thus:

Loss in availability = – 81.103 kW … Ans.

Alternatively:

Let us solve this problem by Exergy balance method:

We have:

"Exergy going in = Exergy going out + Losses"

"Exergy going in = (Exergy of water going in + exergy of oil going in):"

"Exergy of water going in:"

RealFluid$ = 'Steam_NBS'

P1_water = 1E05"Pa …. assumed"

P2_water = P1_water

P1_oil = 1E05 "Pa … assumed"

P2_oil = P1_oil

P_0 = 1E05"Pa"

V = 0"m/s ….. velocity"

Z = 0"m … datum"

"Exergy of water going in:"

e_1_water = m_water * Exergy_massflow_RealFluid(RealFluid$,T1_water, P1_water, V, Z,T_0, P_0) "J/K … using the EES Function written earlier"

"Exergy of water going out:"

e_2_water = m_water * Exergy_massflow_RealFluid(RealFluid$,T2_water, P2_water, V, Z,T_0, P_0) "J/K … using the EES Function written earlier"

{Remember: Exergy_massflow_RealFluid := (h – h0) – (T0 + 273) * (s – s0) + V^2 / 2 + g * Z}

"Exergy of oil going in:"

e_1_oil = m_oil * (cp_oil * (T1_oil – T_0) – (T_0 + 273) * cp_oil * ln ((T1_oil + 273)/(T_0 + 273))) "J/K"

"Exergy of oil going out:"

e_2_oil = m_oil * (cp_oil * (T2_oil – T_0) – (T_0 + 273) * cp_oil * ln ((T2_oil + 273)/(T_0 + 273))) "J/K"

"Then, by Exergy balance:"

e_1_water + e_1_oil = e_2_water + e_2_oil + Losses "...finds exergy loss"

Results:

Unit Settings: SI C Pa J mass deg

cp_{oil} = 2500 [J/kg-K]	cp_{water} = 4180 [J/kg-K]	$e1_{oil}$ = 151446 [J]
$e1_{water}$ = 29030 [J/s]	$e2_{oil}$ = 14535 [J/s]	$e2_{water}$ = 85130 [J/s]
Losses = 80811 [J/s]	m_{oil} = 1 [kg/s]	m_{water} = 4.067 [kg/s]
$P1_{oil}$ = 100000 [Pa]	$P1_{water}$ = 100000 [Pa]	$P2_{oil}$ = 100000 [Pa]
$P2_{water}$ = 100000	P_0 = 100000 [Pa]	RealFluid$ = 'Steam_NBS'
$T1_{oil}$ = 260 [C]	$T1_{water}$ = 60 [C]	$T2_{oil}$ = 90 [C]
$T2_{water}$ = 85 [C]	T_0 = 27 [C]	V = 0 [m/s]
Z = 0 [m]		

Thus:

Exergy Losses = 80.811 kW … Ans.

Note: Here, the sign of Losses is not negative, because of the way we wrote the Exergy balance. But, remember that it is an exergy loss in the heat exchanger.

===

"**Prob.8.11.** Steam enters a turbine at 3 MPa and 450 C at a rate of 8 kg/s and exits at 0.2 MPa and 150 C. Steam is losing heat to the surroundings at 100 kPa and 25 C at a rate of 300 kW. Changes in K.E. and P.E. are negligible. Determine: (i) actual power output (ii) max. possible power output (iii) Second Law efficiency (iv) exergy destroyed, and (v) exergy of steam at inlet conditions [Ref: 1]"

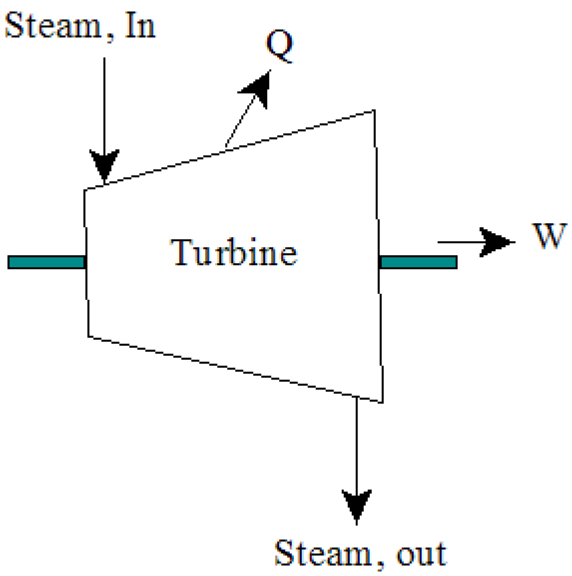


Fig.Prob.8.11

"EES Solution:"

"This is a worked out example in Ref;1. However, it is reworked here using the EES Function for Exergy of mass flow for Real Fluid:"

"Data:"

P1 = 3E06"Pa"
T1 = 450 "C"
m_steam = 8 "kg/s"

P2 = 0.2E06"Pa"
T2 = 150 "C"
Q_loss = 300E03 "W"

P0 = 100E03 "Pa"
T0 = 25 "C"

V = 0 "m/s"
Z = 0 "m"

"Calculations:"

"For exergy of mass flow:

we shall use the EES Function already written:

viz. Exergy_massflow_RealFluid(RealFluid$,T1_water, P1_water, V, Z,T_0, P_0) ... J/kg"

RealFluid$ = 'Steam_NBS'

"Exergy at Inlet:"

e_f1 = Exergy_massflow_RealFluid(RealFluid$,T1, P1, V, Z,T0, P0) " ... J/kg"

"Exergy at exit:"

e_f2 = Exergy_massflow_RealFluid(RealFluid$,T2, P2, V, Z,T0, P0) " ... J/kg"

"Reversible work, or Max. possible work:"

W_rev = m_steam * (e_f1 – e_f2) "J/s"

"Actual work output:

By I Law applied to turbine:

m_steam * (h1- h2) = W_actual + Q"

h1 = Enthalpy(Steam_NBS,T=T1,P=P1) "J/kg …. enthalpy of steam at inlet"

h2 = Enthalpy(Steam_NBS,T=T2,P=P2) "J/kg …. enthalpy of steam at exit"

"Therefore: actual work output is found from"

m_steam * (h1- h2) = W_actual + Q_loss".W .... actual work output"

"Then, Second Law efficiency:"

eta_II = W_actual / W_rev "...Second Law effcy."

"Exergy destroyed:"

e_destroyed = W_rev – W_actual "W .... exergy destroyed"

"--"

"Alternatively:

Exergy destroyed = T0 * DELTAS_gen"

s1 = Entropy(Steam_NBS,T=T1,P=P1)"J/kg.K ... entropy of steam at inlet"

s2 = Entropy(Steam_NBS,T=T2,P=P2)"J/kg.K .... entropy of steam at exit"

dS_steam = m_steam * (s2 – s1) "W/K ... entropy change of steam"

dS_surr = Q_loss /(T0 + 273) "W/K ... entropy change of surroundings"

dS_gen = dS_steam + dS_surr "W/K ... entropy generated"

e_destr2 = (T0 + 273) * dS_gen "W ... Irreversibility or exergy destroyed"

"=="

Results:

Unit Settings: SI C Pa J mass deg

dS_{gen} = 2573 [W/K]	dS_{steam} = 1567 [W/K]	dS_{surr} = 1007 [W/K]
η_{II} = 0.8488	e_{destr2} = 766889 [W]	$e_{destroyed}$ = 766889 [W]
e_{f1} = 1.238E+06 [J/kg]	e_{f2} = 603877 [J/kg]	h1 = 3.344E+06 [J/kg]
h2 = 2.769E+06 [J/kg]	m_{steam} = 8 [kg/s]	P0 = 100000 [Pa]
P1 = 3.000E+06 [Pa]	P2 = 200000 [Pa]	Q_{loss} = 300000 [W]
RealFluid$ = 'Steam_NBS'	s1 = 7083 [J/kg-K]	s2 = 7279 [J/kg-K]
T0 = 25 [C]	T1 = 450 [C]	T2 = 150 [C]
V = 0 [m/s]	W_{actual} = 4.304E+06 [W]	W_{rev} = 5.071E+06 [W]
Z = 0 [m]		

Thus:

Actual power output: W_actual = 4304 kW … Ans.

Max. power output: W_rev = 5071 kW … Ans.

Second Law efficiency: eta_II = 0.8488 … Ans.

Exergy destroyed: e_destroyed = 766.889 kW …. Ans.

Note that by the alternative method too,

we get: exergy destroyed = e_destr2 = 766.889 kW … same as earlier…. Ans.

==

"**Prob.8.12.** In a turbine, 1 kg/s of air expands from 8 bar, 650 C to 1 bar, 250 C. 9 kJ/kg of heat is lost to the surroundings, which is at 1 bar, 20 C. Neglect changes in K.E. and P.E. Determine: (i) decrease in availability (ii) Max. work (iii) actual work, (iv) Second Law efficiency, and (v) Irreversibility"

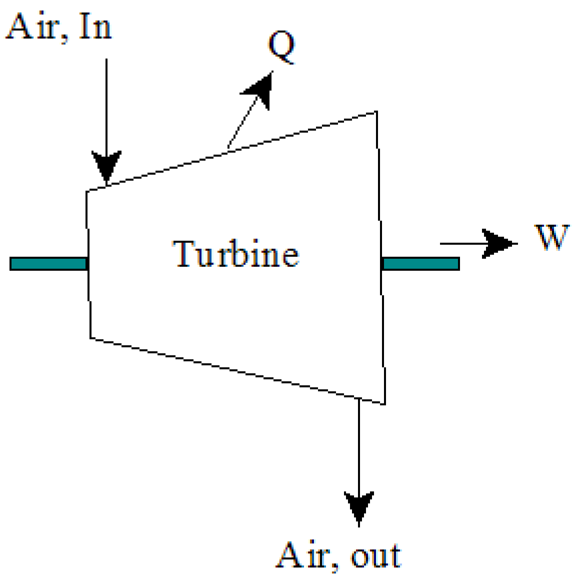


Fig.Prob.8.12

"EES Solution:"

"This is an example of using the EES Function for exergy of mass flow for Ideal Gas:"

"Data:"

P1 = 8E05"Pa"
T1 = 650 "C"
m_air = 1 "kg/s"

P2 = 1E05"Pa"
T2 = 250 "C"
Q_loss = 9E03 "W"

P0 = 1E05 "Pa"
T0 = 20 "C"

V = 0 "m/s"
Z = 0 "m"

"Calculations:"

"For exergy of mass flow:

we shall use the EES Function already written:

viz. Exergy_massflow_IdealGas(IdealGas$,T, P, V, Z,T0, P0) ...J/kg"

IdealGas$ = 'Air'

"Exergy at Inlet:"

e_f1 = Exergy_massflow_IdealGas(IdealGas$,T1, P1, V, Z,T0, P0) " ... J/kg"

"Exergy at exit:"

e_f2 = Exergy_massflow_IdealGas(IdealGas$,T2, P2, V, Z,T0, P0) " ... J/kg"

"Reversible work, or Max. possible work:"

W_rev = m_air * (e_f1 – e_f2) "J/s"

"Actual work output:

By I Law applied to turbine:

m_air * (h1- h2) = W_actual + Q"

h1 = Enthalpy(,Air',T=T1) "J/kg"

h2 = Enthalpy(,Air',T=T2) "J/kg"

"Therefore: actual work output is found from"

m_air * (h1- h2) = W_actual + Q_loss".W .... actual work output"

"Then, Second Law efficiency:"

eta_II = W_actual / W_rev "...Second Law effcy."

"Exergy destroyed, or Irreversibility:"

e_destroyed = W_rev – W_actual "W .... exergy destroyed"

"---"

Results:

Unit Settings: SI C Pa J mass deg

η_{II} = 0.9885	$e_{destroyed}$ = 4901 [W]	e_{f1} = 489527 [J/kg]	e_{f2} = 61628 [J/kg]
h1 = 959215 [J/kg]	h2 = 527217 [J/kg]	IdealGas$ = 'Air'	m_{air} = 1 [kg/s]
P0 = 100000 [Pa]	P1 = 800000 [Pa]	P2 = 100000 [Pa]	Q_{loss} = 9000 [W]
T0 = 20 [C]	T1 = 650 [C]	T2 = 250 [C]	V = 0 [m/s]
W_{actual} = 422998 [W]	W_{rev} = 427899 [W]	Z = 0 [m]	

Thus:

Decrease in availability = (e_f1 – e_f2) = 427.8891 kW …. Ans.

Max. power output: W_rev = (e_f1 – e_f2) = 427.8891 kW … Ans.

Actual power output: W_actual = 422.998 kW … Ans.

Second Law efficiency: eta_II = 0.9885 … Ans.

Irreversibility = Exergy destroyed: e_destroyed = 4.901 kW …. Ans.

===

"**Prob.8.13.** Refrigerant R134a enters compressor at 150 kPa, -10 C and is compressed to 1 MPa. Compressor has a Second Law efficiency of 75%. Determine: (i) actual work input, (ii) isentropic efficiency (iii) exergy destroyed."

EES Solution:

"This is an example of using the EES Function for exergy of mass flow for a RealFluid:"

"Data:"

P1 = 150E03"Pa"
T1 = -10"C"
m_R134a = 1 "kg/s"

P2 = 1E06"Pa"

P0 = 1E05"Pa"
T0 = 20 "C"

V = 0 "m/s"
Z = 0 "m"

eta_II = 0.75

"Calculatons:"

"For isentropic compression:"

s1 = Entropy(R134a,T=T1,P=P1)"J/kg.K"

s2 = s1 "...for isentropic compression"

"Therefore, find T2:"

s2 = Entropy(R134a,T=T2,P=P2)"J/kg.K ..... finds T2 (C)"

" Now, Exergy at Inlet and exit .... using the Exergy Function already written:"

RealFluid$ = 'R134a'

e_f1 = Exergy_massflow_RealFluid(RealFluid$,T1, P1, V, Z,T0, P0) " ... J/kg"

" And, Exergy at exit:"

e_f2 = Exergy_massflow_RealFluid(RealFluid$,T2, P2, V, Z,T0, P0) " ... J/kg"

"Therefore: Reversible work = minimum required work:"

W_rev = e_f2 – e_f1 "J/kg ... rev. work"

"Actual work is determined, knowing Second Law efficiency, as:"

eta_II = W_rev / W_act "…. detrmines W_act, the actual work required"

"Then: Exergy destroyed or Loss:"

e_loss = W_act – W_rev "W"

"Isentropic efficiency:"

h2s =Enthalpy(R134a,T=T2,s=s2)"J/kg ... enthalpy at exit if compression were isentropic"

"h2 is determined from: W_act = h2 – h1"

"Then:"

h1 =Enthalpy(R134a,T=T1,s=s1)"J/kg .... enthalpy at inlet to compressor"

W_act = h2 – h1 "...determines h2, enthalpy at exit for actual compression process"

eta_isentropic = (h2s-h1) / (h2 – h1) ".... by definition of Isentropic efficiency"

Results:

Unit Settings: SI C Pa J mass deg

η_{II} = 0.75	$\eta_{isentropic}$ = 0.75	e_{f1} = 10780 [J/kg]	e_{f2} = 51798 [J/kg]
e_{loss} = 13673 [W]	h1 = 246081 [J/kg]	h2 = 300771 [J/kg]	h2s = 287099 [J/kg]
m_{R134a} = 1 [kg/s]	P0 = 100000 [Pa]	P1 = 150000 [Pa]	P2 = 1000000 [Pa]
RealFluid$ = 'R134a'	s1 = 966 [J/kg-K]	s2 = 966 [J/kg-K]	T0 = 20 [C]
T1 = -10 [C]	T2 = 54.05 [C]	V = 0 [m/s]	W_{act} = 54691 [W]
W_{rev} = 41018 [W]	Z = 0 [m]		

Thus:

Actual work required = W_act = 54.691 kW … Ans.

Isentropic efficiency = eta_isentropic = 0.75 … Ans.

Exergy destroyed = e_loss = 13.673 kW … Ans.

===

"**Prob.8.14**. Air is throttled from 900 kPa, 70 C to a pressure of 200 kPa at a rate of 0.5 kg/s in an environment of 25 C. Neglecting the changes in K.E. and P.E. determine the power potential wasted."

"EES Solution:"

"Data:"

P1 = 900E03 "Pa"

T1 = 70 "C"

P2 = 200E03 "Pa"

P0 = 1E05 "Pa"

T0 = 25 "C"

m_air = 0.5 "kg/s"

"Calculations:"

"Exergy loss is easily calculated as: T0 * S_gen, (remember: T0 in Kelvin)"

h1 = Enthalpy(Air,T=T1) "J/kg ... enthalpy at inlet to the throttle valve"

h2 = h1 "...since enthalpy remains constant during throttling"

s1 = Entropy(Air,T=T1,P=P1) "J/kg.K ... entropy at inlet"

s2 = Entropy(Air,P=P2,h=h2) "J/kg.K ... entropy at exitt"

dS_air = m_air * (s2 – s1) "W/K ...entropy change for air"

dS_surr = 0 "...since Q = 0, W = 0 for the throttle valve"

"Therefore: entropy generated:"

dS_gen = dS_air + dS_surr "W/K .... entropy generated"

"Therefore: Exergy loss or, power potential wasted:"

e_loss = (T0 + 273) * dS_gen "W"

"Second Law efficiency:"

"eta_II is defined as:

eta_II = (e_f1 – e_loss) /e_f1"

IdealGas$ = 'Air'

V = 0"m/s"

Z = 0 "m"

e_f1 = m_air * Exergy_massflow_IdealGas(IdealGas$,T1, P1, V, Z,T0, P0) "W"

"Therefore:"

eta_II = (e_f1 – e_loss) /e_f1

Results:

Unit Settings: SI C Pa J mass deg

dS_{air} = 215.9 [W/K]	dS_{gen} = 215.9 [W/K]	dS_{surr} = 0 [W/K]	η_{II} = 0.3265
e_{f1} = 95514 [J/kg]	e_{loss} = 64325 [W]	h1 = 343838 [J/kg]	h2 = 343838 [J/kg]
IdealGas$ = 'Air'	m_{air} = 0.5 [kg/s]	P0 = 100000 [Pa]	P1 = 900000 [Pa]
P2 = 200000 [Pa]	s1 = 5210 [J/kg-K]	s2 = 5642 [J/kg-K]	T0 = 25 [C]
T1 = 70 [C]	V = 0 [m/s]	Z = 0 [m]	

Thus:

Power potential wasted = exergy destroyed = e_loss = 64.325 kW … Ans.

Second Law efficiency = eta_II = 0.3265 … Ans.

==

"**Prob.8.15.** Air is flowing through a pipe and the temp decreases from 600 C at inlet to 590 C at exit, due to heat losses. Neglecting pressure losses, determine the exergy lost per kg during the flow. Take cp for air as 1100 J/kg.K, and ambient temp as 27 C."

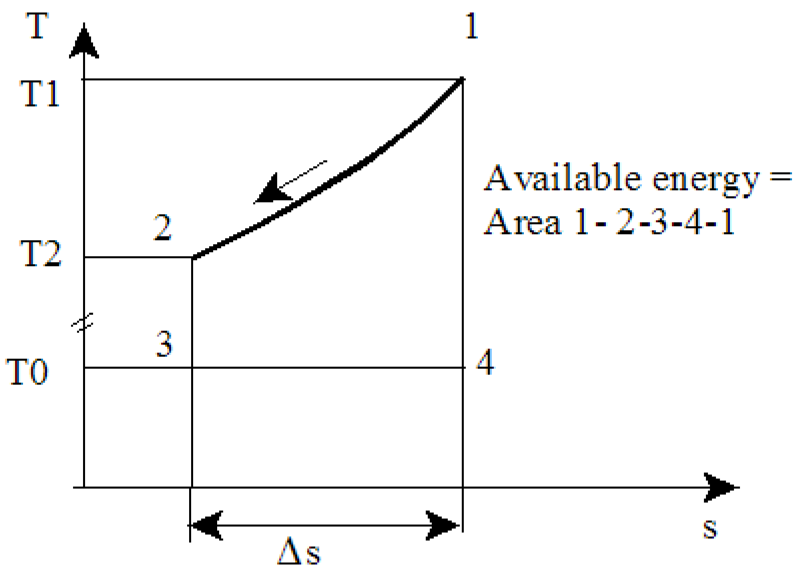


Fig.Prob.8.15

"EES Solution:"

"Data:"

T1 = 600 "C"

T2 = 590 "C"

P0 = 1E05 "Pa"

T0 = 27 "C"

m_air = 1 "kg/s"

cp_air = 1100 "J/kg.K"

"Calculations:"

Q_lost = m_air * cp_air * (T1 – T2) "W ... heat lost at constant pressure"

dS_air = m_air * cp_air * ln((T1+273) / (T2 + 273)) "J/kg.K .... entropy change during the heat loss at const. pressure"

e_loss = Q_lost – (T0 + 273) * dS_air "W"

Results:

Unit Settings: SI C Pa J mass deg

cp_{air} = 1100	dS_{air} = 12.67 [W/K]	e_{loss} = 7198 [W]	m_{air} = 1 [kg/s]
P0 = 100000 [Pa]	Q_{lost} = 11000	T0 = 27 [C]	T1 = 600 [C]
T2 = 590 [C]			

Thus:

Exergy lost or energy degradation due to heat loss in pipe = e_loss = 7.198 kW ….. Ans.

===

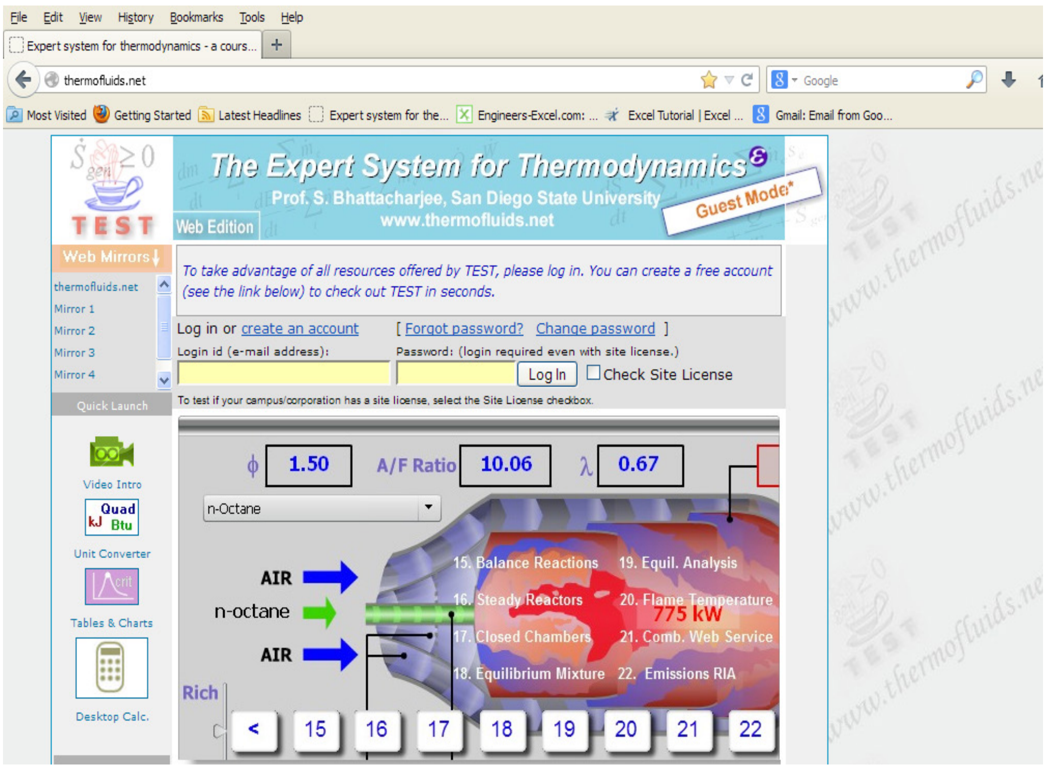
8.3 Problems solved with TEST:

Prob.8.16. A piston – cylinder device contains 5 kg of R134a at 0.7 MPa and 60 C. The refrigerant is now cooled at constant pressure until it exists as a liquid at 24 C. If the surroundings are at 100 kPa and 24 C, determine: (i) the exergy of the refrigerant at the initial and final states, and (ii) the exergy destroyed during this process.[Ref:1]

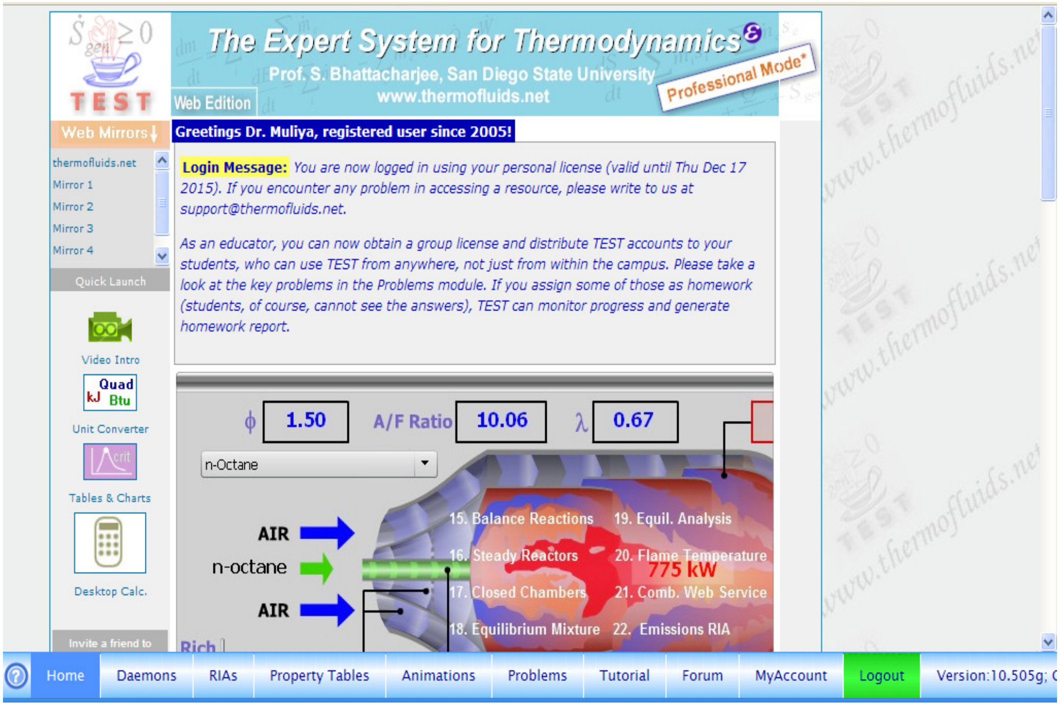
TEST Solution:

Following are the steps:

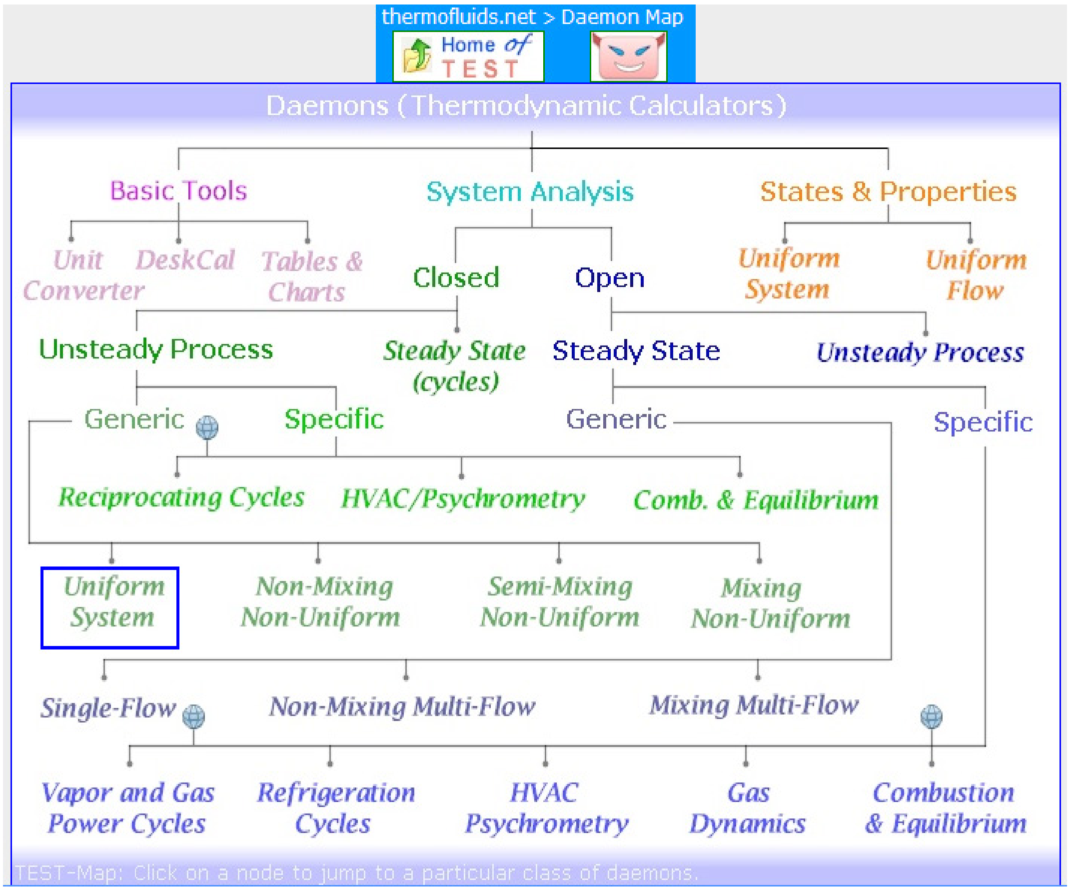
1. Go to www.thermofluids.net:



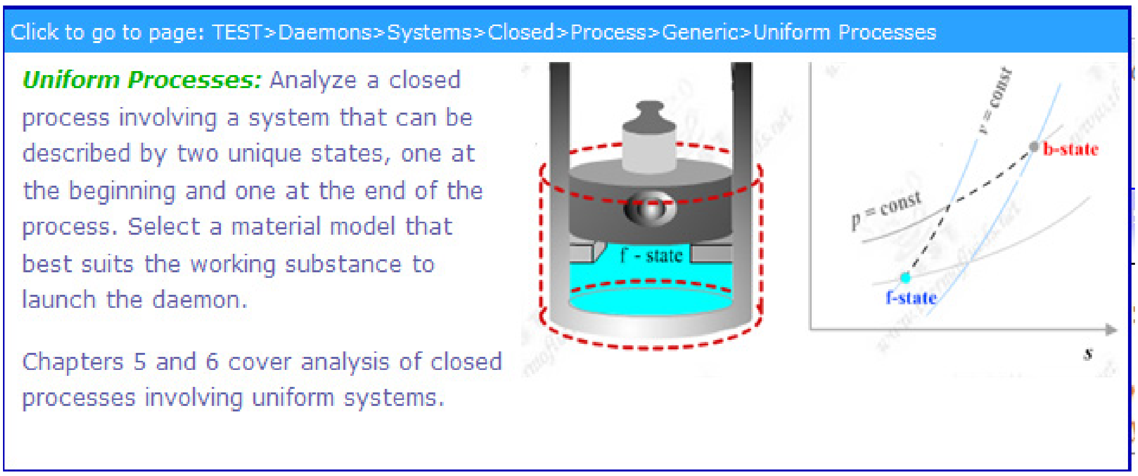
2. Fill in the e-mail address and password; you get the personalized greeting screen:



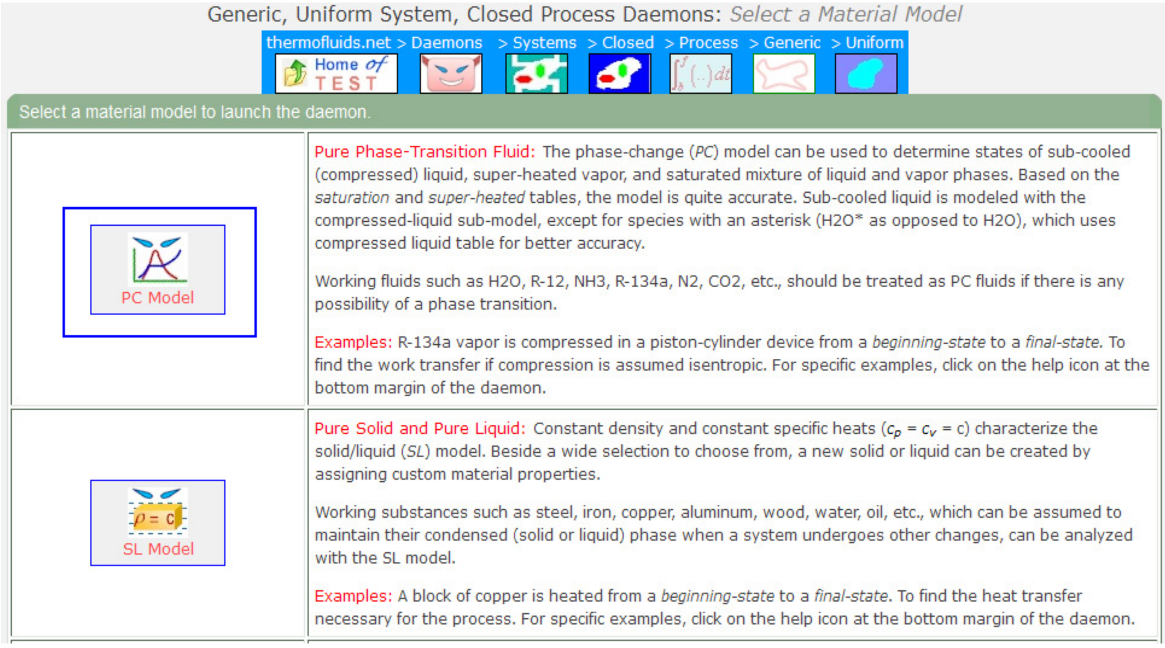
3. Click on Daemons at the bottom of screen above. We get the Daemon tree and click on System Analysis–Closed–Uniform System as shown below:



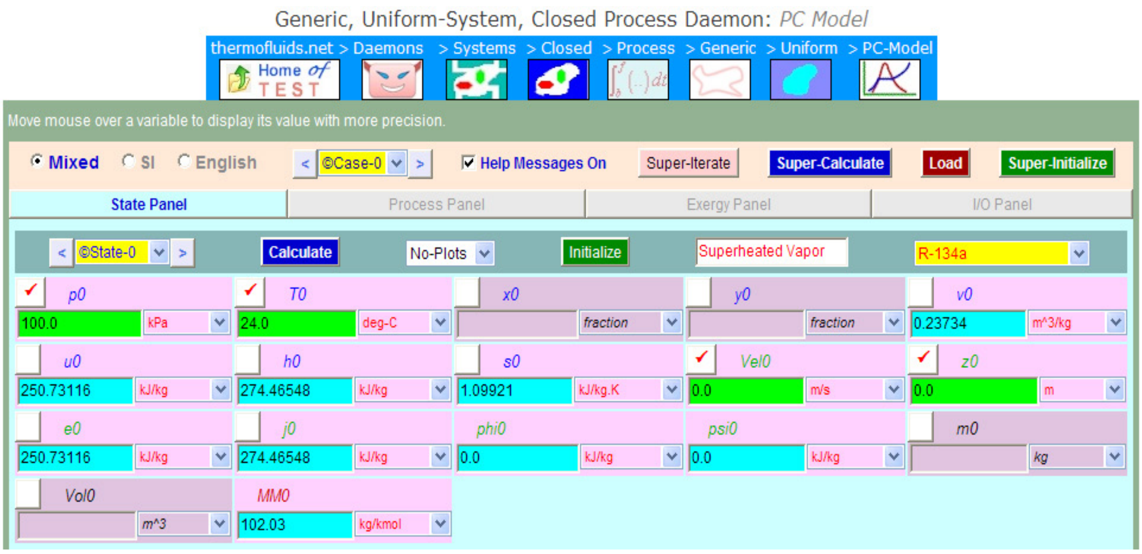
Hovering the mouse pointer over 'Uniform System' brings up the following explanatory pop up:



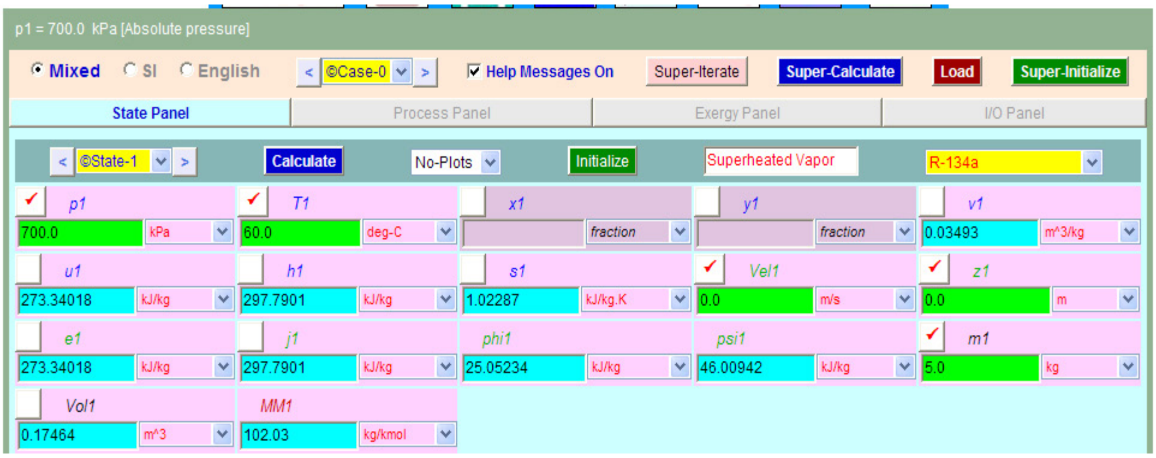
4. For Material model, choose OC Model since R134a is the substance:



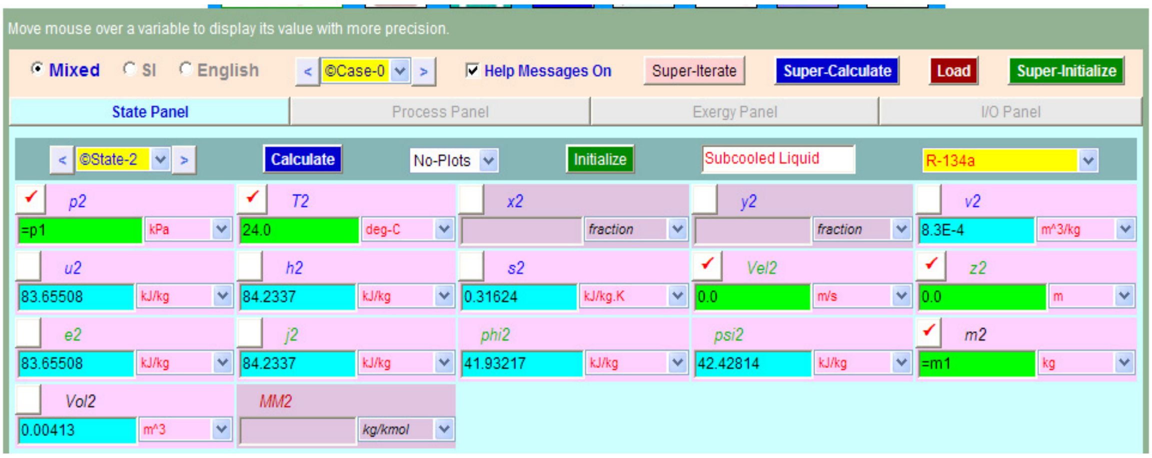
5. Select R134a for the substance. Then, enter for State '0', the ambient conditions, viz. p0 = 100 kPa, T0 = 24 C. This will be required to make exergy calculations. Hit Enter. We get:



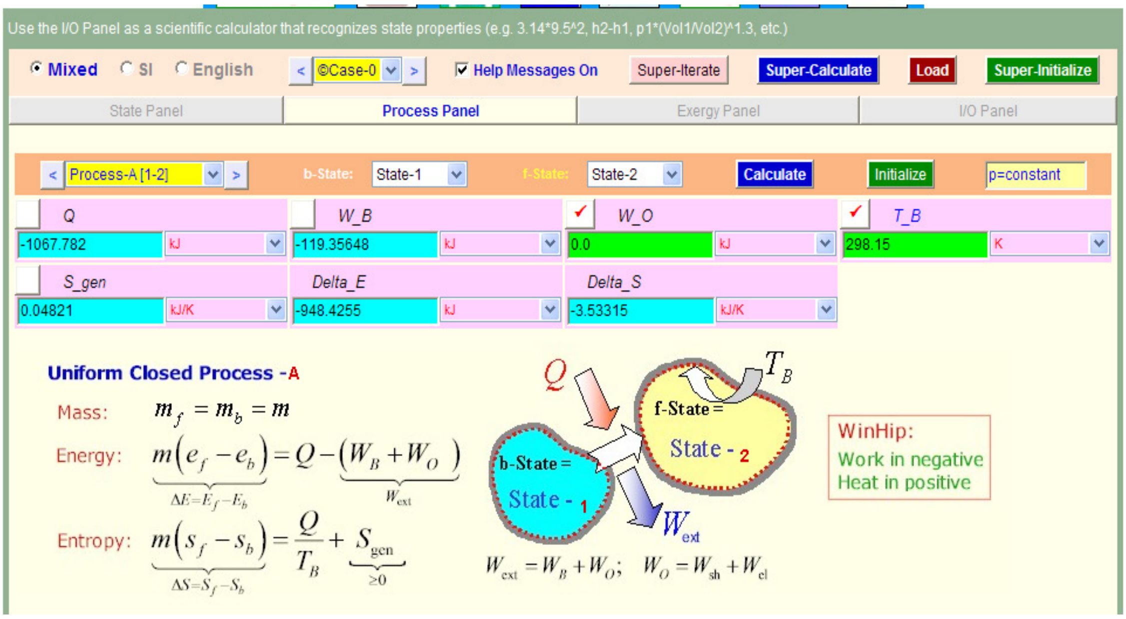
6. Now, go to State 1, and enter the data, i.e. p1 = 700 kPa, T1 = 60 C, m1 = 5 kg. Hit Enter. Immediately, all State properties are calculated:

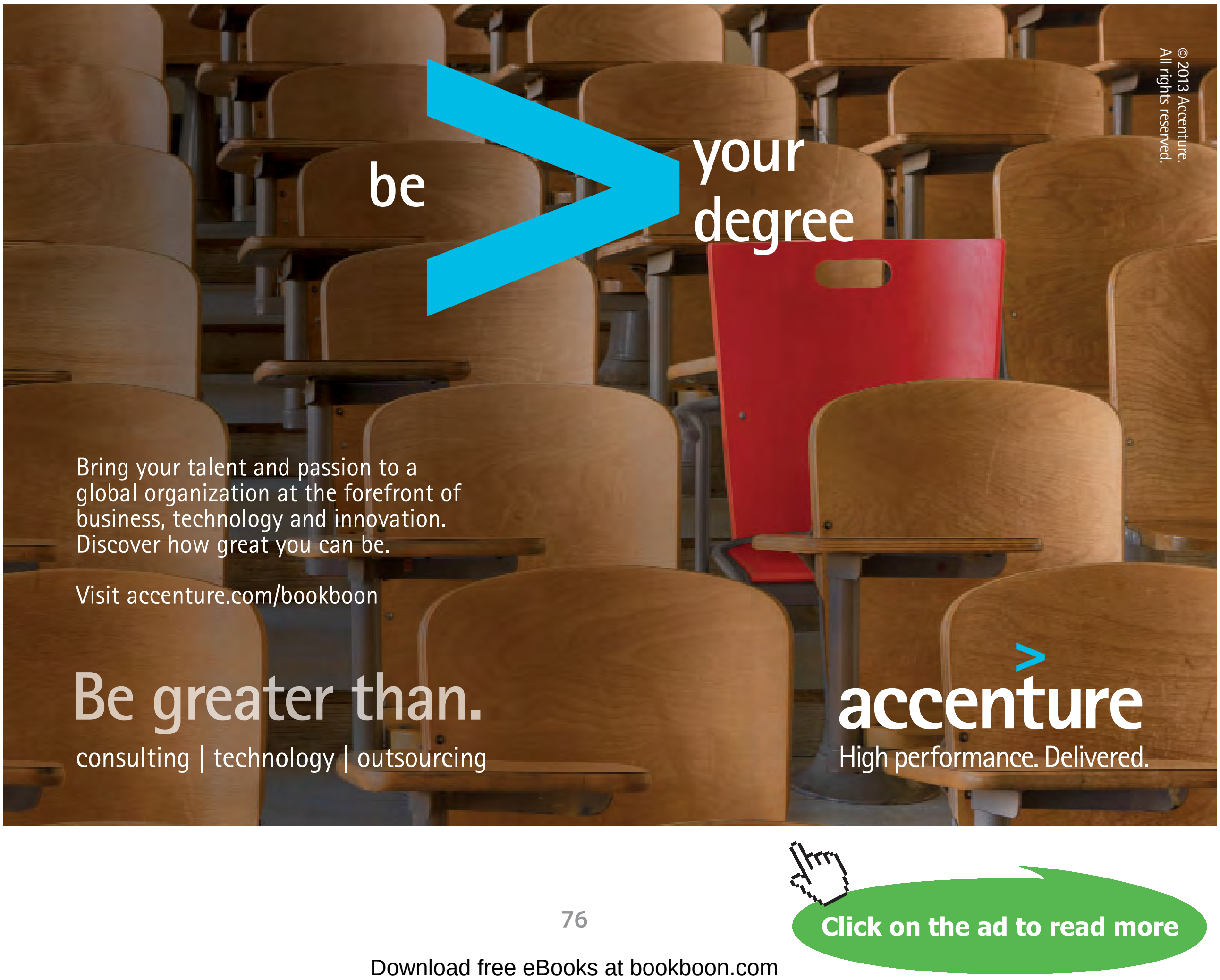


7. Now, go to State 2, enter p2 = p1 (since i-2 is a constant pressure process), T2 = 24 C, m2 = m1. Hit Enter. We get:

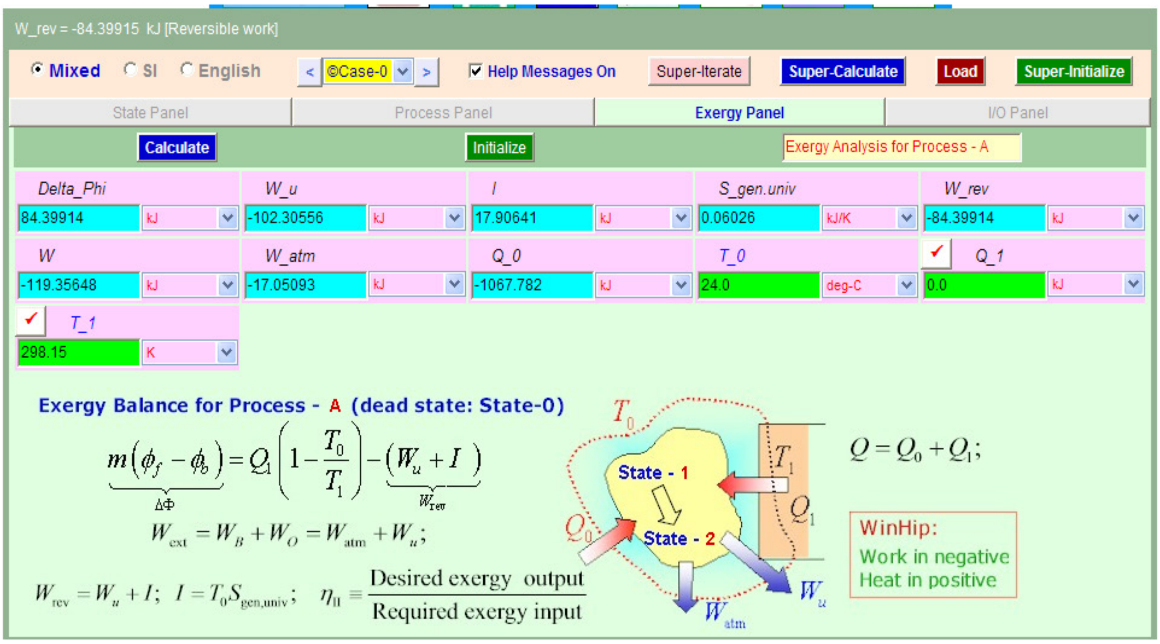


8. Now, go to Process Panel. Enter State 1 and State 2 for b-state and f-state respectively. Also, W_O (i.e. other work) = 0. Click on Calculate , and also on SuperCalculate. We get:





9. Now, go to Exergy Panel. We see that the exergy calculations are made:



10. Thus, we see that:

Entropy generated = S_gen_univ = 0.06026 kJ/K

Irreversibility or exergy destroyed = I = 17.906 kJ … Ans.

Exergy difference between states 1 and 2 = Delta_Phi = 84.399 kJ.

Also, note that reversible work, useful work, heat transfer Q_0 etc are available.

Now, exergies at Inlet and exit:

At State 1:
Phi_1 = m1 * {(u1 – u0) – T0 * (s1 – s0) + p0 * (v1 – v0)} = 123.725 kJ…. Ans.

At State 2:
Phi_2 = m2 * {(u2 – u0) – T0 * (s2 – s0) + p0 * (v2 – v0)} = 207.595 kJ…. Ans.

Therefore: **Phi_2 – Phi_1 = exergy difference = 207.595 – 123.725 = 83.87 kJ.**

This closely matches with the value of **Delta_Phi = 84.4 kJ … Ans.**

---

11. Get the TEST code etc from the I/O panel:

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

#        Daemon Path: Systems>Closed>Process>Generic>Uniform>PC-Model; v-10.cb01

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

States    {

        State-0: R-134a;
        Given: { p0= 100.0 kPa; T0= 24.0 deg-C; Vel0= 0.0 m/s; z0= 0.0 m; }
        State-1: R-134a;
        Given: { p1= 700.0 kPa; T1= 60.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 5.0 kg; }
        State-2: R-134a;
        Given: { p2= "P1" kPa; T2= 24.0 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 -----------------------------------------------------------------------

#******DETAILED OUTPUT:

# Evaluated States:

#        State-0: R-134a > Superheated Vapor;
#                Given: p0= 100.0 kPa; T0= 24.0 deg-C; Vel0= 0.0 m/s;
#                        z0= 0.0 m;
#                Calculated: v0= 0.2373 m^3/kg; u0= 250.7312 kJ/kg; h0= 274.4655 kJ/kg;
#                        s0= 1.0992 kJ/kg.K; e0= 250.7312 kJ/kg; j0= 274.4655 kJ/kg;
#                        phi0= 0.0 kJ/kg; psi0= 0.0 kJ/kg; MM0= 102.03 kg/kmol;
#        State-1: R-134a > Superheated Vapor;
#                Given: p1= 700.0 kPa; T1= 60.0 deg-C; Vel1= 0.0 m/s;
#                        z1= 0.0 m; m1= 5.0 kg;
#                Calculated: v1= 0.0349 m^3/kg; u1= 273.3402 kJ/kg; h1= 297.7901 kJ/kg;
#                        s1= 1.0229 kJ/kg.K; e1= 273.3402 kJ/kg; j1= 297.7901 kJ/kg;
#                        phi1= 25.0523 kJ/kg; psi1= 46.0094 kJ/kg; Vol1= 0.1746 m^3;
#                        MM1= 102.03 kg/kmol;
```

State-2: R-134a > Subcooled Liquid;
Given: p2= "P1" kPa; T2= 24.0 deg-C; Vel2= 0.0 m/s;
z2= 0.0 m; m2= "m1" kg;
Calculated: v2= 8.0E-4 m^3/kg; **u2= 83.6551 kJ/kg;** h2= 84.2337 kJ/kg;
s2= 0.3162 kJ/kg.K; e2= 83.6551 kJ/kg; j2= 84.2337 kJ/kg;
phi2= 41.9322 kJ/kg; psi2= 42.4281 kJ/kg; Vol2= 0.0041 m^3;
#--------Property spreadsheet starts:

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 00	100.0	297.2		0.2373	250.73	274.47	1.099
# 01	700.0	333.2		0.0349	273.34	297.79	1.023
# 02	700.0	297.2		8.0E-4	83.66	84.23	0.316
#							

 # 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= -1067.782 kJ; W_B= -119.35648 kJ; S_gen= 0.04820816 kJ/K; Delta_E= -948.4255 kJ;
Delta_S= -3.5331502 kJ/K;
 # Exergy Analysis Results:
 # Exergy Analysis for Process – A (Dead state: State-0)
Given: Q= -1067.782 kJ; T_0= 24.0 deg-C; Q_1= 0.0 kJ;
T_1= 298.15 K;
Calculated: Delta_Phi= 84.39914 kJ; W_u= -102.30556 kJ; I= 17.90641 kJ;
S_gen.univ= 0.06026 kJ/K; W_rev= -84.39914 kJ; W= -119.35648 kJ;
W_atm= -17.05093 kJ; Q_0= -1067.782 kJ;

==

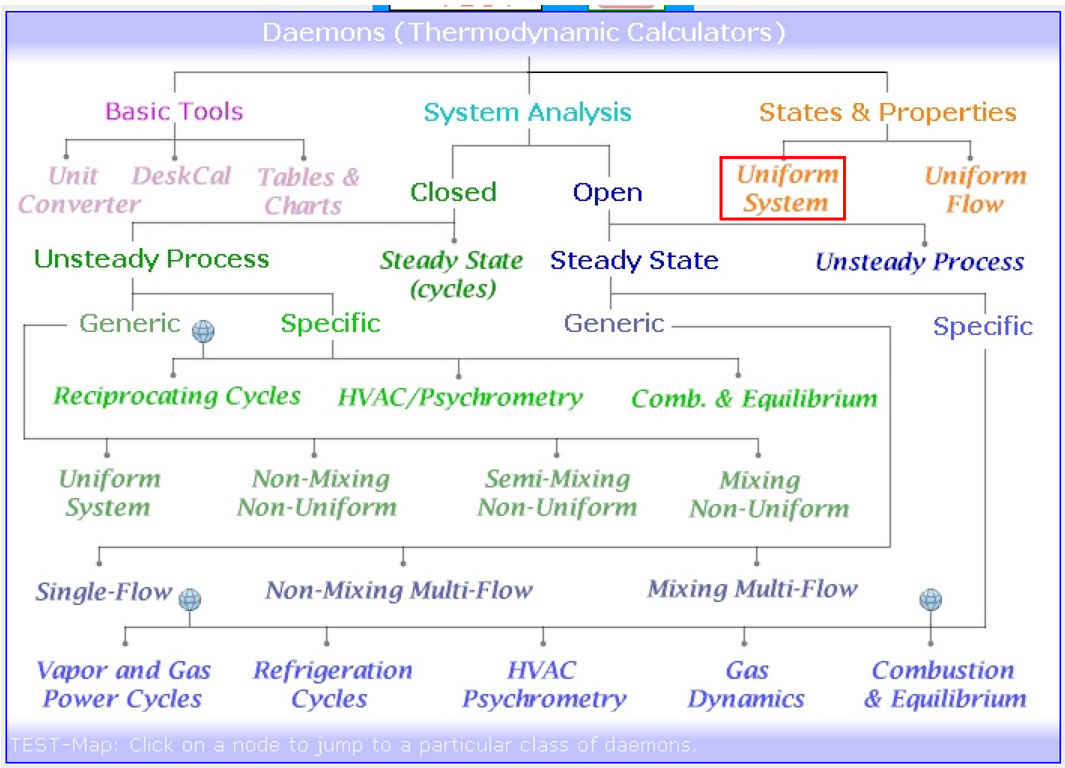
Prob.8.17. A rigid container with 200 L volume is divided in to two equal volumes by a partition. Both sides contain nitrogen, one side is at 2 MPa, 300 C, and the other at 1 MPa, 50 C. The partition ruptures, and the nitrogen comes to a uniform state at 100 C. Assuming the surroundings are at 25 C, find the actual heat transfer and the Irreversibility in the process. [Ref: 2]

TEST Solution:

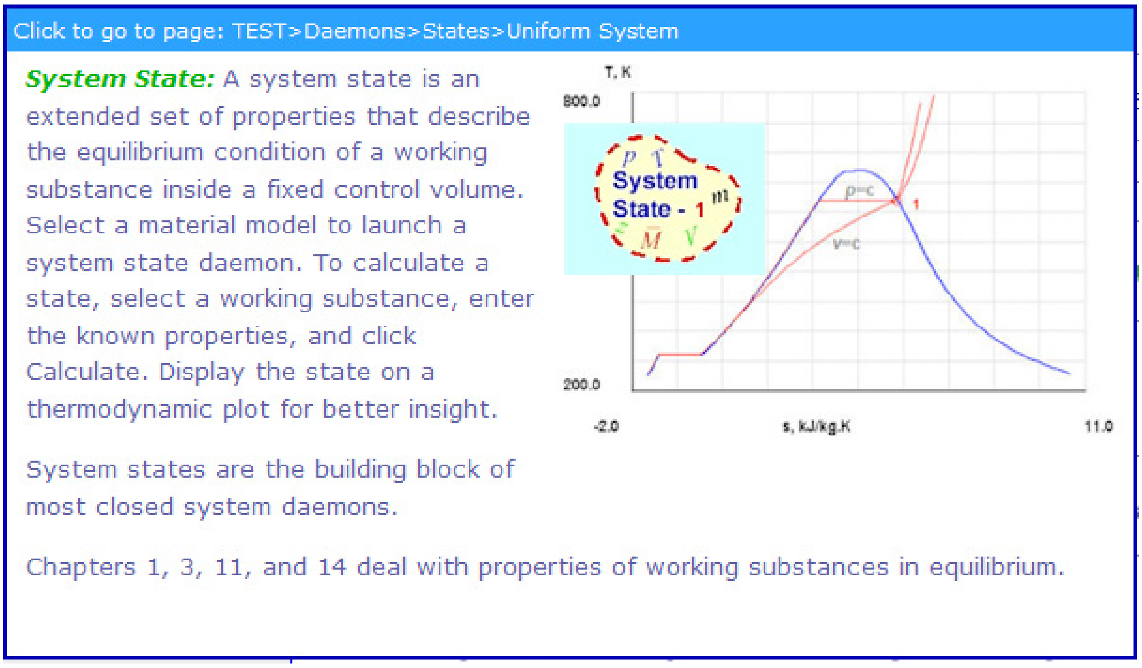
We shall use TEST to find out the properties at States before and after mixing and then make simple calculations to find out heat transfer and exergy loss.

Following are the steps:

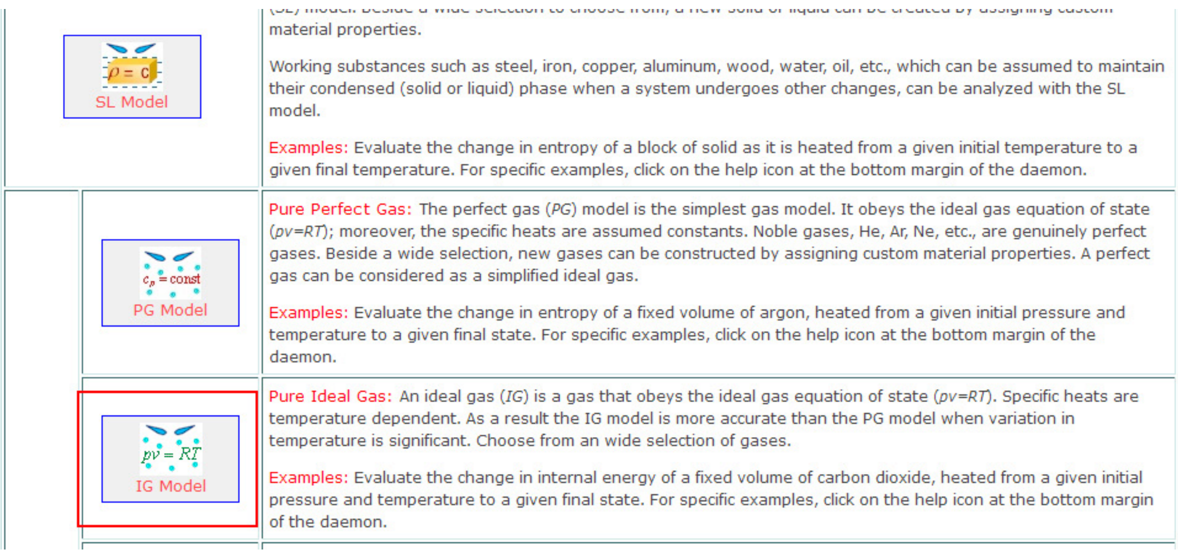
1. From the Daemon tree, choose States & Properties-Uniform System daemon:



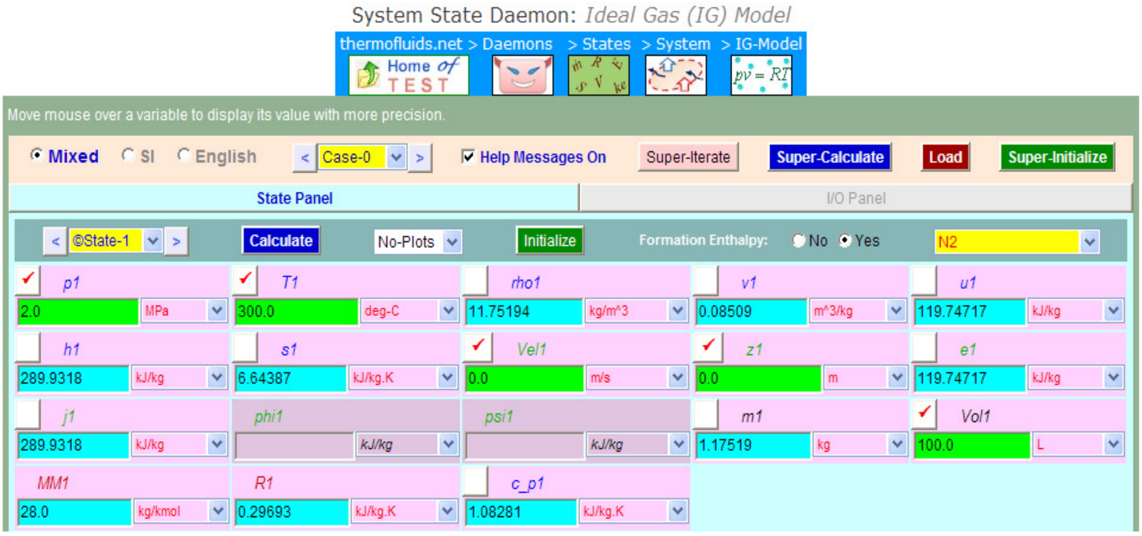
Hovering the mouse pointer on Uniform system brings up:



2. For material model, choose Ideal Gas (IG) model.

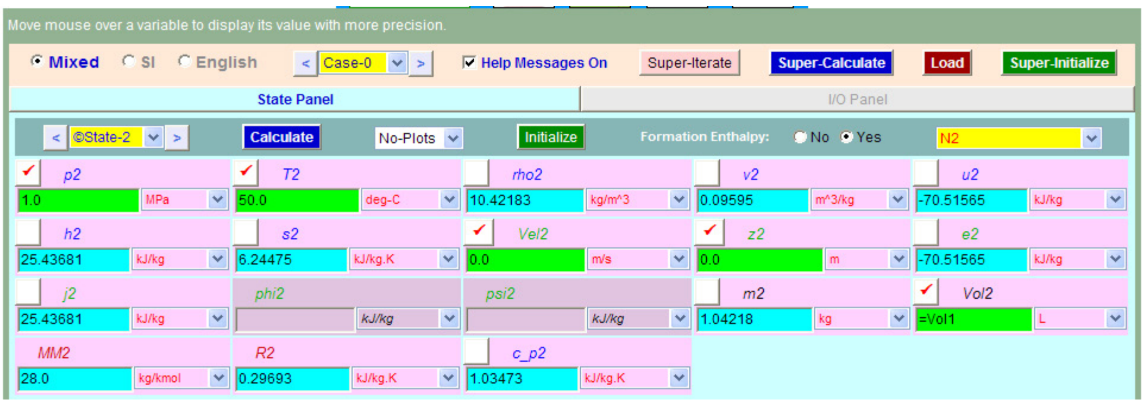


3. Choose N2 for substance and enter for State 1, p1, T1 and Vol1. Hit Enter. We get:



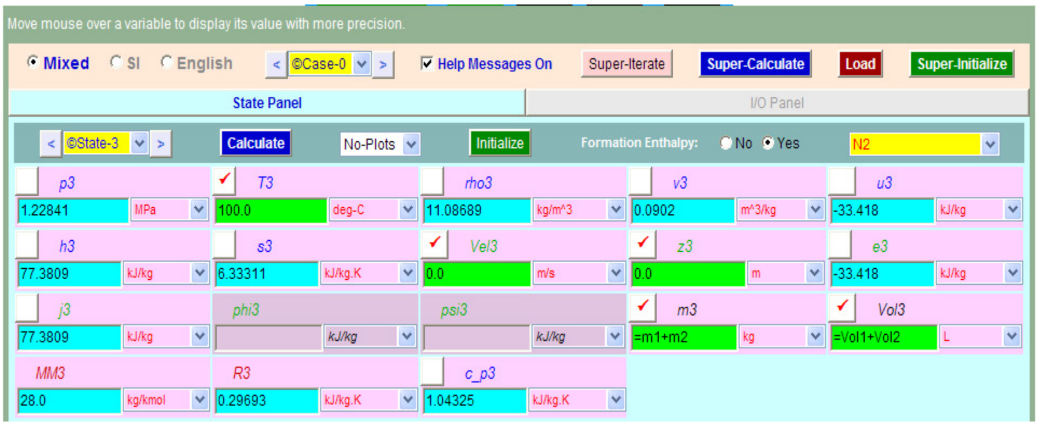
Note that mass, m1, Int. energy, u1, entropy, s1 etc are immediately calculated.

4. Similarly, for State 2, enter p2, T2 and Vol2. Hit Enter, and we get:



Note that mass, m2, Int. energy, u2, entropy, s2 etc are immediately calculated.

5. Now, enter for State 3, the state after mixing. Enter T3, Vol3 and m3. Hit Enter. We get:



6. Now, hit SuperCalculate, and go to I/O panel, where we get TEST code etc. I/O panel is also used as a calculator. The advantage in doing so is that the variables can be directly entered in calculations. See below:

#To find Q:

#Q = dU + W and, W = 0

=m3*u3 – (m1*u1 + m2*u2)

i.e. Q = m3*u3 – (m1*u1 + m2*u2) = -141.336 kJ … Ans… heat rejected to ambient

 # To find S_gen: S_gen = dS_sys + dS_amb

dS_sys= m3*s3 – (m1*s1 + m2*s2) = -0.27312 kJ/K

#dS_amb:= Q/T0

dS_amb = 141.3363/(25+273) = 0.474283 kJ/K

#Therefore: S_gen:

S_gen= -0.273120+ 0.47428 = 0.20116 kJ/K

#Then, exergy lost = Irreversibility:

I = (25+273)*0.20116 = 59.94568 kJ .... Ans.

TEST code etc are given below:

```
#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE
#	Daemon Path: States>System>IG-Model; v-10.ca08
#
#--------------------Start of TEST-code -----------------------------------------------------------------------

States	{
	State-1: N2;
	Given: { p1= 2.0 MPa; T1= 300.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 100.0 L; }
	State-2: N2;
	Given: { p2= 1.0 MPa; T2= 50.0 deg-C; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= "Vol1" L; }
	State-3: N2;
	Given: { T3= 100.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1+m2" kg; Vol3= "Vol1+
Vol2" L; }
	}

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

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

# Evaluated States:
#	State-1: N2 > IG-Model;
#		Given: p1= 2.0 MPa; T1= 300.0 deg-C; Vel1= 0.0 m/s;
#			z1= 0.0 m; Vol1= 100.0 L;
#		Calculated: rho1= 11.7519 kg/m^3; v1= 0.0851 m^3/kg; u1= 119.7472 kJ/kg;
#			h1= 289.9318 kJ/kg; s1= 6.6439 kJ/kg.K; e1= 119.7472 kJ/kg;
#			j1= 289.9318 kJ/kg; m1= 1.1752 kg; MM1= 28.0 kg/kmol;
#			R1= 0.2969 kJ/kg.K; c_p1= 1.0828 kJ/kg.K;
```

```
#	State-2: N2 > IG-Model;
#		Given: p2= 1.0 MPa; T2= 50.0 deg-C; Vel2= 0.0 m/s;
#			z2= 0.0 m; Vol2= "Vol1" L;
#		Calculated: rho2= 10.4218 kg/m^3; v2= 0.0959 m^3/kg; u2= -70.5156 kJ/kg;
#			h2= 25.4368 kJ/kg; s2= 6.2448 kJ/kg.K; e2= -70.5156 kJ/kg;
#			j2= 25.4368 kJ/kg; m2= 1.0422 kg; MM2= 28.0 kg/kmol;
#			R2= 0.2969 kJ/kg.K; c_p2= 1.0347 kJ/kg.K;
#	State-3: N2 > IG-Model;
#		Given: T3= 100.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m;
#			m3= "m1+m2" kg; Vol3= "Vol1+Vol2" L;
#		Calculated: p3= 1.2284 MPa; rho3= 11.0869 kg/m^3; v3= 0.0902 m^3/kg;
#			u3= -33.418 kJ/kg; h3= 77.3809 kJ/kg; s3= 6.3331 kJ/kg.K;
#			e3= -33.418 kJ/kg; j3= 77.3809 kJ/kg; MM3= 28.0 kg/kmol;
#			R3= 0.2969 kJ/kg.K; c_p3= 1.0432 kJ/kg.K;
#

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

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	2000.0	573.2	0.0851	119.75	289.93	6.644
#	2	1000.0	323.2	0.096	-70.52	25.44	6.245
#	3	1228.41	373.2	0.0902	-33.42	77.38	6.333

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

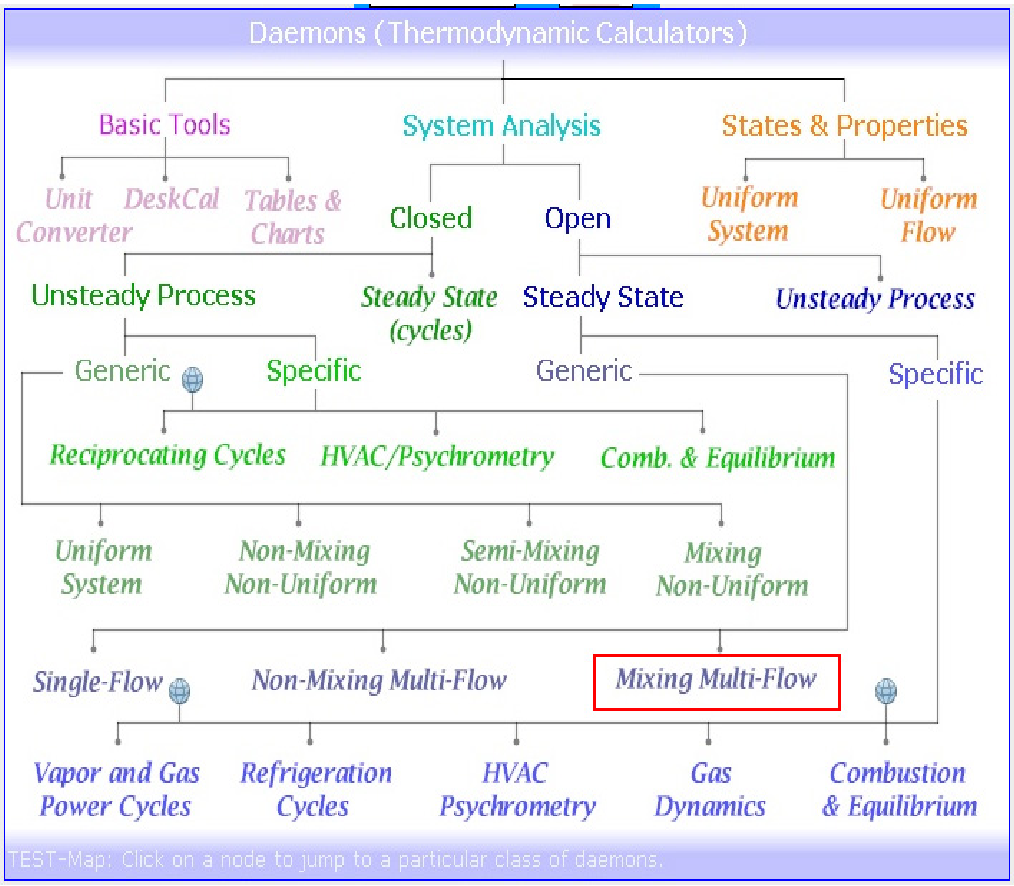
Prob.8.18. Two flows of air, both at 200 kPa, of equal flow rates mix in an insulated mixing chamber. One flow is at 1500 K, and the other at 300 K. Find the Irreversibility in the process per kg of air flowing out. [Ref: 2]

TEST Solution:

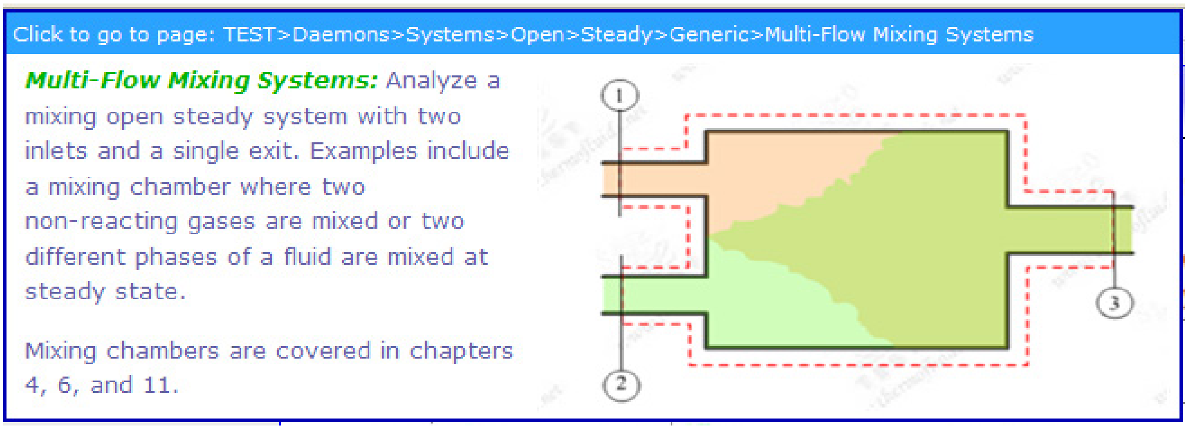
We shall assume the two flow rates as 0.5 kg/s each.

Following are the steps:

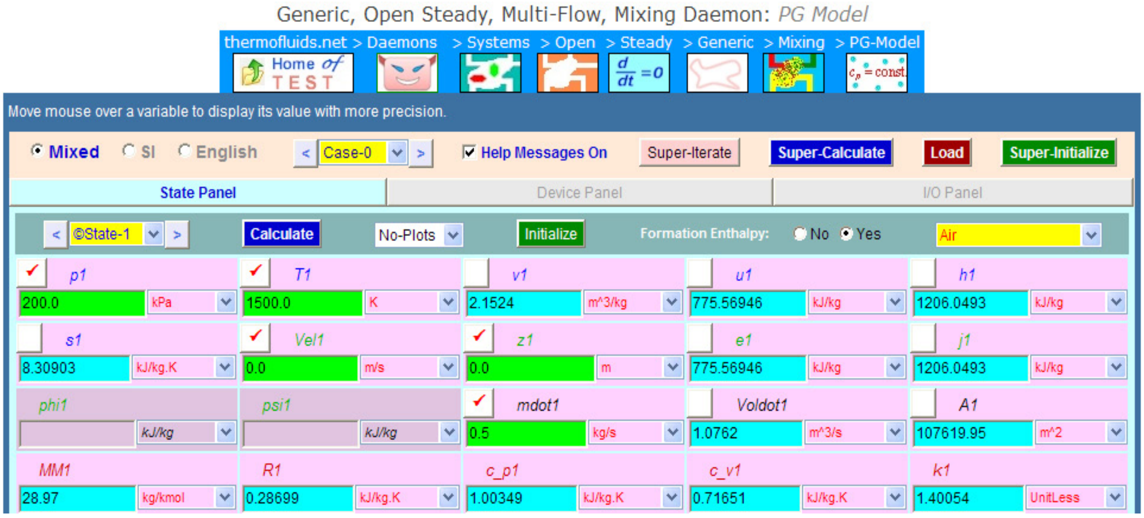
1. From the Daemon tree, choose System Analysis-Open-Mixing Multi-flow daemon.



Hovering the mouse pointer over the Mixing Multi-flow gives the following explanatory pop up:



2. Choose PG model for material model, select Air as the substance, and enter p1, T1 and mdot1 for State 1. Hit Enter. We get:

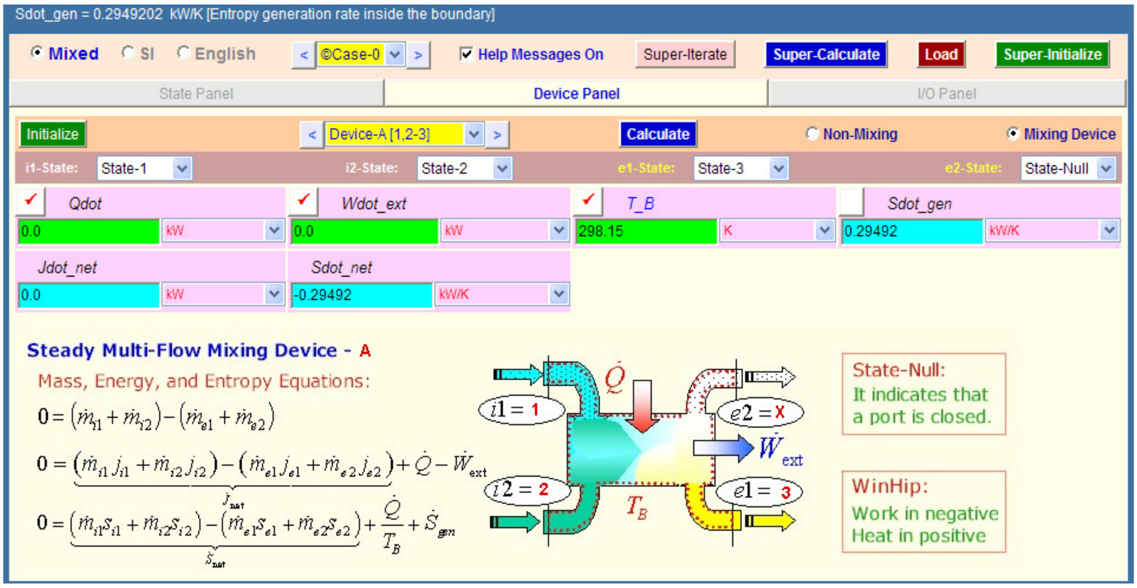


3. For State 2, enter p2, T2 and mdot2, and hit Enter. We get:

4. For State 3, enter p3, h3 = (m1*h1 + m2*h2)/ (m1 + m2), and mdot3 = (mdot1 + mdot2) and hit Enter. We get:

Note that temp after mixing, entropy etc are calculated immediately.

5. Now, go to the Device Panel. Enter State 1 and State 2 for i1-state and i-2 state (i.e. two inlet states) respectively. For e-1 State enter State 3 and for e-2 state, enter null, since there is only one exit from the mixing chamber. Also, Qdot = 0, since chamber is insulated, and Wdot_ext = 0, since there is no external work. Hit Enter. Also, press SuperCalculate. See the fig. below, in the Device panel:



Note that S_gen is calculated as 0.29492 kW/K.

Calculate the Irreversibility as shown below:

#Exergy lost = Irreversibility: = T0 * S_gen

i.e. Irreversibility = (25+273) * 0.29492 = 87.886 kW ... Ans.

---

6. Go to I/O panel to get TEST code etc:

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

Daemon Path: Systems>Open>SteadyState>Generic>MultiFlowMixed>PG-Model; v-10.ca08

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

States {

State-1: Air;
Given: { p1= 200.0 kPa; T1= 1500.0 K; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 0.5 kg/s; }

State-2: Air;
Given: { p2= 200.0 kPa; T2= 300.0 K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= 0.5 kg/s; }

State-3: Air;
Given: { p3= 200.0 kPa; h3= "(m1*h1+m2*h2)/m3" kJ/kg; 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 ------------------------------------------------------------------

#******DETAILED OUTPUT:

# Evaluated States:
#       State-1: Air > PG-Model;
#               Given: p1= 200.0 kPa; T1= 1500.0 K; Vel1= 0.0 m/s;
#                       z1= 0.0 m; mdot1= 0.5 kg/s;
#               Calculated: v1= 2.1524 m^3/kg; u1= 775.5695 kJ/kg; h1= 1206.0493 kJ/kg;
#                       s1= 8.309 kJ/kg.K; e1= 775.5695 kJ/kg; j1= 1206.0493 kJ/kg;
#                       Voldot1= 1.0762 m^3/s; A1= 107619.95 m^2; 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= 200.0 kPa; T2= 300.0 K; Vel2= 0.0 m/s;
#                       z2= 0.0 m; mdot2= 0.5 kg/s;
#               Calculated: v2= 0.4305 m^3/kg; u2= -84.2395 kJ/kg; h2= 1.8565 kJ/kg;
#                       s2= 6.694 kJ/kg.K; e2= -84.2395 kJ/kg; j2= 1.8565 kJ/kg;
#                       Voldot2= 0.2152 m^3/s; A2= 21523.99 m^2; 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= 200.0 kPa; h3= "(m1*h1+m2*h2)/m3" kJ/kg; Vel3= 0.0 m/s;
#                       z3= 0.0 m; mdot3= "mdot1+mdot2" kg/s;
#               Calculated: T3= 900.0 K; v3= 1.2914 m^3/kg; u3= 345.665 kJ/kg;
#                       s3= 7.7964 kJ/kg.K; e3= 345.665 kJ/kg; j3= 603.9529 kJ/kg;
#                       Voldot3= 1.2914 m^3/s; A3= 129143.945 m^2; 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;
```

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

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	200.0	1500.0	2.1524	775.57	1206.05	8.309
#	2	200.0	300.0	0.4305	-84.24	1.86	6.694
#	3	200.0	900.0	1.2914	345.66	603.95	7.796

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

 # 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= 0.2949202 kW/K**; Jdot_net= 0.0 kW; Sdot_net= -0.2949202 kW/K;

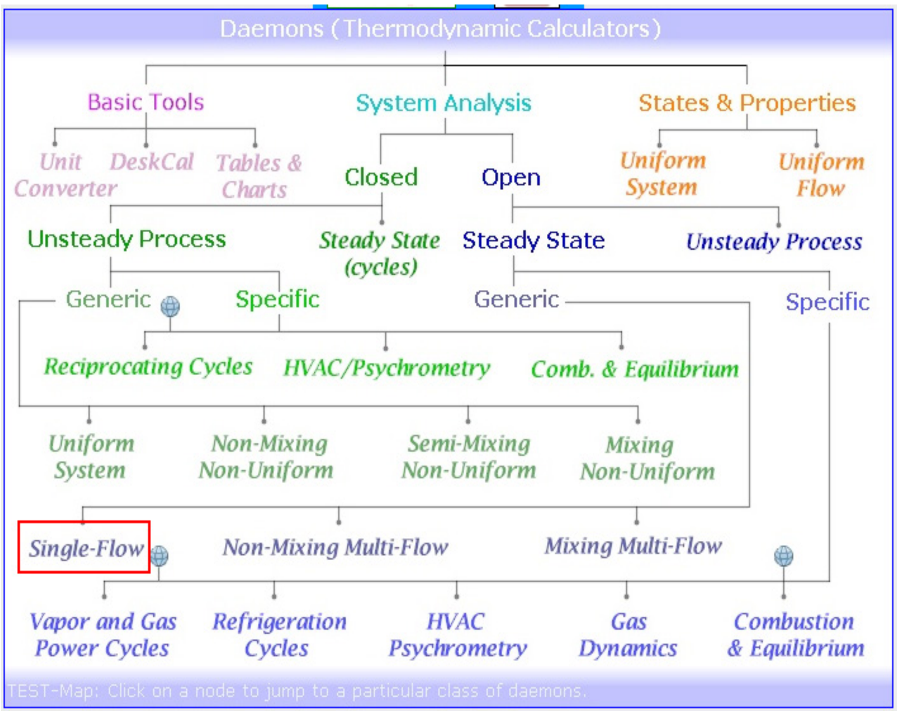
===

Prob.8.19. A steady stream of R-22 at ambient temp 10 C and at 750 kPa enters a solar collector. The stream exits at 80 C and 700 kPa. Calculate the change in availability of R-22 between these two states. [Ref: 2]

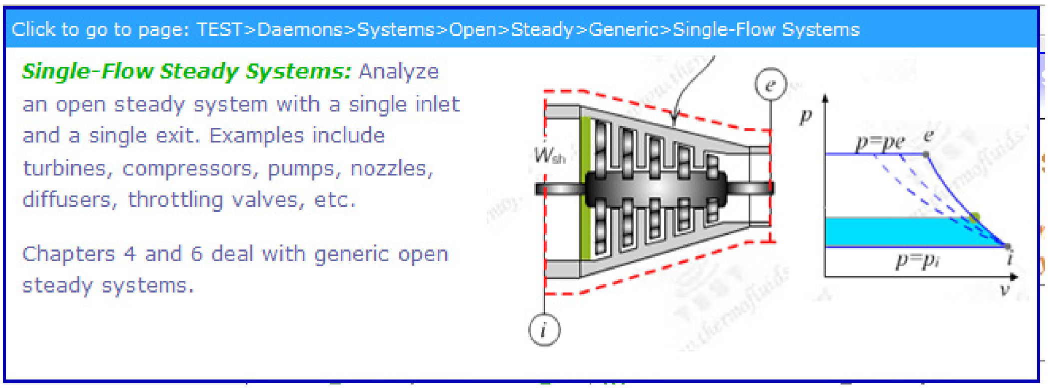
TEST Solution:

Following are the steps:

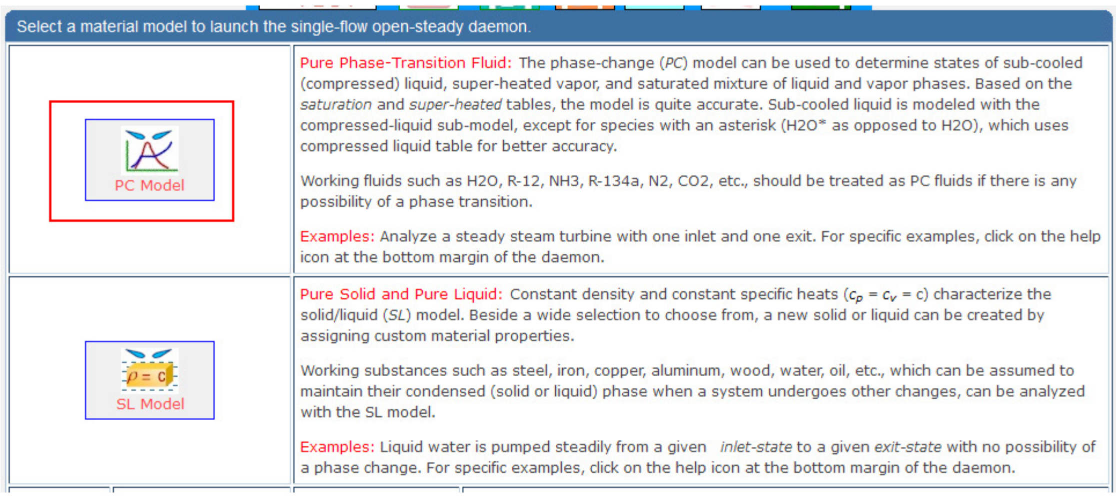
1. From the Daemon tree choose System Analysis-Open-Single Flow daemon:



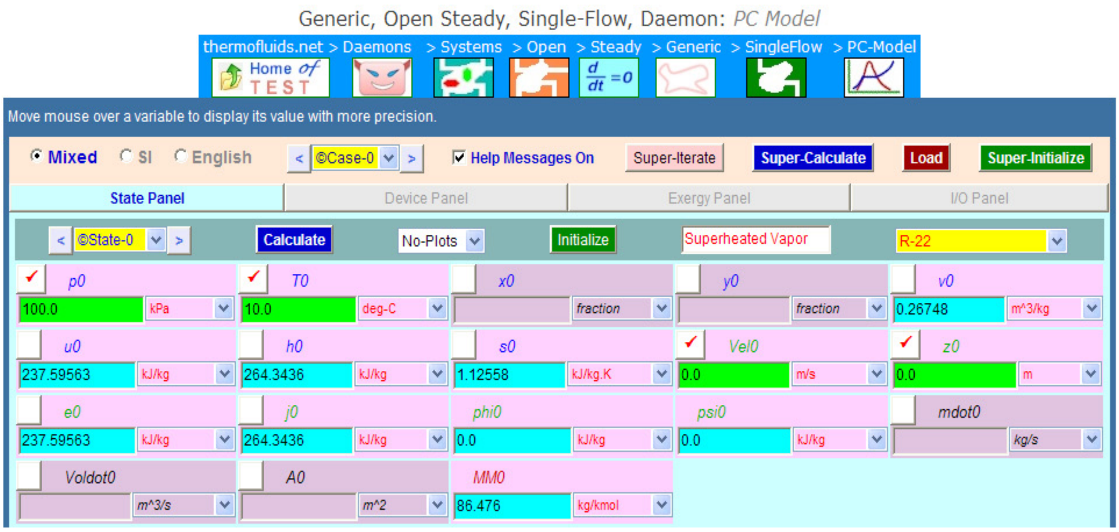
Hovering the mouse pointer over Single-Flow gives following pop up:



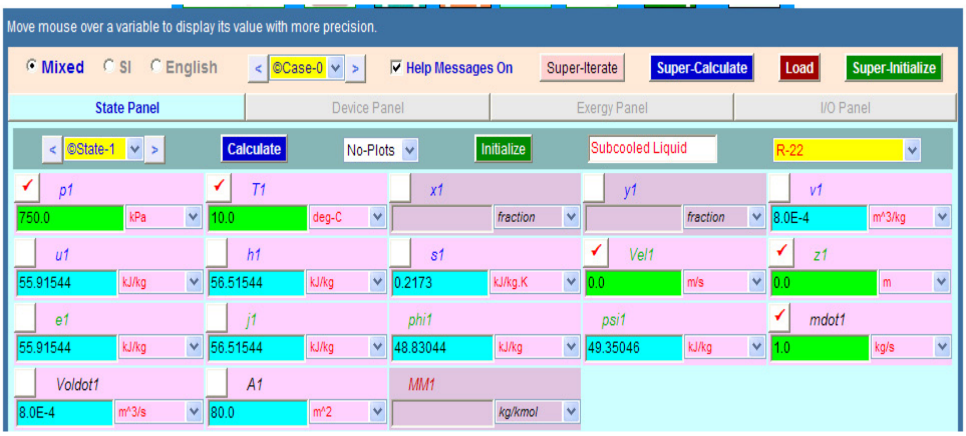
2. Choose PC model for material model:



3. And, select R-22 for the substance and enter p0 = 100 kPa and T0 = 10 C for State '0' (required for exergy calculations). Hit Enter:

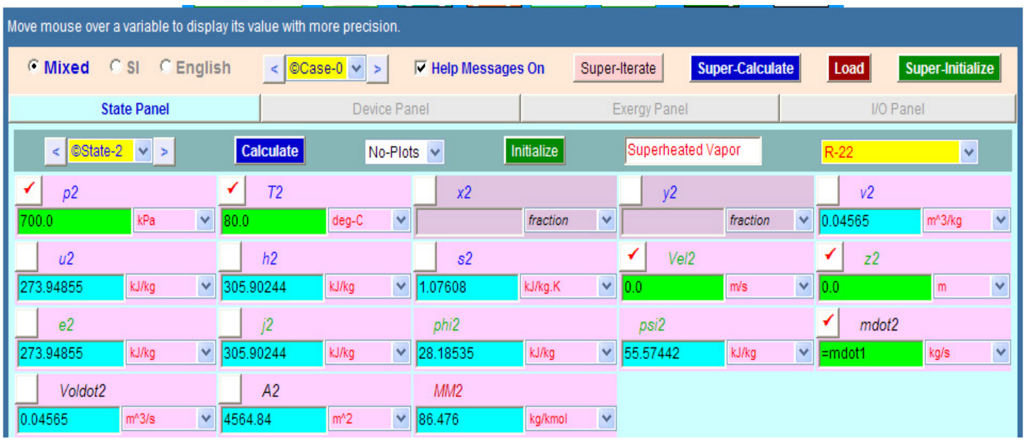


4. For State 1: Enter p1, T1 and mdot1 as shown, and hit Enter. We get:



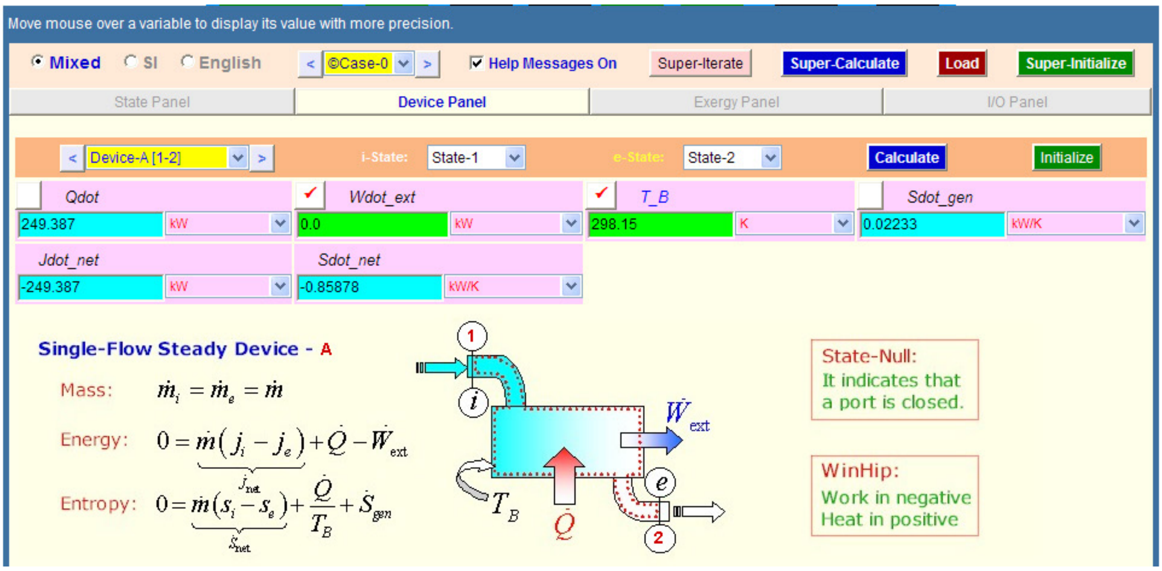
Note that all properties such as h1, s1 etc at State 1 are calculated.

5. Now, for State 2: enter p2, T2 and mdot2, hit Enter. We get:



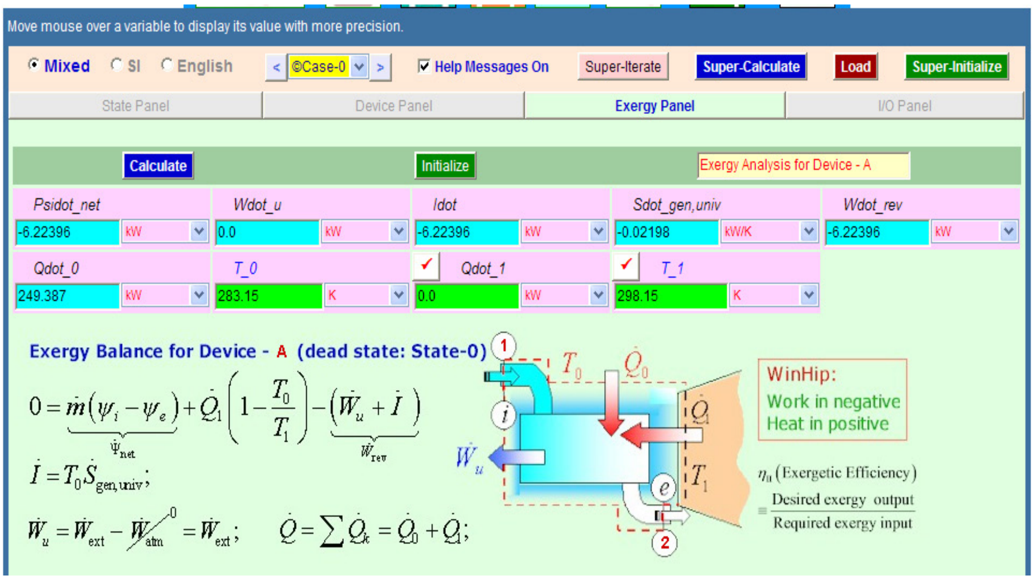
Again note that all properties such as h2, s2 are calculated.

6. Now, go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. And, Wdot_ext = 0. Click on Calculate and SuperCalculate. We get:



Note that Sdot_gen and Qdot are calculated. Qdot is +ve…means that heat is entering in to the system.

7. Go to the Exergy panel. Note that all calculations are available here.



Note that exergy difference between inlet and exit is Psidot_net = -6.22396 kW …. Ans.
Remember: Exergy difference = mdot * {(h2 – h1) – T0 * (s2 – s1)}

8. I/O panel gives the TEST code etc:

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

Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.cb01

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

States {

State-0: R-22;

Given: { p0= 100.0 kPa; T0= 10.0 deg-C; Vel0= 0.0 m/s; z0= 0.0 m; }

State-1: R-22;

Given: { p1= 750.0 kPa; T1= 10.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }

State-2: R-22;

Given: { p2= 700.0 kPa; T2= 80.0 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: { 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)
# 00     100.0       283.2       0.2675     237.6      264.34     1.126
# 01     750.0       283.2       8.0E-4     55.92      56.52      0.217
# 02     700.0       353.2       0.0456     273.95     305.9      1.076

#
```

 # Mass, Energy, and Entropy Analysis Results:

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

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

#               Calculated: Qdot= 249.387 kW; Sdot_gen= 0.022330081 kW/K; Jdot_net= -249.387 kW;
Sdot_net= -0.8587782 kW/K;
```

 # Exergy Analysis Results:

 # Exergy Analysis for Device – A (Dead state: State-0)

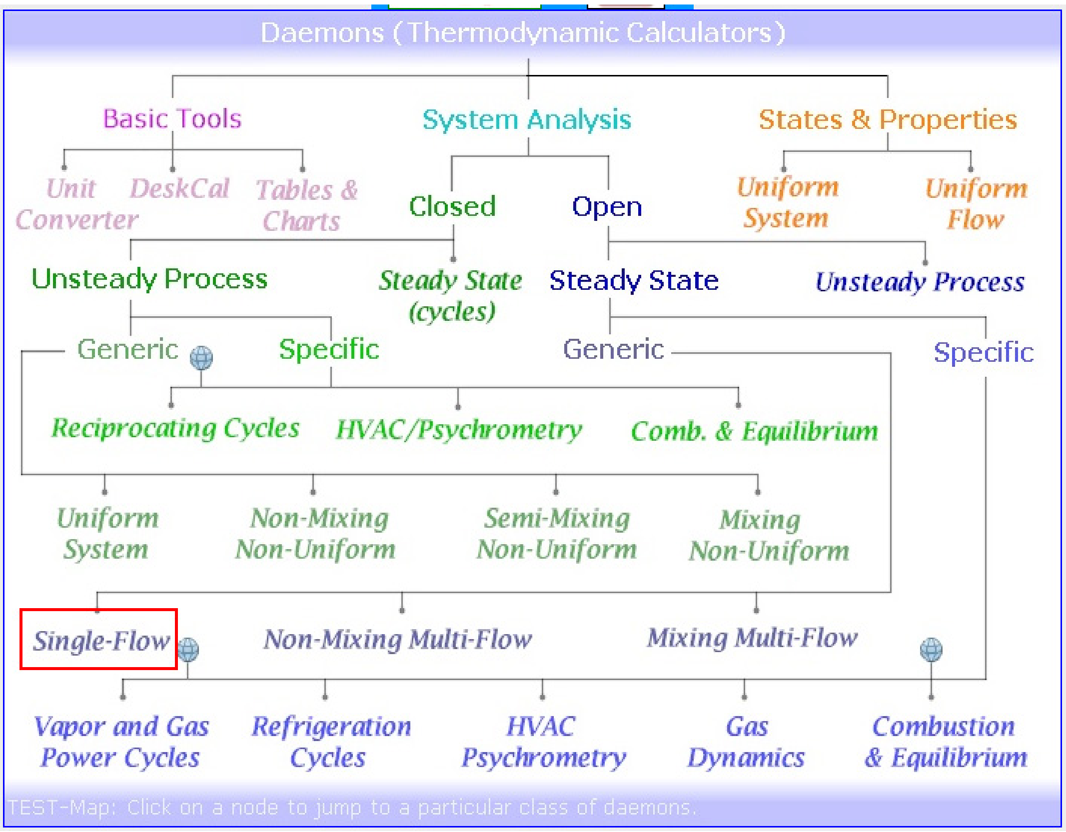
```
#               Given: Qdot= 249.387 kW; T_0= 283.15 K; Qdot_1= 0.0 kW;

#               T_1= 298.15 K;

#               Calculated: Psidot_net= -6.22396 kW; Wdot_u= 0.0 kW; Idot= -6.22396 kW;

#               Sdot_gen,univ= -0.02198 kW/K; Wdot_rev= -6.22396 kW; Qdot_0= 249.387 kW;

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

Prob.8.20. Steam enters a turbine at 25 MPa, 550 C and exits at 5 MPa, 325 C at a flow rate of 70 kg/s. Determine the total power output of the turbine, its isentropic efficiency and the Second Law efficiency. [Ref: 2]

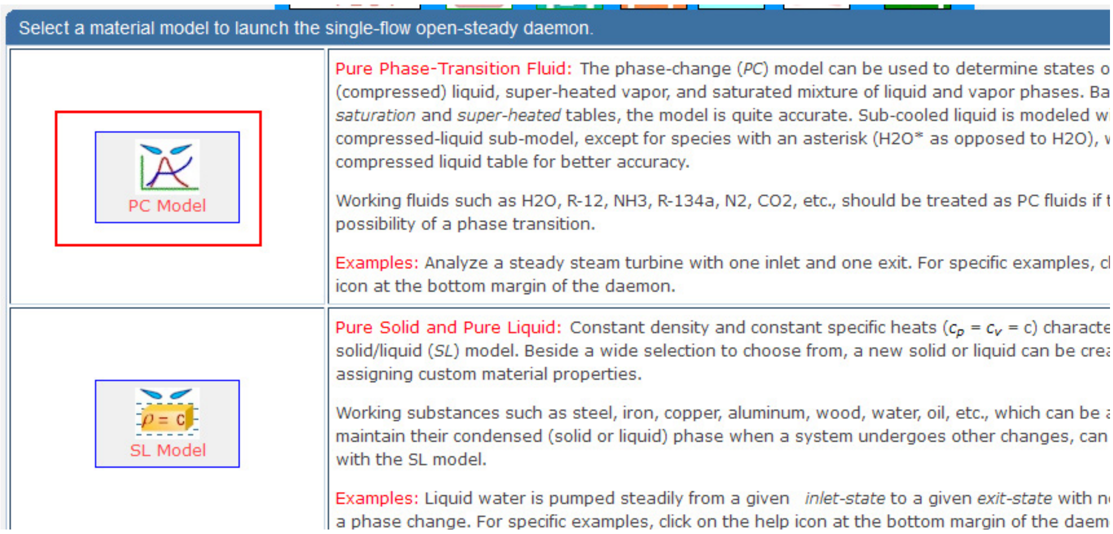
TEST Solution:

Following are the steps:

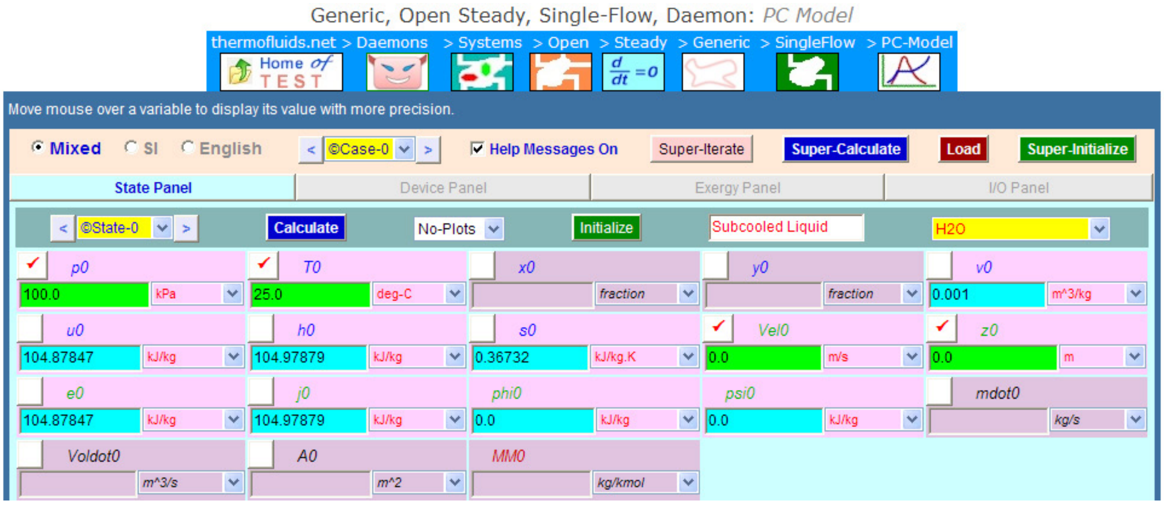
1. Choose System Analysis-Open-Single Flow daemon:



2. Choose PC model for material model:

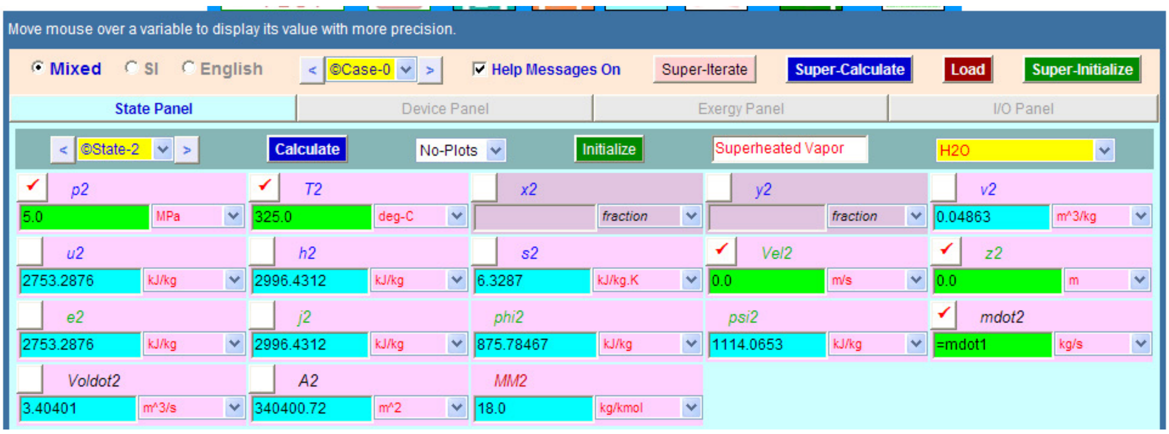


3. And, select H2O for substance, enter for State – '0' values of p0, T0 (for exergy calculations). Hit Enter:



4. Enter p1, T1 and mdot1 for State 1, hit Enter. We get:

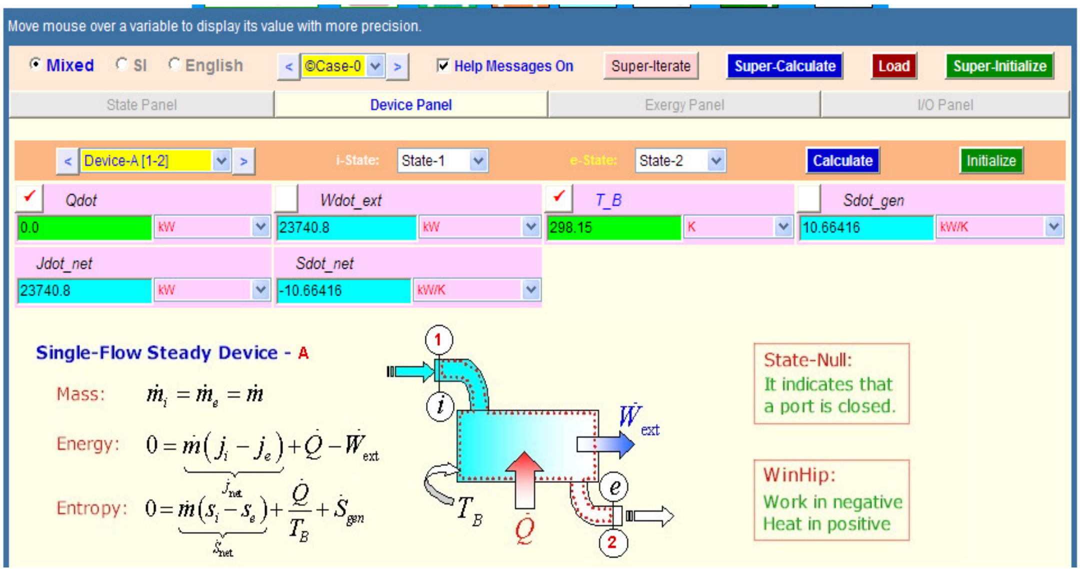
5. Similarly, for State 2: enter p2, T2 and mdot2, and hit Enter:



6. Have a State 3 where we get properties if the expansion in the turbine is isentropic. i.e. Enter for State 3: p3 = p2, s3 = s1 and mdot3 = mdot1. Hit Enter. We get:

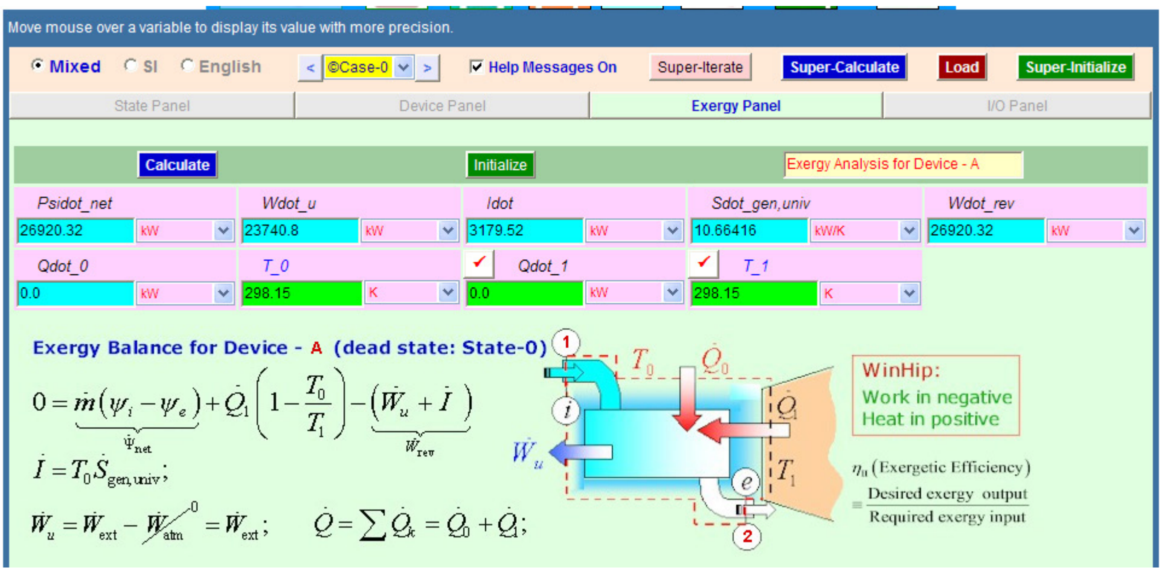
Note that if the expansion were isentropic, h3 would be: h3 = 2906.832 kJ/kg

7. Go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. Also, Qdot = 0. Click on Calculate and then SuperCalculate. We get:



Note that Wdot_ext = 23740.8 kW … actual work output …. Ans.

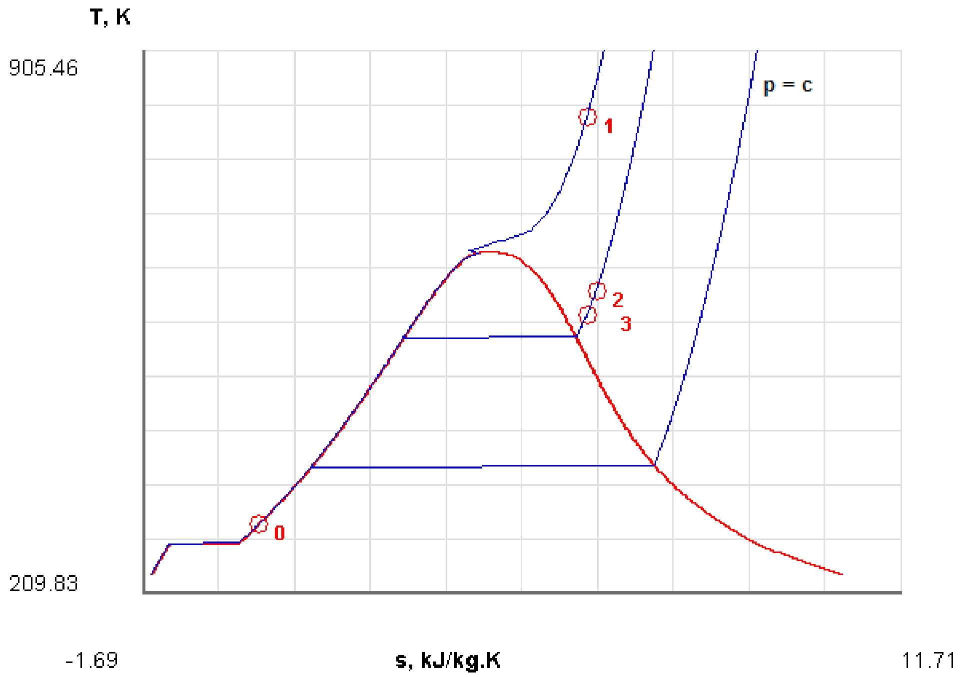
8. Go to Exergy Panel. All calculations are available there:



Note that Wdot_rev = rev. work = 26920.32 kW. … Ans.

Indicative T-s plot drawn in TEST is given below:

Here, 1–2 is actual expansion and 1–3 is isentropic expansion.



Therefore:

By definition, Second Law efficiency =eta_II = W / W_rev = 0.882

Isentropic efficiency = eta_iso = (h1 – h2) / (h1 – h3) = 0.791

9. From the I/O panel, get the TEST code etc:

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

Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.cb01

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

States {

State-0: H2O;

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

State-1: H2O;

Given: { p1= 25.0 MPa; T1= 550.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 70.0 kg/s; }

```
        State-2: H2O;

        Given: { p2= 5.0 MPa; T2= 325.0 deg-C; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }

        State-3: H2O;

        Given: { p3= "P2" MPa; s3= "s1" kJ/kg.K; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= "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: #
```

 # Evaluated States:

```
#       State-0: H2O > Subcooled Liquid;
#               Given: p0= 100.0 kPa; T0= 25.0 deg-C; Vel0= 0.0 m/s;
#                       z0= 0.0 m;
#               Calculated: v0= 0.001 m^3/kg; u0= 104.8785 kJ/kg; h0= 104.9788 kJ/kg;
#                       s0= 0.3673 kJ/kg.K; e0= 104.8785 kJ/kg; j0= 104.9788 kJ/kg;
#                       phi0= 0.0 kJ/kg; psi0= 0.0 kJ/kg;
#       State-1: H2O > Superheated Vapor;
#               Given: p1= 25.0 MPa; T1= 550.0 deg-C; Vel1= 0.0 m/s;
#                       z1= 0.0 m; mdot1= 70.0 kg/s;
#               Calculated: v1= 0.0127 m^3/kg; u1= 3017.4932 kJ/kg; h1= 3335.5854 kJ/kg;
#                       s1= 6.1764 kJ/kg.K; e1= 3017.4932 kJ/kg; j1= 3335.5854 kJ/kg;
#                       phi1= 1181.8214 kJ/kg; psi1= 1498.6414 kJ/kg; Voldot1= 0.8907 m^3/s;
#                       A1= 89065.76 m^2; MM1= 18.0 kg/kmol;
#       State-2: H2O > Superheated Vapor;
#               Given: p2= 5.0 MPa; T2= 325.0 deg-C; Vel2= 0.0 m/s;
#                       z2= 0.0 m; mdot2= "mdot1" kg/s;
#               Calculated: v2= 0.0486 m^3/kg; u2= 2753.2876 kJ/kg; h2= 2996.4312 kJ/kg;
#                       s2= 6.3287 kJ/kg.K; e2= 2753.2876 kJ/kg; j2= 2996.4312 kJ/kg;
#                       phi2= 875.7846 kJ/kg; psi2= 1114.0653 kJ/kg; Voldot2= 3.404 m^3/s;
#                       A2= 340400.72 m^2; MM2= 18.0 kg/kmol;
```

```
#        State-3: H2O > Superheated Vapor;
#                 Given: p3= "P2" MPa; s3= "s1" kJ/kg.K; Vel3= 0.0 m/s;
#                          z3= 0.0 m; mdot3= "mdot1" kg/s;
#                 Calculated: T3= 295.1138 deg-C; v3= 0.0445 m^3/kg; u3= 2684.2283 kJ/kg;
#                          h3= 2906.832 kJ/kg; e3= 2684.2283 kJ/kg; j3= 2906.832 kJ/kg;
#                          phi3= 851.7362 kJ/kg; psi3= 1069.888 kJ/kg; Voldot3= 3.1164 m^3/s;
#                          A3= 311645.16 m^2; 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)
# 00	100.0	298.2		0.001	104.88	104.98	0.367
# 01	25000.0	823.2		0.0127	3017.49	3335.59	6.176
# 02	5000.0	598.2		0.0486	2753.29	2996.43	6.329
# 03	5000.0	568.3		0.0445	2684.23	2906.83	6.176

 # 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= 23740.8 kW; Sdot_gen= 10.664163 kW/K; Jdot_net= 23740.8 kW; Sdot_net= -10.664163 kW/K;

 # Exergy Analysis Results:

 # Exergy Analysis for Device – A (Dead state: State-0)

Given: Qdot= 0.0 kW; T_0= 298.15 K; Qdot_1= 0.0 kW;

T_1= 298.15 K;

Calculated: Psidot_net= 26920.32 kW; Wdot_u= 23740.8 kW; Idot= 3179.52 kW;

Sdot_gen,univ= 10.66416 kW/K; Wdot_rev= 26920.32 kW; Qdot_0= 0.0 kW;

==

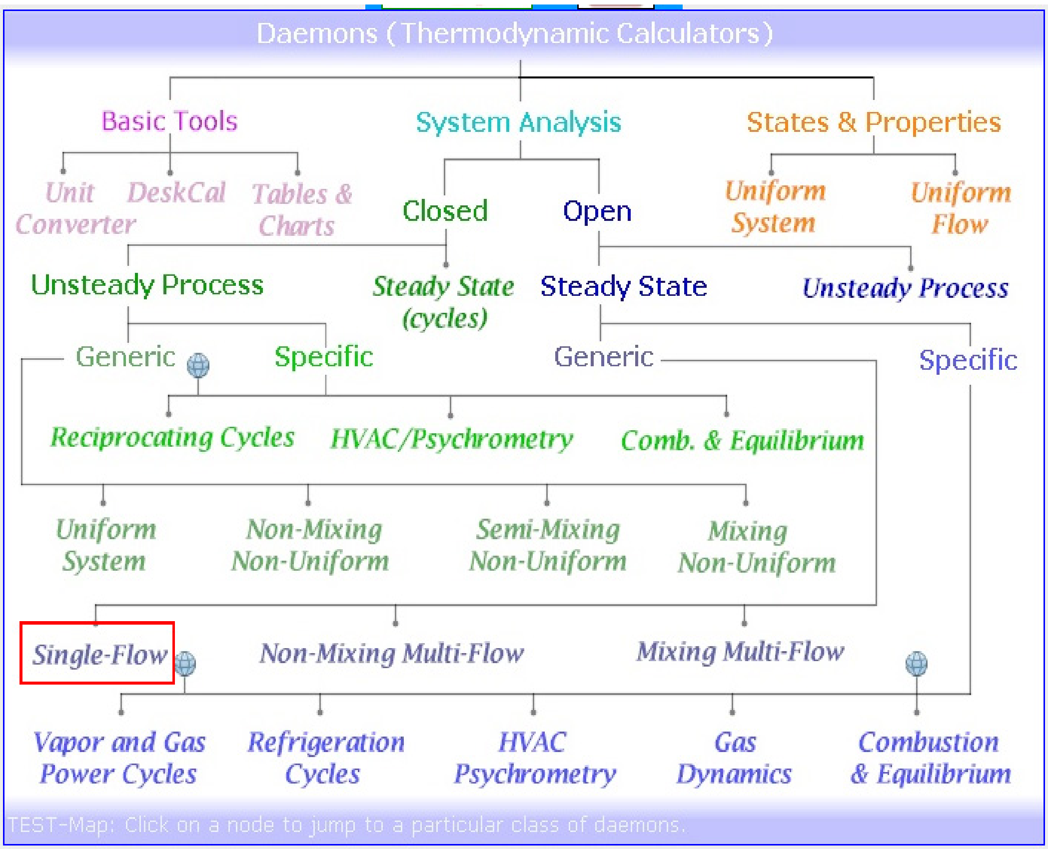
Prob.8.21. Air is compressed by a compressor from 101 kPa and 27 C to 400 kPa and 220 C at a rate of 0.15 kg/s. Neglecting the changes in K.E. and P.E. and assuming the surroundings to be at 25 C, determine the reversible power input for this process

(b) Also , plot the reversible power against compressor exit pressure p2, as p2 varies from 200 to 600 kPa. [Ref: 1]

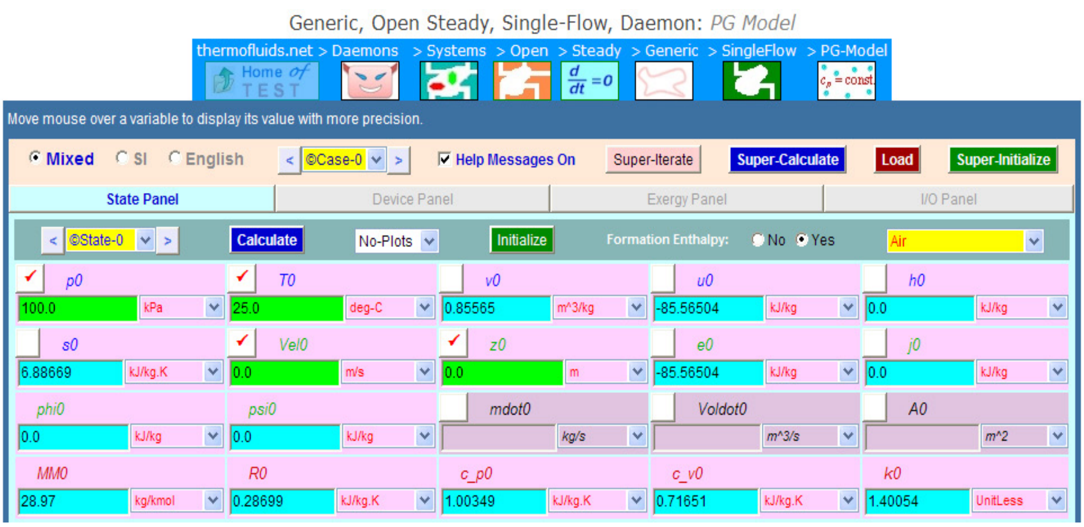
TEST Solution:

Following are the steps:

1. Choose Open steady Single Flow daemon from the daemon tree:



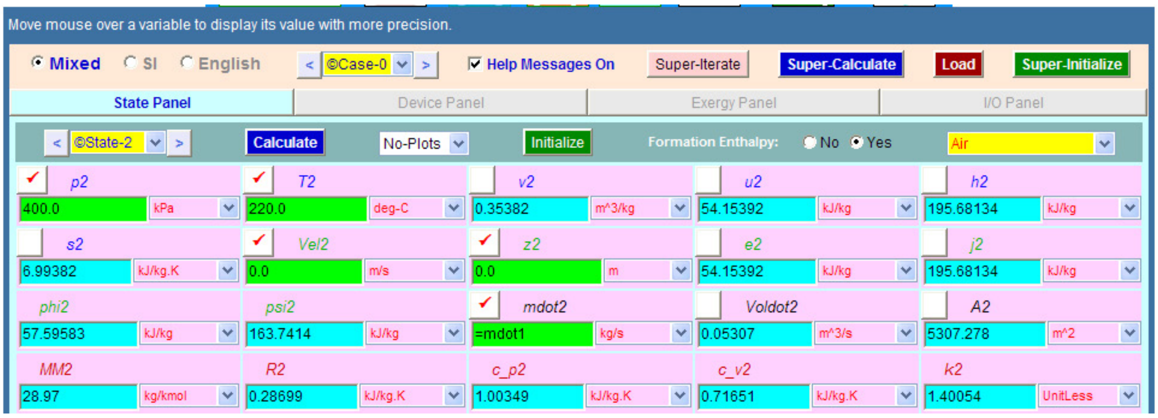
2. Choose the PG model for material model, and select air as the working substance. Enter p0 = 100 kPa and T0 = 25 C for State '0'. (This is required for exergy calculations.). Hit Enter. We get:



3. For State 1: enter p1, T1 and mdot1 as shown below, and hit Enter. We get:

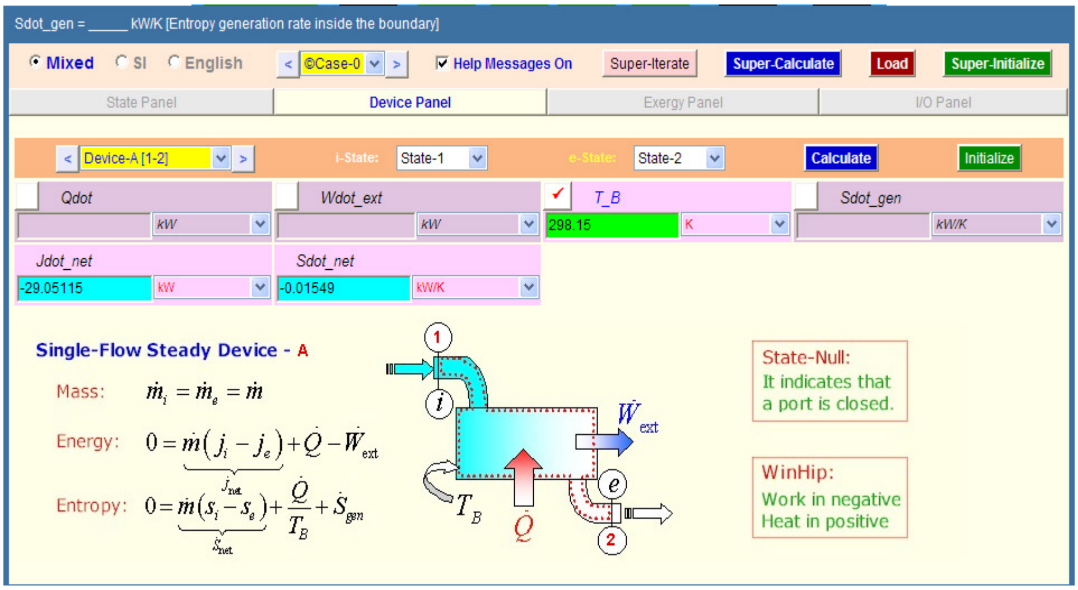
Note that all properties at State 1 are immediately calculated.

4. Similarly, enter p2, T2 and mdot2 for State 2, and hit Enter:

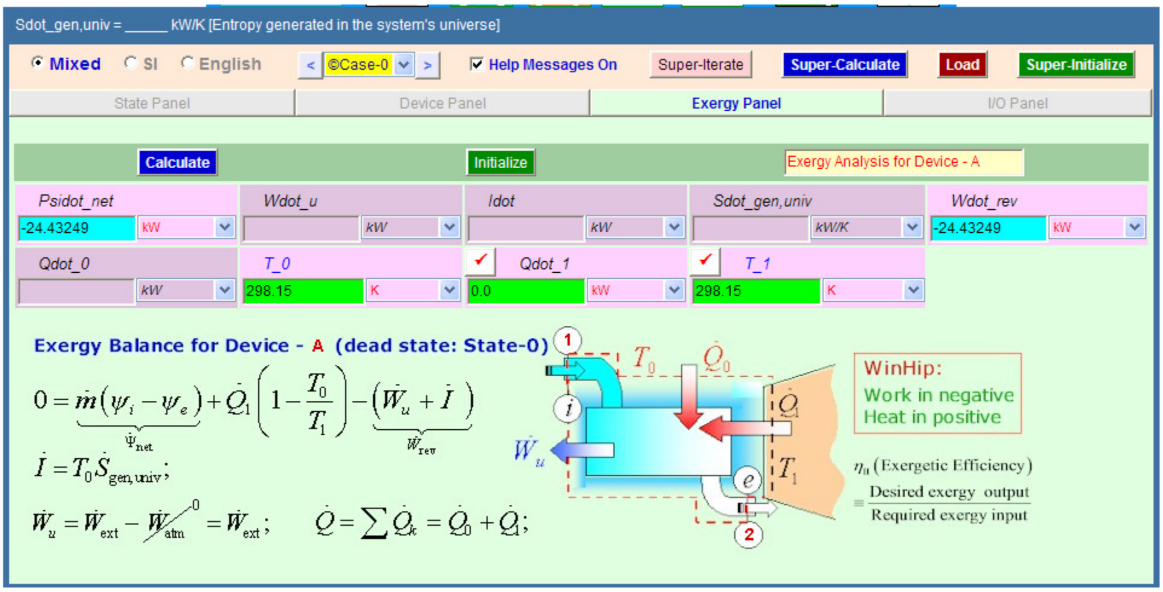


Note that all properties at State 2 are immediately calculated.

5. Now, go to Device panel. Enter State 1 and State 2 for i-state and e-state respectively. Click on Calculate and then SuperCalculate. We get:



6. Now, go to Exergy panel. There we see that calculations are already made:



Thus:

Reversible work = -24.4325 kW …Ans. (-ve sign means that work has to be supplied to the compressor)

Remember: W_rev = change in Exergy between inlet and exit of compressor = Psidot (See the above screen shot.)

7. I/O panel gives the TEST code etc:

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

Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PG-Model; v-10.ca08

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

States {

State-0: Air;

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

State-1: Air;

Given: { p1= 101.0 kPa; T1= 27.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 0.15 kg/s; }

```
        State-2: Air;

        Given: { p2= 400.0 kPa; T2= 220.0 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: { T_B= 298.15 K; }

        }

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

#******DETAILED OUTPUT: #

 # Evaluated States:

```
#	State-0: Air > PG-Model;
#		Given: p0= 100.0 kPa; T0= 25.0 deg-C; Vel0= 0.0 m/s;
#			z0= 0.0 m;
#		Calculated: v0= 0.8556 m^3/kg; u0= -85.565 kJ/kg; h0= 0.0 kJ/kg;
#			s0= 6.8867 kJ/kg.K; e0= -85.565 kJ/kg; j0= 0.0 kJ/kg;
#			phi0= 0.0 kJ/kg; psi0= 0.0 kJ/kg; MM0= 28.97 kg/kmol;
#			R0= 0.287 kJ/kg.K; c_p0= 1.0035 kJ/kg.K; c_v0= 0.7165 kJ/kg.K;
#			k0= 1.4005 UnitLess;
#	State-1: Air > PG-Model;
#		Given: p1= 101.0 kPa; T1= 27.0 deg-C; Vel1= 0.0 m/s;
#			z1= 0.0 m; mdot1= 0.15 kg/s;
#		Calculated: v1= 0.8529 m^3/kg; u1= -84.132 kJ/kg; h1= 2.007 kJ/kg;
#			s1= 6.8905 kJ/kg.K; e1= -84.132 kJ/kg; j1= 2.007 kJ/kg;
#			phi1= 0.0052 kJ/kg; psi1= 0.8581 kJ/kg; Voldot1= 0.1279 m^3/s;
#			A1= 12792.922 m^2; 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= 400.0 kPa; T2= 220.0 deg-C; Vel2= 0.0 m/s;
#			z2= 0.0 m; mdot2= "mdot1" kg/s;
#		Calculated: v2= 0.3538 m^3/kg; u2= 54.1539 kJ/kg; h2= 195.6813 kJ/kg;
#			s2= 6.9938 kJ/kg.K; e2= 54.1539 kJ/kg; j2= 195.6813 kJ/kg;
#			phi2= 57.5958 kJ/kg; psi2= 163.7414 kJ/kg; Voldot2= 0.0531 m^3/s;
#			A2= 5307.278 m^2; 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 starts:
```

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	0	100.0	298.2	0.8557	-85.57	0.0	6.887
#	1	101.0	300.2	0.8529	-84.13	2.01	6.891
#	2	400.0	493.2	0.3538	54.15	195.68	6.994

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

 # Mass, Energy, and Entropy Analysis Results:

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

Given: T_B= 298.15 K;

Calculated: Jdot_net= -29.051151 kW; Sdot_net= -0.015491056 kW/K;

 # Exergy Analysis Results:

 # Exergy Analysis for Device – A (Dead state: State-0)

#

Given: T_0= 298.15 K; Qdot_1= 0.0 kW; T_1= 298.15 K;

Calculated: **Psidot_net= -24.43249 kW; Wdot_rev= -24.43249 kW;**

(b) To plot W_rev against compressor exit pressure, with the exit temp maintained at 220 C:

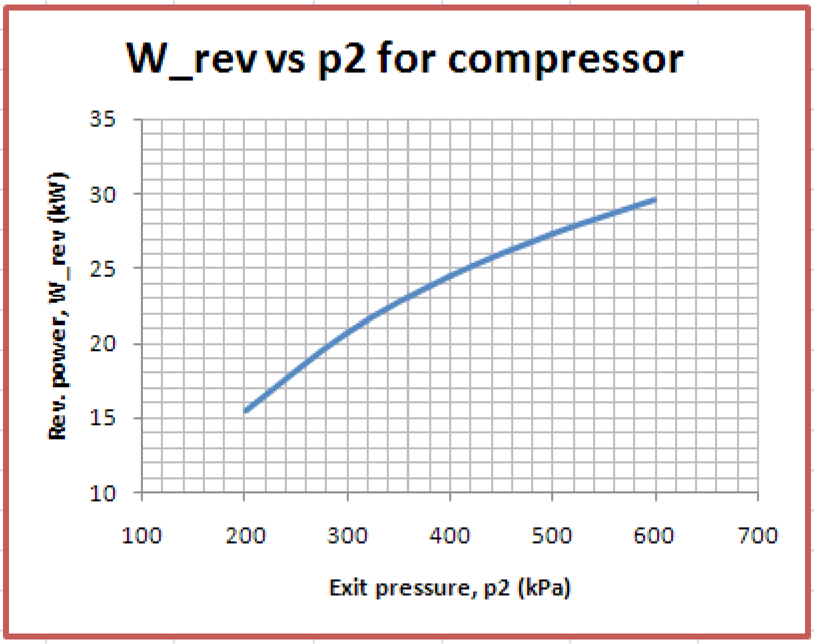
To do this, following are the simple steps:

a) Go to States panel, select State 2.
b) Change the p2 to the desired value
c) Click on Calculate, and then SuperCalculate
d) Go to Exergy panel and read the value of W_rev
e) Repeat this procedure for other desired values of p2
f) Tabulate the results, i.e. W_rev against p2.

p2 (kPa)	W_rev (kW)
200	-15.536
300	-20.740
400	-24.432
500	-27.296
600	-29.637

Now, plot these results in EXCEL:

Note: -ve sign in W_rev is removed, since it only indicates that work is supplied to compressor.



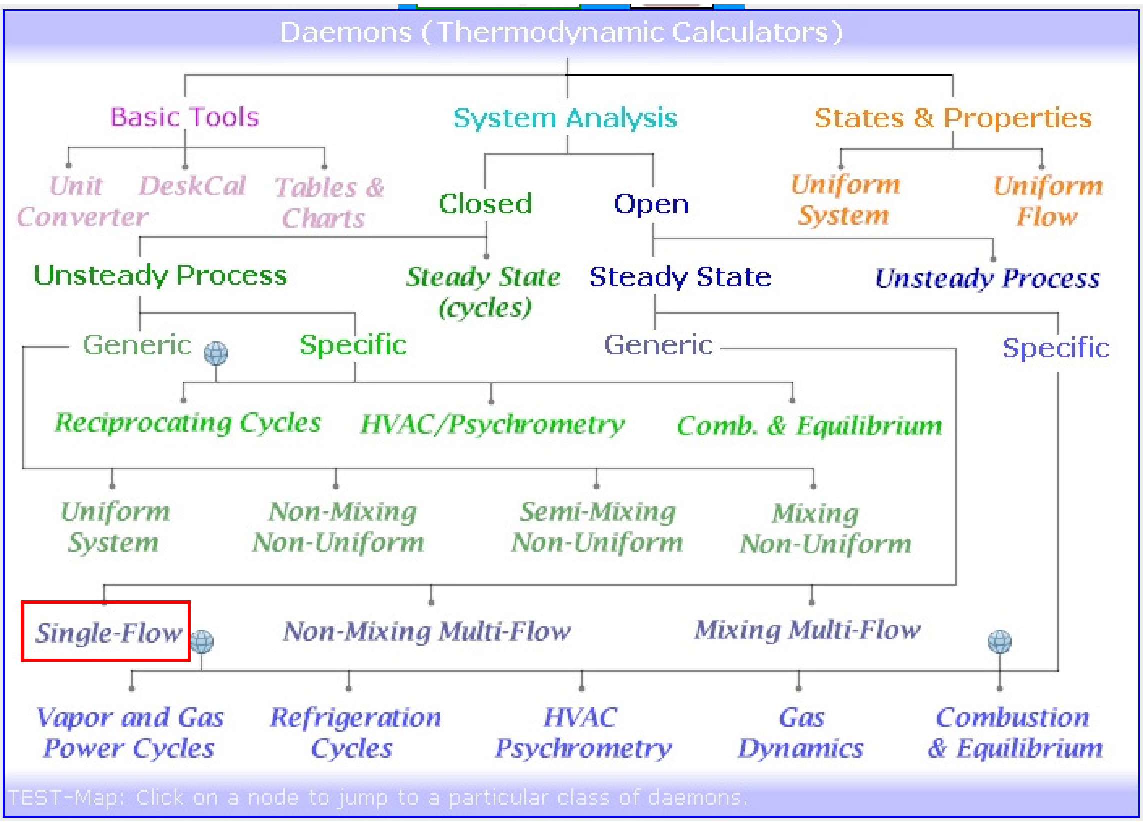
===

Prob.8.22. Air enters a compressor t ambient conditions of 100 kPa and 17 C with a low velocity and exits at 1 MPa, 327 C, and 105 m/s. The compressor is cooled by the ambient air at 17 C at a rate of 1500 kJ/min. The power input to the compressor is 300 kW. Determine (a) the mass flow rate of air, and (b) the portion of power input that is used just to overcome the irreversibilities.[Ref: 1]

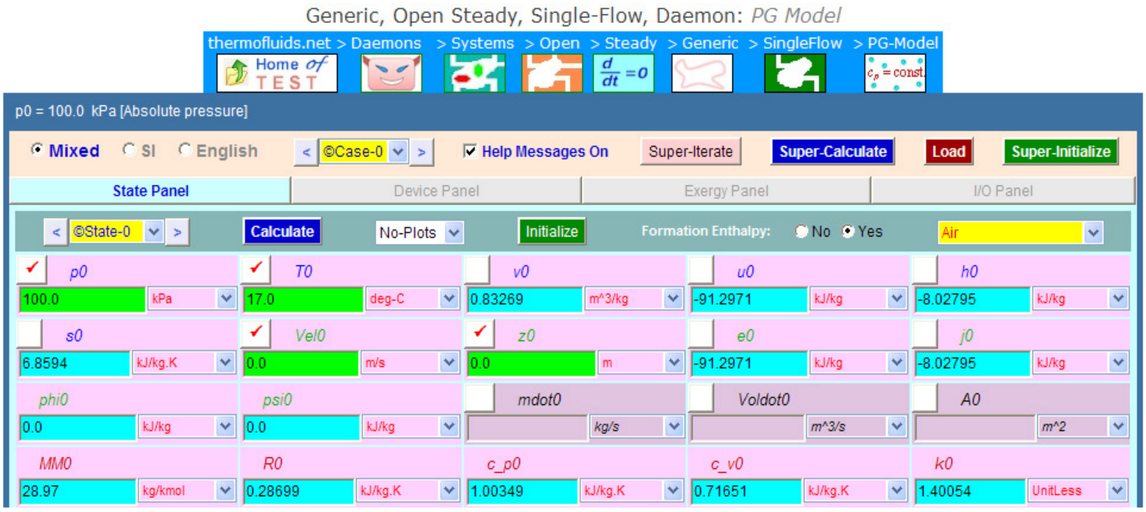
TEST Solution:

Following are the steps:

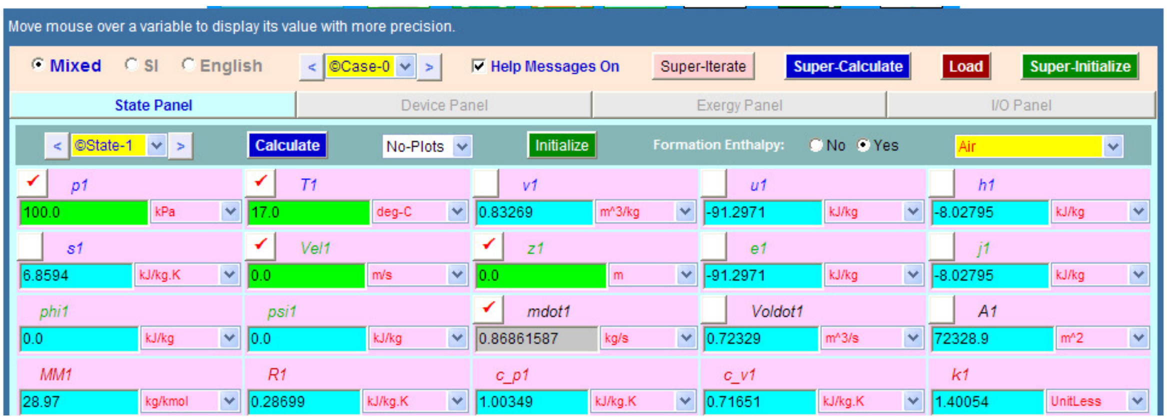
1. Choose Open steady Single Flow daemon from the daemon tree:



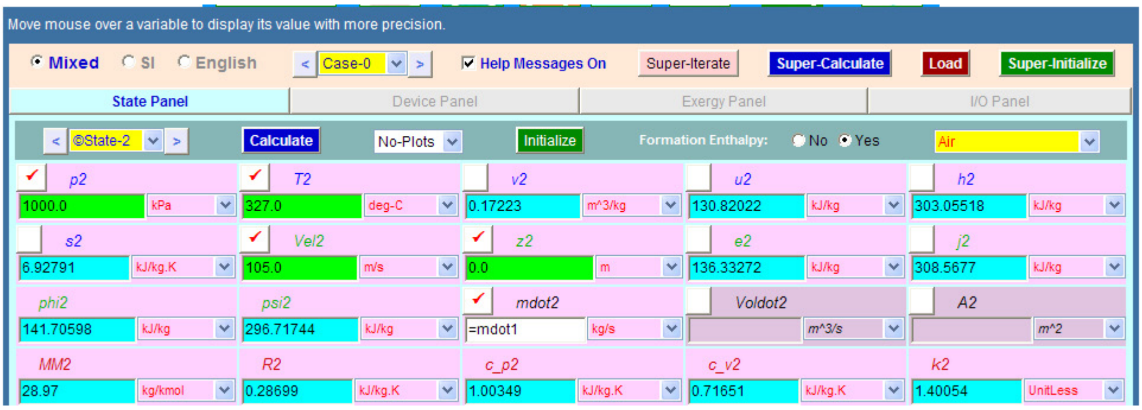
2. Choose the PG model for material model, and select air as the working substance. Enter p0 = 100 kPa and T0 = 17 C for State '0'. (This is required for exergy calculations.). Hit Enter. We get:



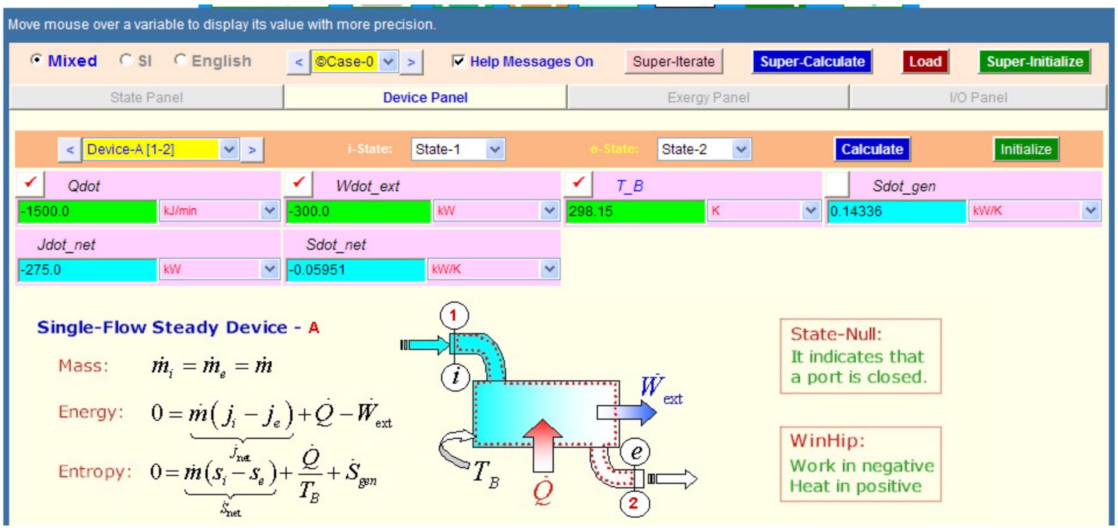
3. For State 1: enter p1, T1 as shown below, and hit Enter. Note that mdot1 is not known, and so, not entered. (However, it is automatically transported to State 1 after the calculations are completed by 'SuperCalculate'.) Hit Enter. We get:



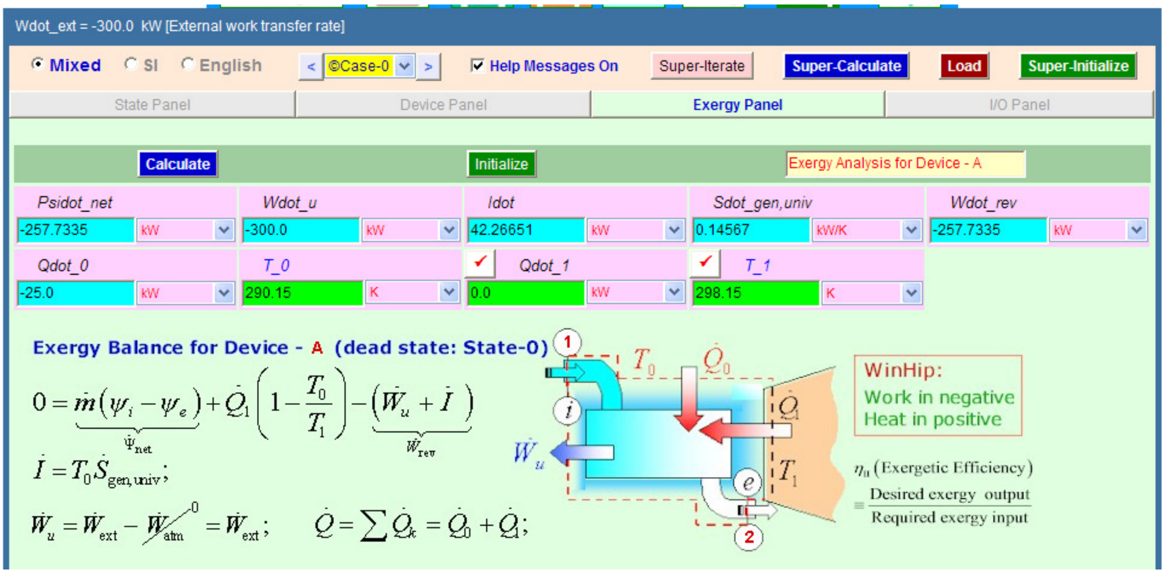
4. For State 2, enter values for p2, T2, Vel2 and mdot2 = mdot1. Again, value of mdot2 is not yet known. Hit Enter. We get:



5. Go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. Enter Wdot_ext = -300 kW (negative sign since work is supplied…remember: WinHip … see screen shot below), and Qdot = -1500 kJ/min. Click on Calculate and also SuperCalculate. We get:



6. Now, go to Exergy panel. All calculations are available there:



Note that Wdot_rev = -257.73 kW whereas actual work required was Wdot_u = -300 kW.

And, Irreversibility = Wdot_rev – Wdot_u = 42.27 kW …. Ans.

7. **Now, go back to State 2 and look for value of mdot2:**

Thus:

Mass flow rate = 0.8686 kg/s …. Ans.

Power to overcome irreversibilities = Idot = Irreversibility = 42.267 kW … Ans.

8. I/O panel gives the TEST code etc:

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

#

Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PG-Model; v-10.ca08

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

States {

State-0: Air;

Given: { p0= 100.0 kPa; T0= 17.0 deg-C; Vel0= 0.0 m/s; z0= 0.0 m; }

State-1: Air;

Given: { p1= 100.0 kPa; T1= 17.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; }

State-2: Air;

Given: { p2= 1000.0 kPa; T2= 327.0 deg-C; Vel2= 105.0 m/s; z2= 0.0 m; }

}

Analysis {

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

Given: { Qdot= -1500.0 kJ/min; Wdot_ext= -300.0 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)
#	0	100.0	290.2	0.8327	-91.3	-8.03	6.859
#	1	100.0	290.2	0.8327	-91.3	-8.03	6.859
#	2	1000.0	600.2	0.1722	130.82	303.06	6.928

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

 # Mass, Energy, and Entropy Analysis Results:

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

Given: Qdot= -1500.0 kJ/min; Wdot_ext= -300.0 kW; T_B= 298.15 K;

Calculated: Sdot_gen= 0.14335933 kW/K; Jdot_net= -275.0 kW; Sdot_net= -0.059508912 kW/K;

#

 # Exergy Analysis Results:

#

 # Exergy Analysis for Device – A (Dead state: State-0)

Given: Qdot= -25.0 kW; T_0= 290.15 K; Qdot_1= 0.0 kW;

T_1= 298.15 K;

Calculated: Psidot_net= -257.7335 kW; Wdot_u= -300.0 kW; **Idot= 42.26651 kW;**

Sdot_gen,univ= 0.14567 kW/K; **Wdot_rev= -257.7335 kW**; Qdot_0= -25.0 kW;

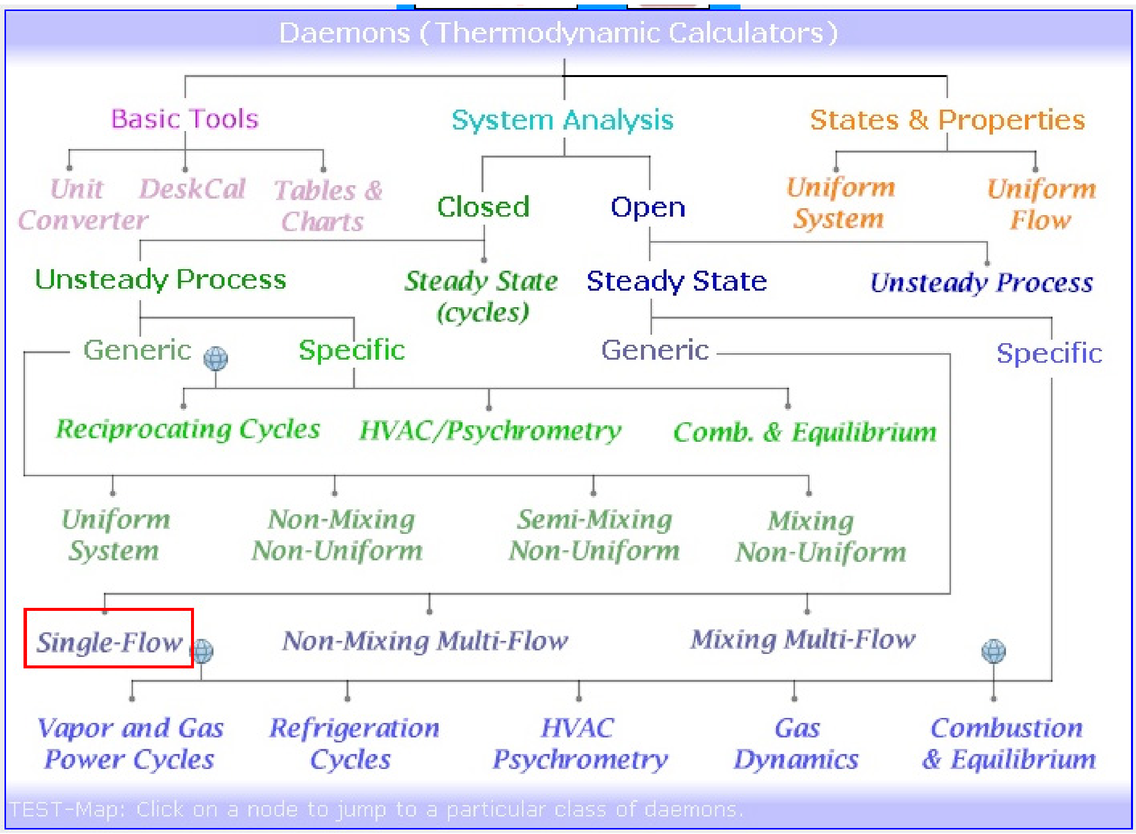
===

Prob.8.23. Refrigerant R134a enters an expansion valve at 1200 kPa as a sat. liquid and leaves at 200 kPa. Determine: (a) the temp of R134a at the exit (b) the entropy generation and the exergy destruction during this process. Take T0 = 25 C. [Ref:1]

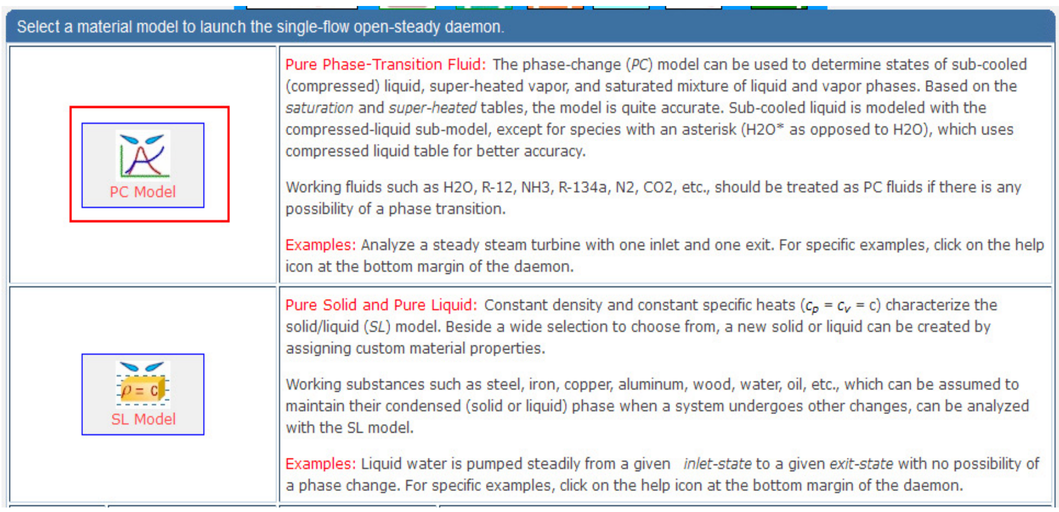
TEST Solution:

Following are the steps:

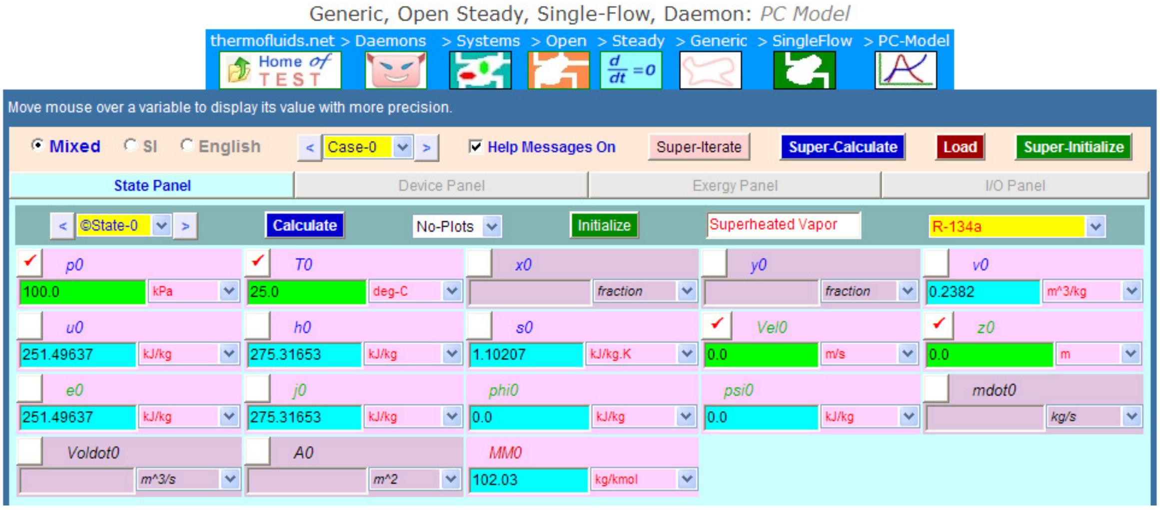
1. Choose Open steady Single Flow daemon from the daemon tree:



2. Choose Phase Change (PC) model for material model, since R134a is the material.



3. Choose R134a for substance and enter T0 = 0 on State '0' i.e. 'dead state'. This is required for exergy calculations.



4. Now, for State 1: enter values for p1, and x1 = 0 (for sat.liq.). Hit Enter. We get:

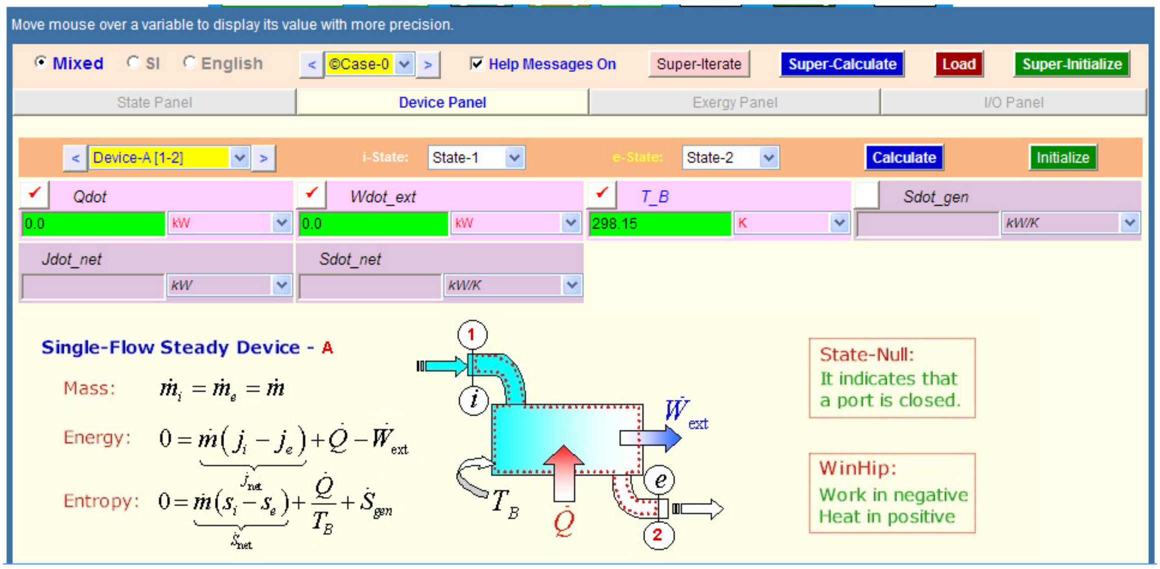
Note that properties such as temp = T1, entropy = s1, enthalpy = h1 etc. are immediately calculated.

5. And, for State 2: enter values of p2 and h2 = h1 *since throttling is an isenthalpic process.*

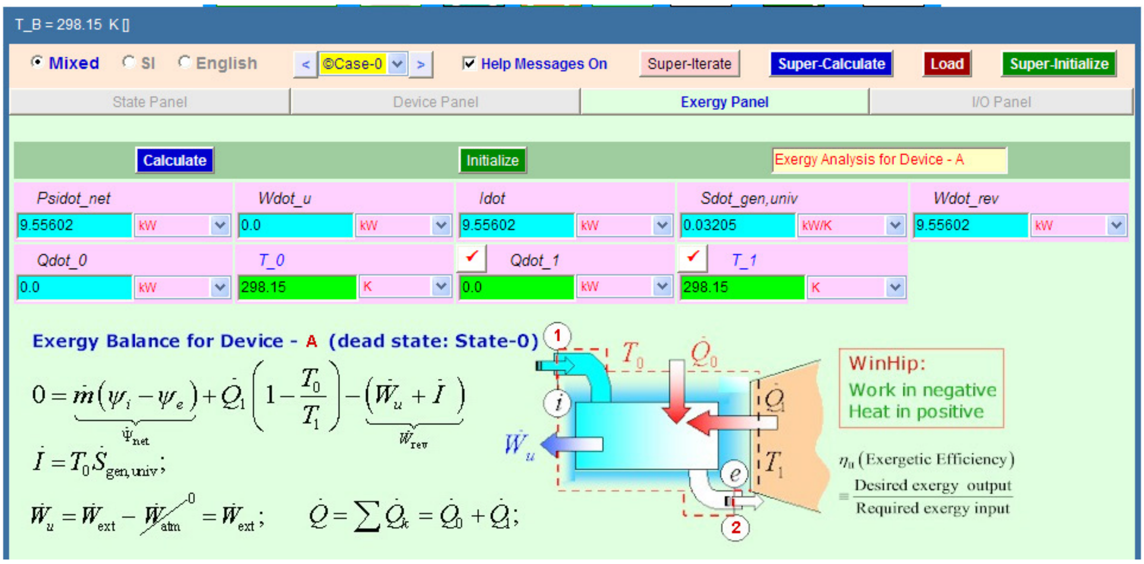
Immediately note that temp after throttling, T2 is calculated as:

T2 = -10.22 C … Ans.

6. Now, go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. Also, enter Qdot = 0 and Wdot_ext = 0, since in throttling there is no heat or work transfer. Click on Calculate and SuperCalculate. We get:



7. Now, go to Exergy panel. Here, exergy calculations are already made:



Thus:

Temp at the outlet of expansion valve = T2 = – 10.22 C .....Ans. .... From State 2

Entropy generation = Sdot_gen.univ = 0.03205 kW ...Ans.... From Exergy Panel

Exergy destruction = Idot = 9.556 kW .... Ans....From Exergy Panel

8. I/O panel gives TEST code etc:

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

#

Daemon Path: Systems>Open>SteadyState>Generic>SingleFlow>PC-Model; v-10.cb01

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

States {

State-0: R-134a;

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

State-1: R-134a;

Given: { p1= 1200.0 kPa; x1= 0.0 fraction; Vel1= 0.0 m/s; z1= 0.0 m; }

```
        State-2: R-134a;

        Given: { p2= 200.0 kPa; h2= "h1" kJ/kg; Vel2= 0.0 m/s; z2= 0.0 m; }

        }

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-0: R-134a > Superheated Vapor;
#               Given: p0= 100.0 kPa; T0= 25.0 deg-C; Vel0= 0.0 m/s;
#                       z0= 0.0 m;
#               Calculated: v0= 0.2382 m^3/kg; u0= 251.4964 kJ/kg; h0= 275.3165 kJ/kg;
#                       s0= 1.1021 kJ/kg.K; e0= 251.4964 kJ/kg; j0= 275.3165 kJ/kg;
#                       phi0= 0.0 kJ/kg; psi0= 0.0 kJ/kg; MM0= 102.03 kg/kmol;
#       State-1: R-134a > Saturated Mixture;
#               Given: p1= 1200.0 kPa; x1= 0.0 fraction; Vel1= 0.0 m/s;
#                       z1= 0.0 m;
#               Calculated: T1= 46.2914 deg-C; y1= 0.0 fraction; v1= 9.0E-4 m^3/kg;
#                       u1= 116.0502 kJ/kg; h1= 117.1239 kJ/kg; s1= 0.4215 kJ/kg.K;
#                       e1= 116.0502 kJ/kg; j1= 117.1239 kJ/kg; phi1= 43.7369 kJ/kg;
#                       psi1= 44.7212 kJ/kg; MM1= 102.03 kg/kmol;
#       State-2: R-134a > Saturated Mixture;
#               Given: p2= 200.0 kPa; h2= "h1" kJ/kg; Vel2= 0.0 m/s;
#                       z2= 0.0 m;
#               Calculated: T2= -10.2226 deg-C; x2= 0.3873 fraction; y2= 0.9882 fraction;
#                       v2= 0.0392 m^3/kg; u2= 109.2846 kJ/kg; s2= 0.4536 kJ/kg.K;
#                       e2= 109.2846 kJ/kg; j2= 117.1239 kJ/kg; phi2= 31.2484 kJ/kg;
#                       psi2= 35.1651 kJ/kg; MM2= 102.03 kg/kmol;
#
```

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

#

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 00	100.0	298.2		0.2382	251.5	275.32	1.102
# 01	1200.0	319.4	0.0	9.0E-4	116.05	117.12	0.421
# 02	200.0	262.9	0.4	0.0392	109.28	117.12	0.454

 # 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:

 # Exergy Analysis Results:

 # Exergy Analysis for Device – A (Dead state: State-0)

Given: Qdot= 0.0 kW; T_0= 298.15 K; Qdot_1= 0.0 kW;

T_1= 298.15 K;

Calculated: Psidot_net= 9.55602 kW; Wdot_u= 0.0 kW; **Idot= 9.55602 kW**;

Sdot_gen,univ= 0.03205 kW/K; Wdot_rev= 9.55602 kW; Qdot_0= 0.0 kW;

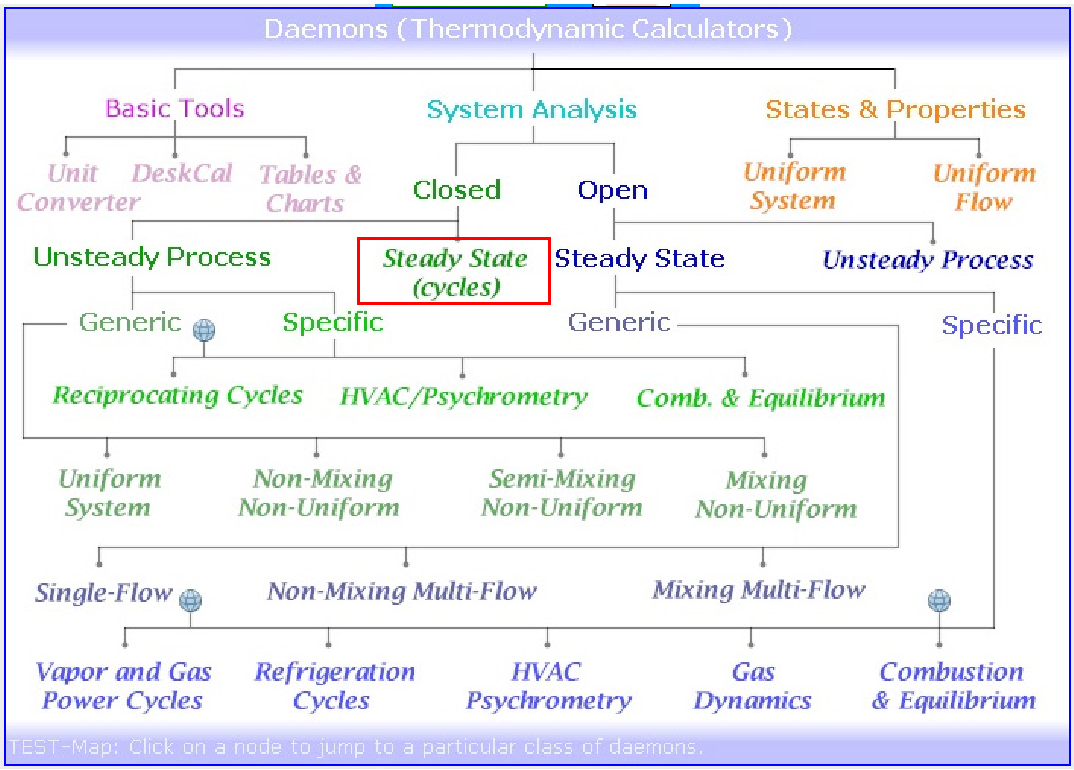
==

Prob.8.24. A freezer is maintained at -7 C by removing heat from it at a rate of 80 kJ/min. The power input to the freezer is 0.5 kW, and the surrounding air is at 25 C. Determine (a) the reversible power, (b) Irreversibility, and (c) Second Law efficiency of this freezer. [Ref: 1]

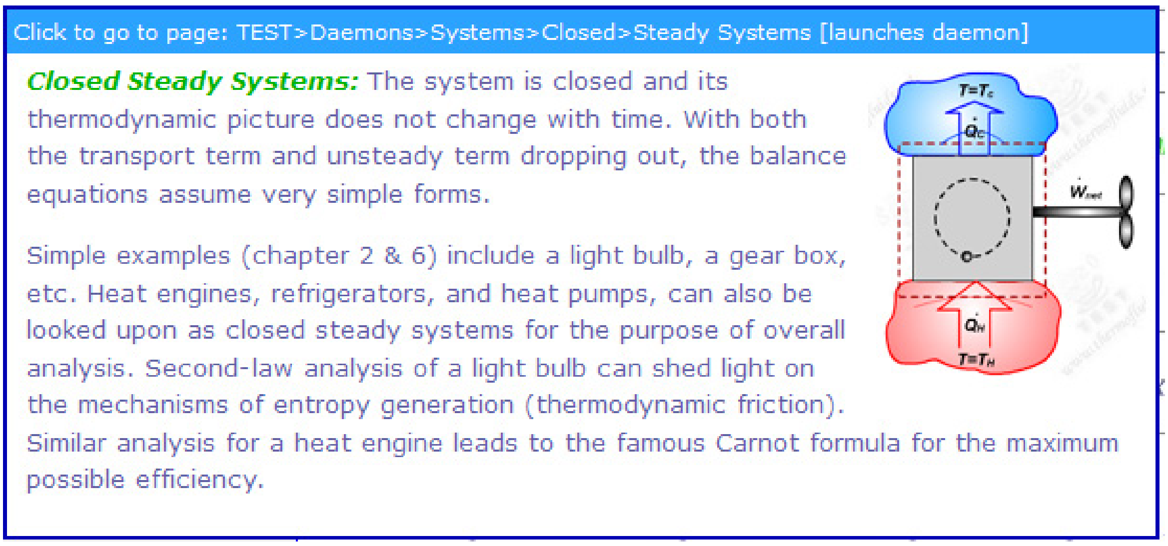
TEST Solution:

Following are the steps:

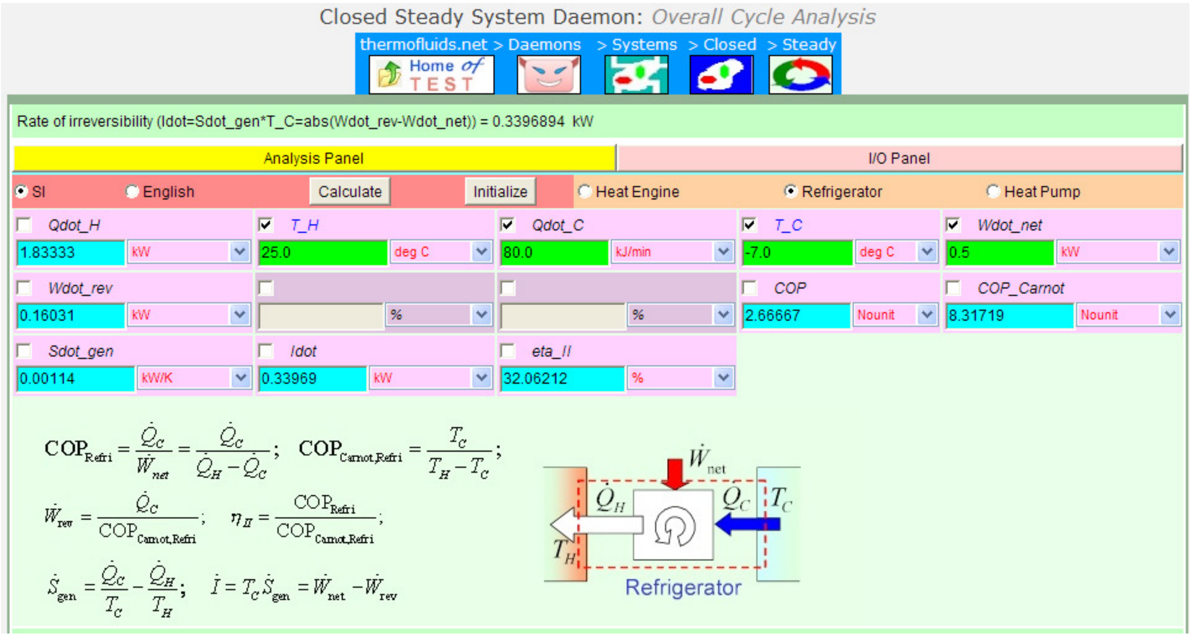
1. Choose System Analysis-Closed-Steady State (cycles)daemon from the daemon tree. Note that we use this daemon when only an overall analysis of a Heat Engine, or a Refrigerator or a Heat Pump is to be made:



Hovering the mouse pointer over 'Steady State (cycles)' brings up the following pop up:



2. Click on 'Steady State (cycles)' and choose the Refrigerator Radio button in the window that appears. Enter T_H = 25 C, Qdot_C = 80 kJ/min, T_C = -7 C and click on Calculate. (It is instructive to see the figure at the bottom of this window).We get:



Thus:

Reversible power = Wdot_rev =0.16031 kW …. Ans.

Irreversibility = Idot = 0.33969 kW… Ans.

Second Law efficiency = eta_II = 32.06% ….Ans.

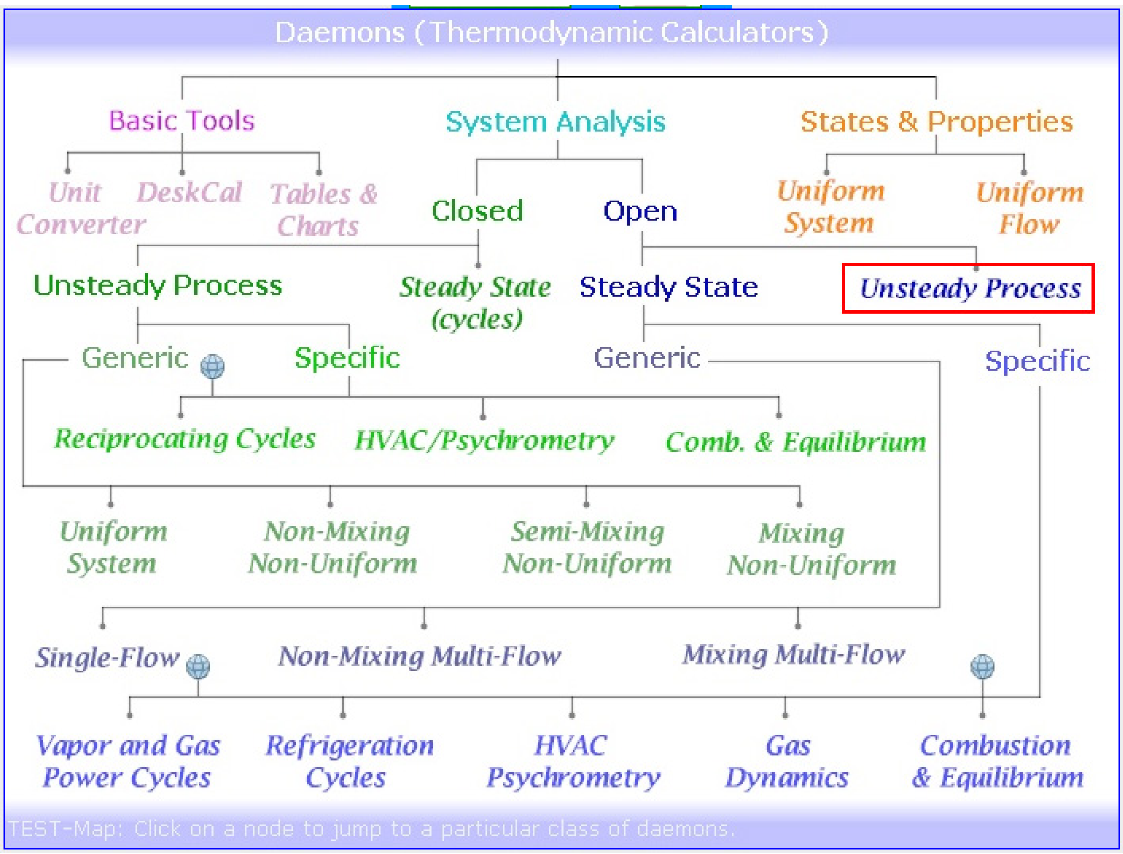
==

Prob.8.25. Air at 5 bar and 20 C flows into an evacuated tank of 1 m^3 capacity until the pressure in the tank is 5 bar. Assume that the process is adiabatic and the temp of surroundings is 20 C. Find (a) the final temp of air (b) net entropy change of air entering the tank, and (c) the irreversibility. [Ref: 4]

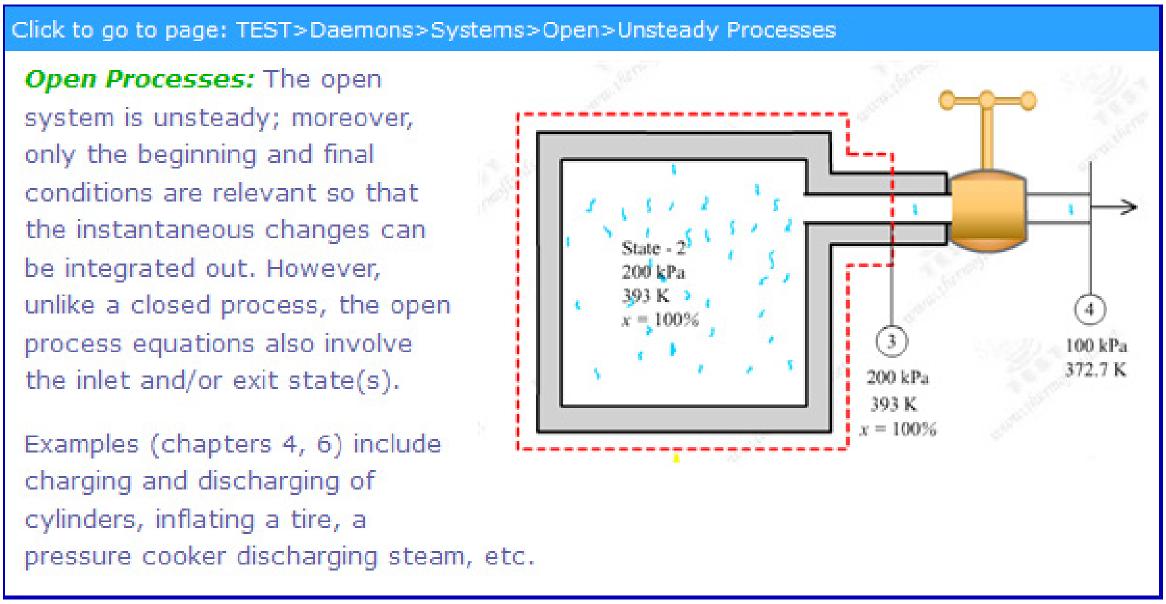
TEST Solution:

Following are the steps:

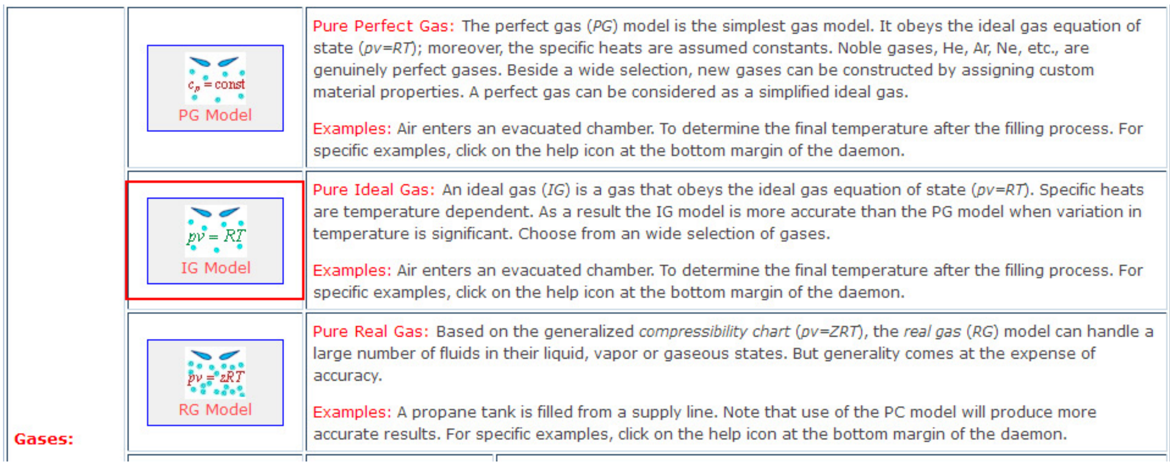
1. Choose System Analysis-Open-Unsteady Process daemon from the daemon tree.



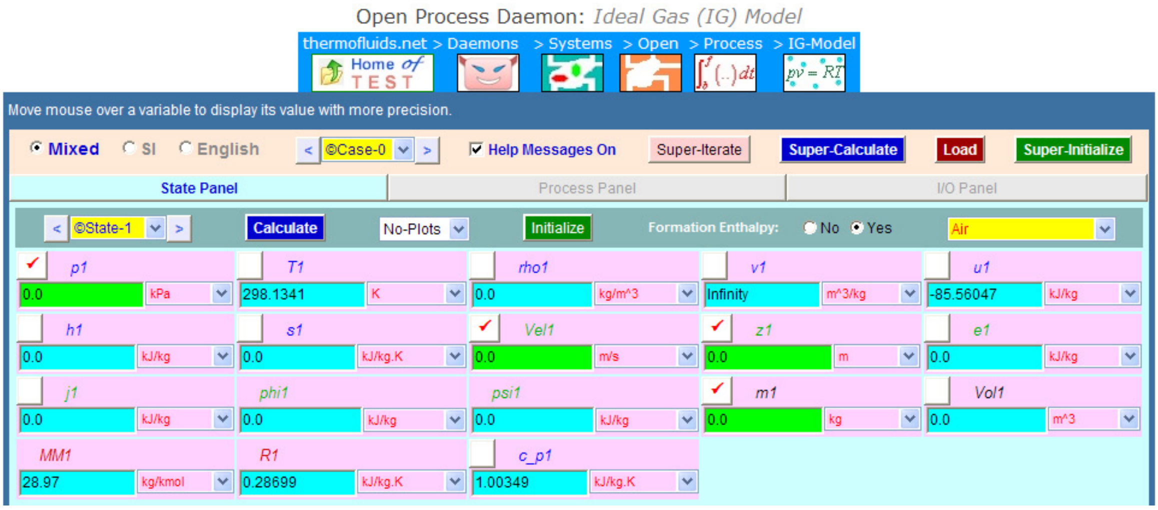
Hovering the mouse pointer on 'Unsteady Process' brings up the following explanatory pop up:



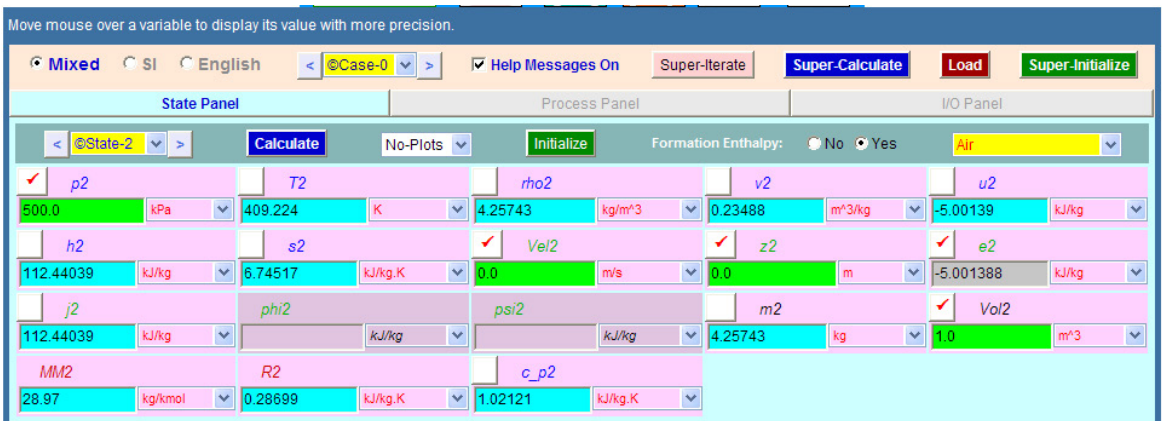
2. For material model, choose IG model:



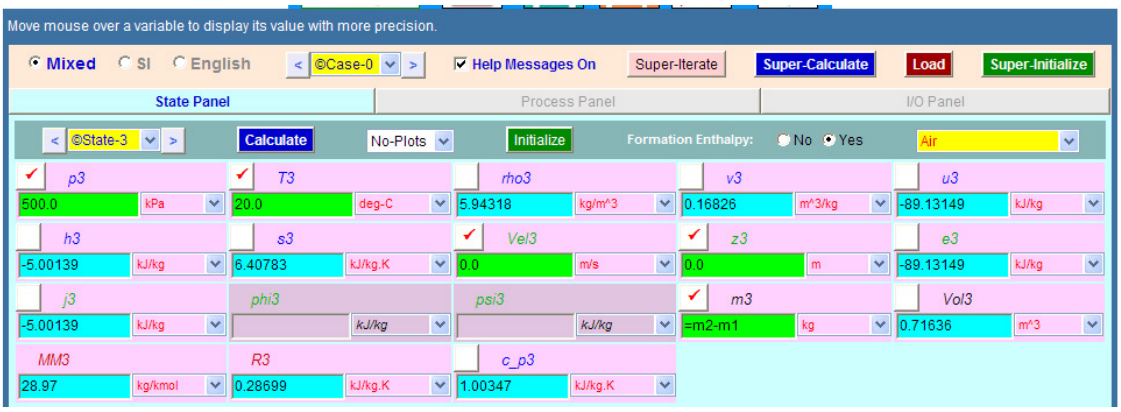
3. Select Air as the working substance, and enter values of properties for State 1. This is vacuum state. So, enter m1 = 0 and p1 = 0. **Do not enter Vol1 even though it is given as 1 m^3… since, vacuum has no volume of air associated with it.**Hit Enter. We get:



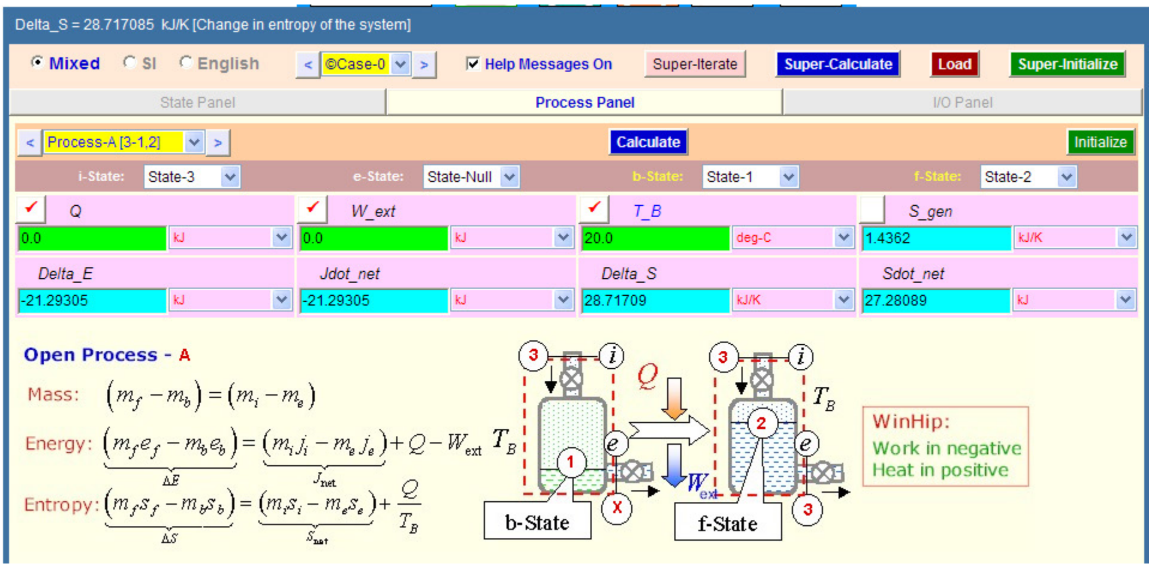
4. Now, enter for State 2. This is the condition of gas in the volume, after it is filled up. Enter p2 = 500 kPa, Vol2 = 1 m^3. Hit Enter. All properties are not calculated since data is not enough. However, they are calculated at the end when SuperCalculate is clicked.



5. Enter for State 3. This is the condition of gas flowing in the pipe line. We enter p3 = 500 kPa, T3 = 20 C, m3 = (m2 – m1), since this is the amount of gas that flows in to the tank.. Click on Calculate (or, hit Enter). We get:



6. Now, go to Process Panel. See the schematic diagram in that window. Enter i-state = State 3, e-state = Null, b-state = State 1 and f-state = State 2 carefully. Also, enter Q = 0, W_ext = 0. Click on Calculate, and also SuperCalculate. We get:



Go to States Panel and in State 2, see the value of T2, the temp after the tank is filled up. Also, m2, the mass that has flown in can be read.

Thus:

Final temp of air = T2 = 409.22 K …. Ans.

Net entropy change of air = Delta_S = 28.717 kJ/K … Ans.

Irreversibility = T0 * S_gen = (20 + 273) * 1.4362 = 392.083 kJ …. Ans.

7. TEST code etc can be obtained from the I/O panel:

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

Daemon Path: Systems>Open>Process>IG-Model; v-10.ca08

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

States    {

          State-1: Air;

          Given: { p1= 0.0 kPa; Vel1= 0.0 m/s; z1= 0.0 m; m1= 0.0 kg; }

          State-2: Air;

          Given: { p2= 500.0 kPa; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= 1.0 m^3; }

          State-3: Air;

          Given: { p3= 500.0 kPa; T3= 20.0 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: { Q= 0.0 kJ; W_ext= 0.0 kJ; T_B= 20.0 deg-C; }

          }

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

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

 # Evaluated States:

```
#         State-1: Air > IG-Model;
#                   Given: p1= 0.0 kPa; Vel1= 0.0 m/s; z1= 0.0 m;
#                             m1= 0.0 kg;
#                   Calculated: T1= 298.1341 K; rho1= 0.0 kg/m^3; v1= Infinity m^3/kg;
#                             u1= -85.5605 kJ/kg; h1= 0.0 kJ/kg; s1= 0.0 kJ/kg.K;
#                             e1= 0.0 kJ/kg; j1= 0.0 kJ/kg; phi1= 0.0 kJ/kg;
#                             psi1= 0.0 kJ/kg; Vol1= 0.0 m^3; MM1= 28.97 kg/kmol;
#                             R1= 0.287 kJ/kg.K; c_p1= 1.0035 kJ/kg.K;
#         State-2: Air > IG-Model;
#                   Given: p2= 500.0 kPa; Vel2= 0.0 m/s; z2= 0.0 m;
#                             Vol2= 1.0 m^3;
```

```
#           Calculated: T2= 409.224 K; rho2= 4.2574 kg/m^3; v2= 0.2349 m^3/kg;
#                  u2= -5.0014 kJ/kg; h2= 112.4404 kJ/kg; s2= 6.7452 kJ/kg.K;
#                  e2= -5.0014 kJ/kg; j2= 112.4404 kJ/kg; m2= 4.2574 kg;
#                  MM2= 28.97 kg/kmol; R2= 0.287 kJ/kg.K; c_p2= 1.0212 kJ/kg.K;
#      State-3: Air > IG-Model;
#           Given: p3= 500.0 kPa; T3= 20.0 deg-C; Vel3= 0.0 m/s;
#                  z3= 0.0 m; m3= "m2-m1" kg;
#           Calculated: rho3= 5.9432 kg/m^3; v3= 0.1683 m^3/kg; u3= -89.1315 kJ/kg;
#                  h3= -5.0014 kJ/kg; s3= 6.4078 kJ/kg.K; e3= -89.1315 kJ/kg;
#                  j3= -5.0014 kJ/kg; Vol3= 0.7164 m^3; MM3= 28.97 kg/kmol;
#                  R3= 0.287 kJ/kg.K; c_p3= 1.0035 kJ/kg.K;
#--------Property spreadsheet starts:

#      State   p(kPa)  T(K)      v(m^3/kg)   u(kJ/kg)    h(kJ/kg)    s(kJ/kg)
#      1       0.0     298.1     Infinity    -85.56      0.0         0.0
#      2       500.0   409.2     0.2349      -5.0        112.44      6.745
#      3       500.0   293.2     0.1683      -89.13      -5.0        6.408

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

 # 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= 20.0 deg-C;

Calculated: **S_gen= 1.436198 kJ/K;** Delta_E= -21.293053 kJ; Jdot_net= -21.293053 kJ; Delta_S= 28.717085 kJ/K;

Sdot_net= 27.280888 kJ;

Also, change in Availability from State 1 to State 2 is:

$$\Delta e = \phi_1 - \phi_2 = (u1 - u2) + p0 \cdot (v1 - v2) - T0 \cdot (s1 - s2)$$

Form the above Table, we have:

$u1 := -85.56$ kJ/kg $u2 := -5$ kJ/kg

$s1 := 0$ kJ/kg.K $s2 := 6.745$ kJ/kg.K

$v1 := 0$ m^3/kg $v2 := 0.2349$ m^3/kg

$T0 := 293$ K $p0 := 100$ kPa

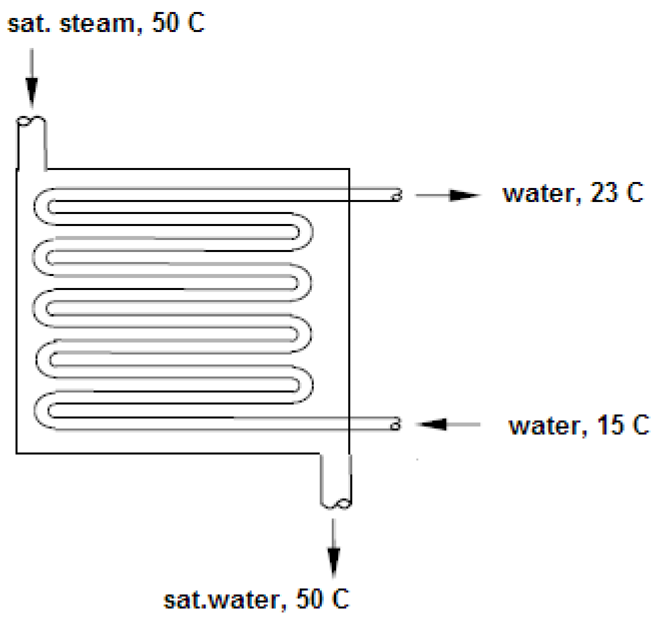
Therefore, change in Availability:

$$\Delta e := (u1 - u2) + p0 \cdot (v1 - v2) - T0 \cdot (s1 - s2)$$

i.e. $\Delta e = 1.872 \times 10^3$ **kJ/kg....Ans.**

==

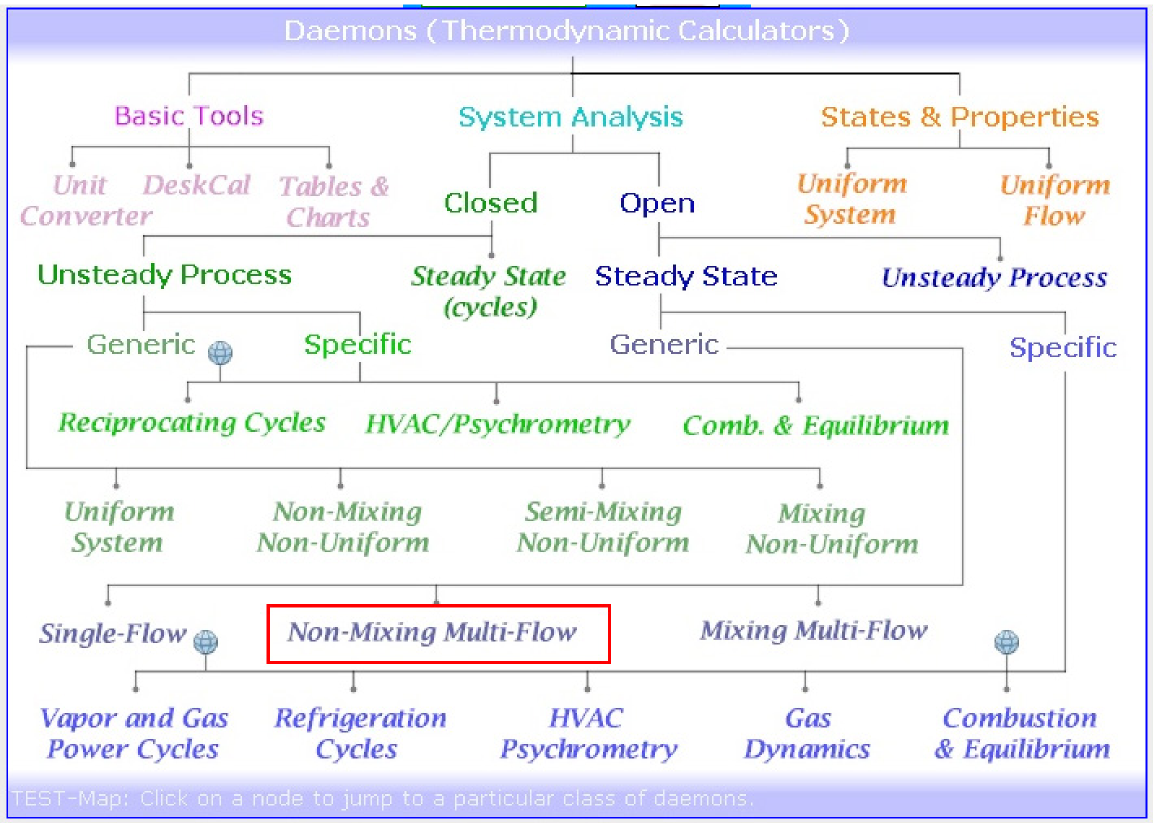
Prob.8.26. Steam is to be condensed on the shell side of a heat exchanger at 50 C. Cooling water enters the tubes at 15 C at a rate of 55 kg/s and leaves at 23 C. Assuming the heat exchanger to be well insulated, determine: (a) rate of heat transfer in the heat exchanger, and (b) rate of exergy destruction in the heat exchanger. Take T0 = 25 C. [Ref:1]



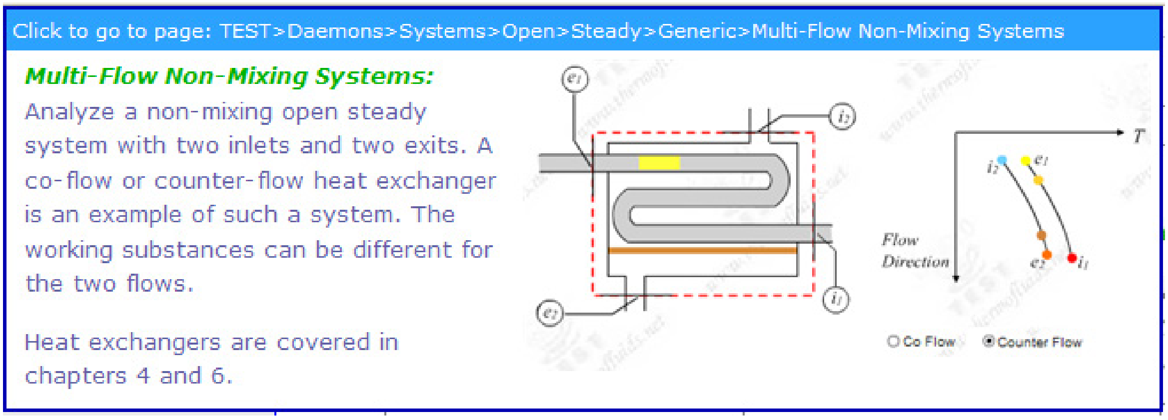
TEST Solution:

Following are the steps:

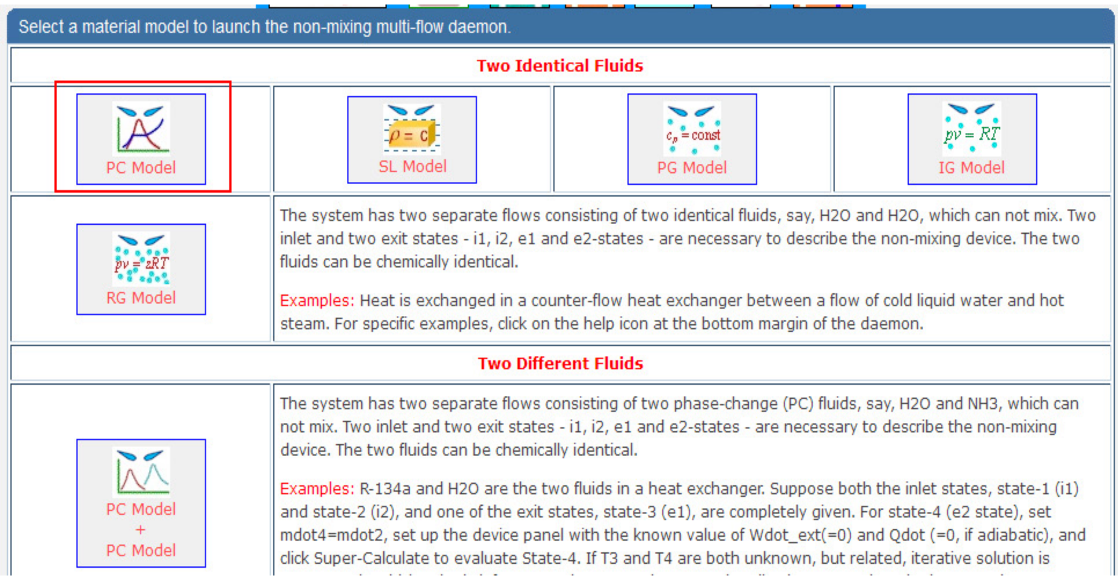
1. Choose System Analysis-Open-Non-Mixing Multi-flow daemon from the daemon tree.



Hovering the mouse pointer over Non-Mixing Multi-flow gives the following pop up:



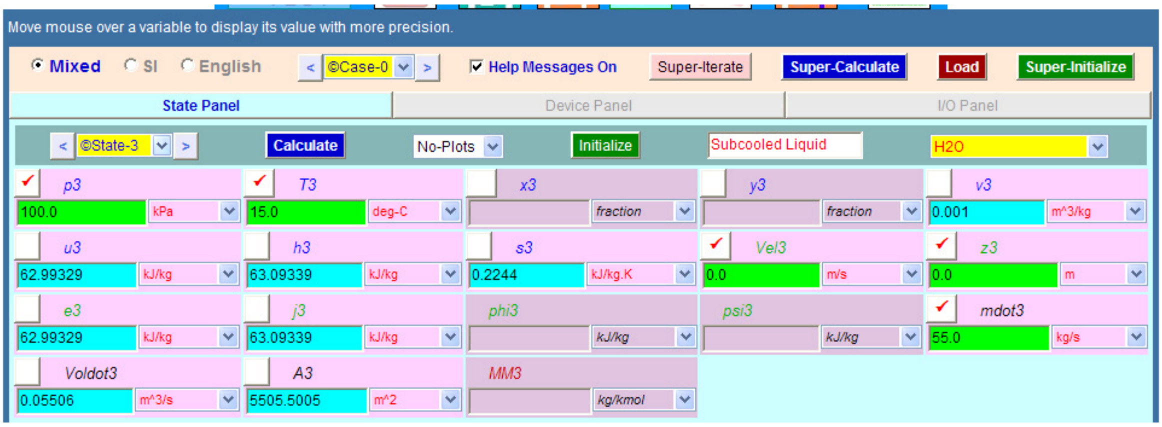
2. For material model, choose PC model since we are dealing with Steam/ water.



3. H2O is the substance selected by default. Enter p1, x1 = 0 for State 1, i.e. exit of steam condensed in the sat. liq. state. Also, enter for mdot1 = mdot3 * (h4 – h3) / (h2 – h1), where States 3 and 4 are inlet and exit of water. Mdot1 is unknown, as of now. But, it will be posted back here at the end, i.e. after all calculations are made by SuperCalculate. Hit Enter:

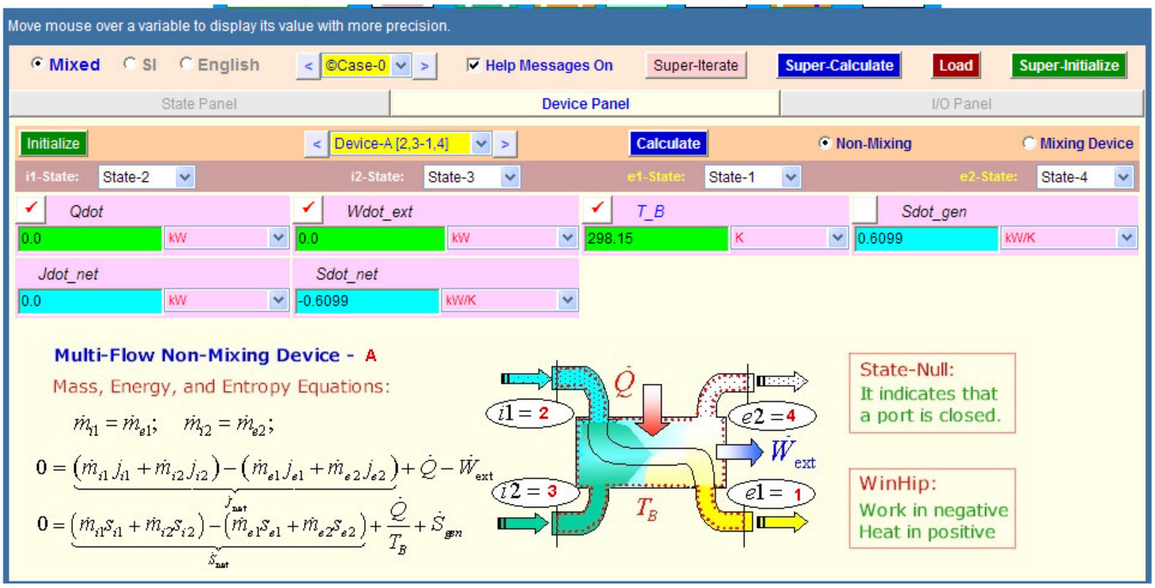
4. For State 2, i.e. sat.vapour state, inlet of steam to condenser: enter T2, x2 = 1 for sat. vap. Also, mdot2 = mdot1, unknown as of now, but will be posted back later. Hit Enter. We get:

5. Now, for State 3: i.e. inlet of water stream in to the tubes. Enter p3, T3 and mdot3. Hit Enter. We get:



6. And, for State 4: i.e. exit of water stream from the tubes. Enter p4, T4 and mdot4= mdot3. Hit Enter. We get:

7. Now, go to Device Panel. Enter: i1-state = State 2, e1-state = State 1, i2-state = State 3 and e2-state = State 4. Also, Qdot = 0 (since heat exchanger is insulated) and Wdot_ext = 0. Click on Non-mixing Radio button. Then, click on Calculate and SuperCalculate. All calculations are now made:



Go back to State 1 or State 2 and look for mdot1.

Thus:

mdot1= 0.7737 kg/s = steam condensation rate…..Ans.

Rate of heat exchange in the heat exchanger = mdot1 * (h2 – h1) = 1843.5482 kW ….Ans.

And, Rate of exergy destruction: I = T0 * S_gen = (25+273)*0.6099 = 181.75 kW....Ans.

{**Also, verify:**

Heat transferred in HX: Q = mdot3*(h4-h3) = 1843.5482 kW .... verified.}

8. Get the TEST code etc from the I/O panel:

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

#Daemon Path: Systems>Open>SteadyState>Generic>MultiFlowUnmixed>PC-Model; v-10.cb01

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

States {

    State-1: H2O;

    Given: { T1= 50.0 deg-C; x1= 0.0 fraction; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= "mdot3*(h4-h3)/(h2-h1)" kg/s; }

    State-2: H2O;

    Given: { T2= 50.0 deg-C; x2= 1.0 fraction; Vel2= 0.0 m/s; z2= 0.0 m; }

    State-3: H2O;

    Given: { p3= 100.0 kPa; T3= 15.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= 55.0 kg/s; }

    State-4: H2O;

    Given: { p4= "P3" kPa; T4= 23.0 deg-C; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= "mdot3" kg/s; }

    }
```

```
Analysis {

        Device-A: i-State = State-2, State-3; e-State = State-1, 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: T1= 50.0 deg-C; x1= 0.0 fraction; Vel1= 0.0 m/s;
#                       z1= 0.0 m; mdot1= "mdot3*(h4-h3)/(h2-h1)" kg/s;
#               Calculated: p1= 12.35 kPa; y1= 0.0 fraction; v1= 0.001 m^3/kg;
#                       u1= 209.3175 kJ/kg; h1= 209.33 kJ/kg; s1= 0.7038 kJ/kg.K;
#                       e1= 209.3175 kJ/kg; j1= 209.33 kJ/kg; Voldot1= 8.0E-4 m^3/s;
#                       A1= 78.2984 m^2; MM1= 18.0 kg/kmol;
#       State-2: H2O > Saturated Mixture;
#               Given: T2= 50.0 deg-C; x2= 1.0 fraction; Vel2= 0.0 m/s;
#                       z2= 0.0 m;
#               Calculated: p2= 12.35 kPa; y2= 1.0 fraction; v2= 12.03 m^3/kg;
#                       u2= 2443.5295 kJ/kg; h2= 2592.1 kJ/kg; s2= 8.0763 kJ/kg.K;
#                       e2= 2443.5295 kJ/kg; j2= 2592.1 kJ/kg; mdot2= 0.7737 kg/s;
#                       Voldot2= 9.3076 m^3/s; A2= 930760.56 m^2; MM2= 18.0 kg/kmol;
#       State-3: H2O > Subcooled Liquid;
#               Given: p3= 100.0 kPa; T3= 15.0 deg-C; Vel3= 0.0 m/s;
#                       z3= 0.0 m; mdot3= 55.0 kg/s;
#               Calculated: v3= 0.001 m^3/kg; u3= 62.9933 kJ/kg; h3= 63.0934 kJ/kg;
#                       s3= 0.2244 kJ/kg.K; e3= 62.9933 kJ/kg; j3= 63.0934 kJ/kg;
#                       Voldot3= 0.0551 m^3/s; A3= 5505.5005 m^2;
#       State-4: H2O > Subcooled Liquid;
#               Given: p4= "P3" kPa; T4= 23.0 deg-C; Vel4= 0.0 m/s;
#                       z4= 0.0 m; mdot4= "mdot3" kg/s;
#               Calculated: v4= 0.001 m^3/kg; u4= 96.5122 kJ/kg; h4= 96.6124 kJ/kg;
#                       s4= 0.3392 kJ/kg.K; e4= 96.5122 kJ/kg; j4= 96.6124 kJ/kg;
#                       Voldot4= 0.0552 m^3/s; A4= 5515.1255 m^2;
```

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

# State	p(kPa)	T(K)	x	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	12.35	323.2	0.0	0.001	209.32	209.33	0.704
# 02	12.35	323.2	1.0	12.03	2443.53	2592.1	8.076
# 03	100.0	288.2		0.001	62.99	63.09	0.224
# 04	100.0	296.2		0.001	96.51	96.61	0.339

 # Mass, Energy, and Entropy Analysis Results:

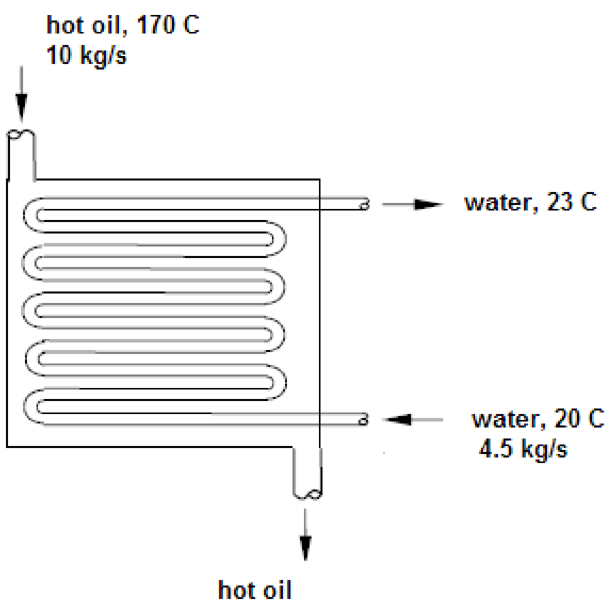
Device-A: i-State = State-2, State-3; e-State = State-1, State-4; Mixing: false;

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

Calculated: Sdot_gen= 0.60990053 kW/K; Jdot_net= 0.0 kW; Sdot_net= -0.60990053 kW/K;

==

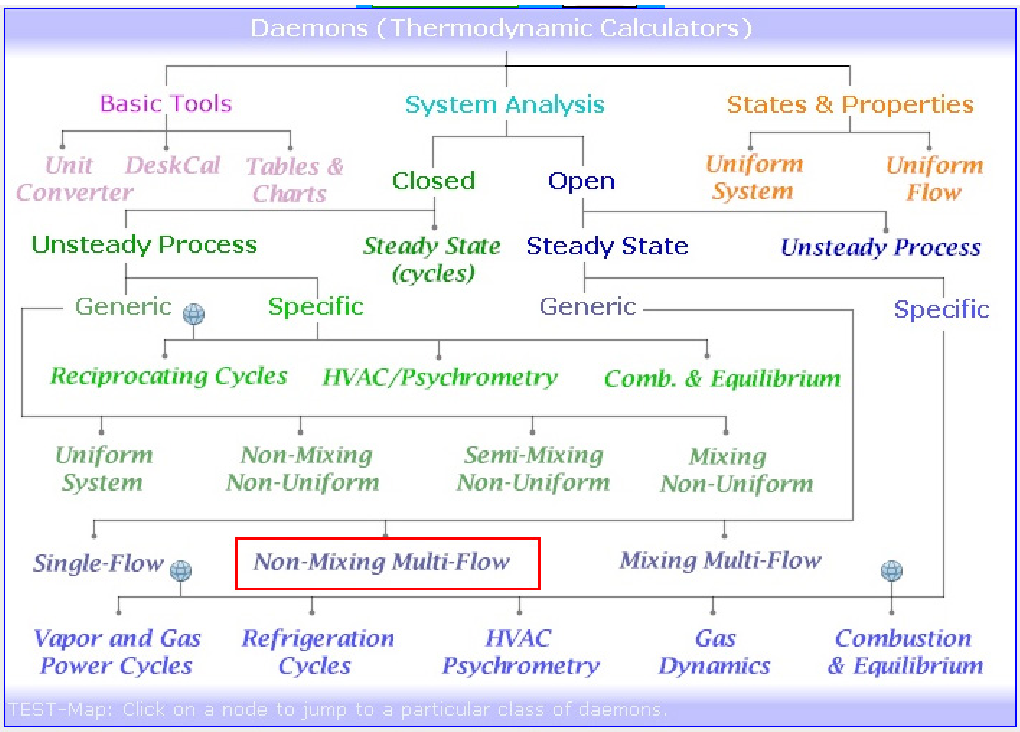
Prob.8.27. A well insulated shell & tube heat exchanger is used to heat water (cp = 4.184 kJ/kg.C) in the tubes from 20 to 70 C at a rate of 4.5 kg/s. Heat is supplied by hot oil (cp = 1.8 kJ/kg.C) that enters the shell side at 170 C at a rate of 10 kg/s. Neglecting the heat loss from the heat exchanger, determine: (a) exit temp of oil (b) rate of heat transfer in the heat exchanger, and (c) the rate of exergy destruction.



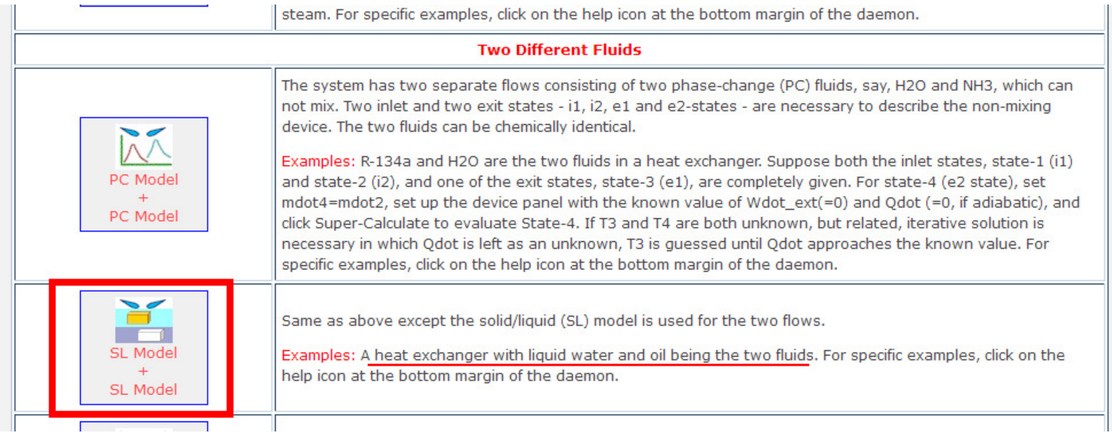
TEST Solution:

Following are the steps:

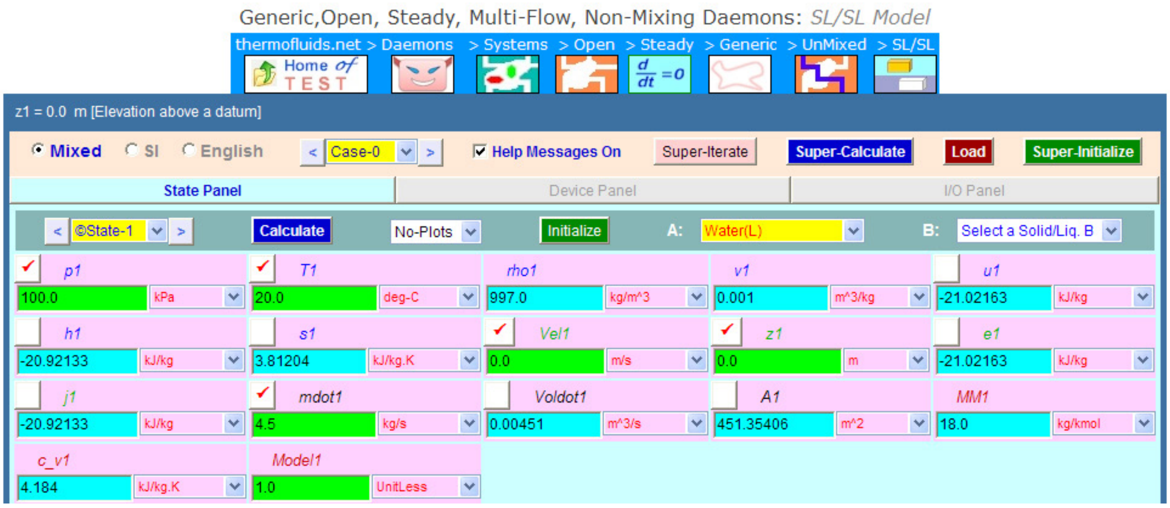
1. Choose System Analysis-Open-Non-Mixing Multi-flow daemon from the daemon tree.



2. For material model, select SL/SL model since we are dealing with water / oil.



3. For State 1: Select water. Enter p1 = 100 kPa (assumed, but it does not matter, since it is a liquid), T1 = 20 C, and mdot1 = 4.5 kg/s. Note that sp. heat value is built-in. Hit Enter. We get:



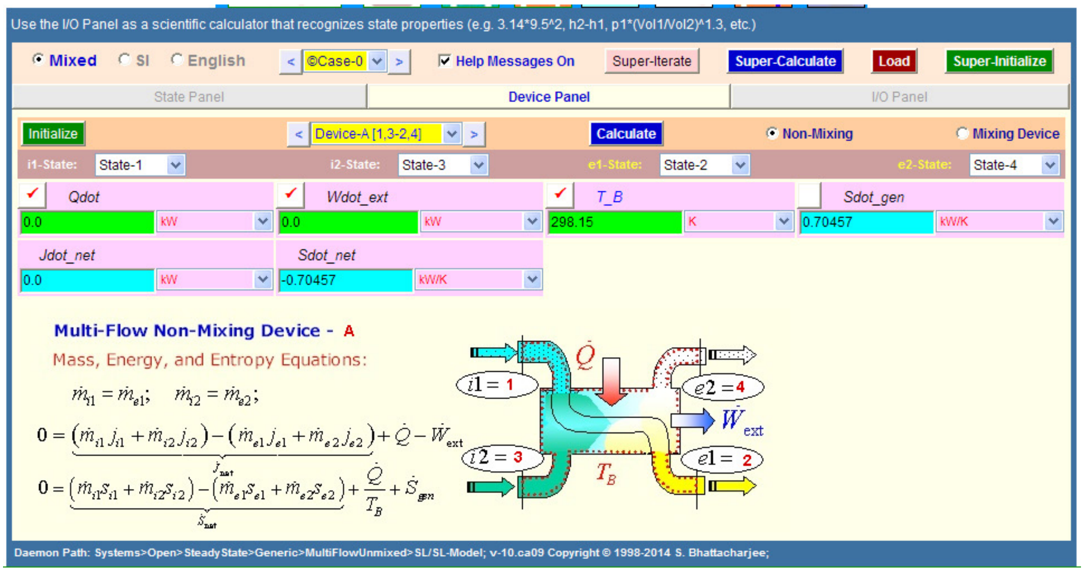
4. Similarly, for State 2, exit of water: enter p2, T2, mdot2. Hit Enter. We get:

5. For State 3: Select oil. Enter p2, T3 and mdot3. Note that sp. heat value is built-in. Hit Enter. We get:

6. For State 4: Enter p4, mdot4, and T4 = T3 – (mdot1 * c_v1) * (T2 – T1) / (mdot3* c_v3). Hit Enter. We get:

Immediately, we get: exit temp of oil, T4 = 117.7 C….. Ans.

7. Now, go to Device panel. Enter: i1-state = State 1, i2-state = State 3, e1-state = State 2 and e2-state = State 4. See how the schematic at the bottom of the window adjusts itself. Also, enter Qdot = 0 (since the HX is insulated) and Wdot_ext = 0. Click on Calculate. Immediately, we get:



8. Do the required calculations in the I/O panel:

#Heat transferred, Q = c_v * mdot1 * (T2 – T1):

Q = 4.184*4.5*(70-20) = 941.4 kW ….Ans.

#Exergy destroyed:

Note that entropy gen. rate = Sdot_gen = 0.70457 kW/K

Then, exergy destroyed = Δe = T0 * S_gen

i.e. Δe = T0 * S_gen = (25+273) * 0.70457 = 209.96 kW …. Ans.

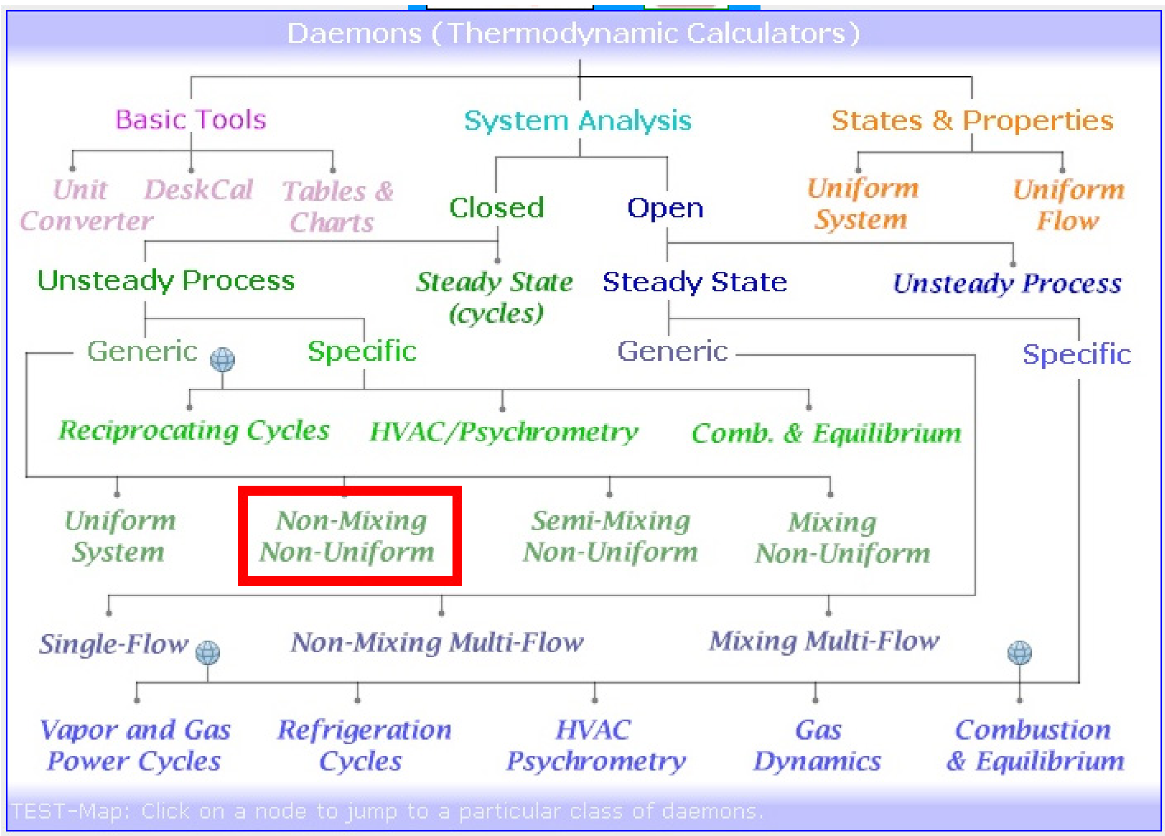
==

Prob.8.28. 70 kg of iron at 80 C is dropped in to an insulated tank containing 0.1 m^3 of water at 20 C. Find out the final, equilibrium temp. Also, what is the entropy generation and the exergy destruction? Take T0 = 20 C.

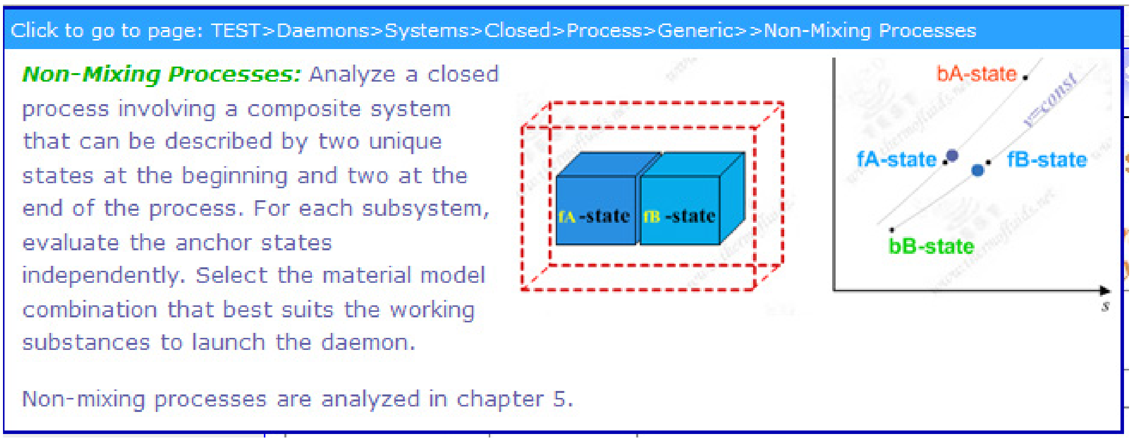
TEST Solution:

Following are the steps:

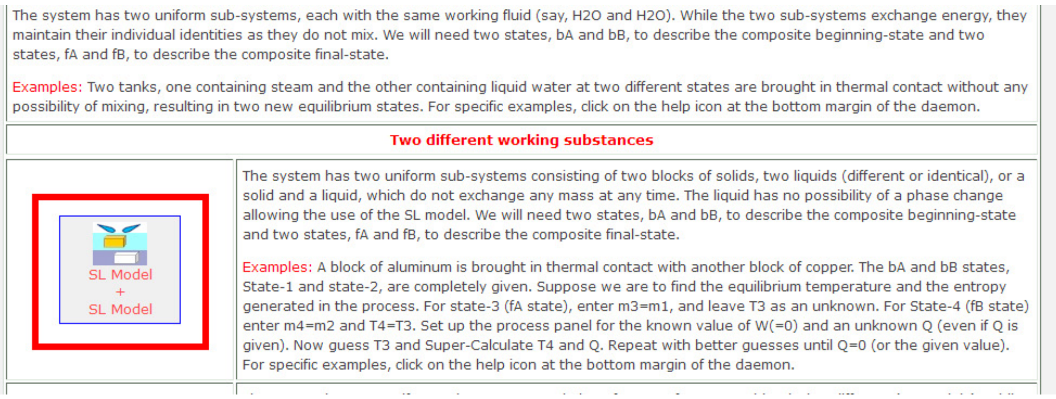
1. Choose System Analysis-Closed-Non-Mixing Non-Uniform daemon from the daemon tree.



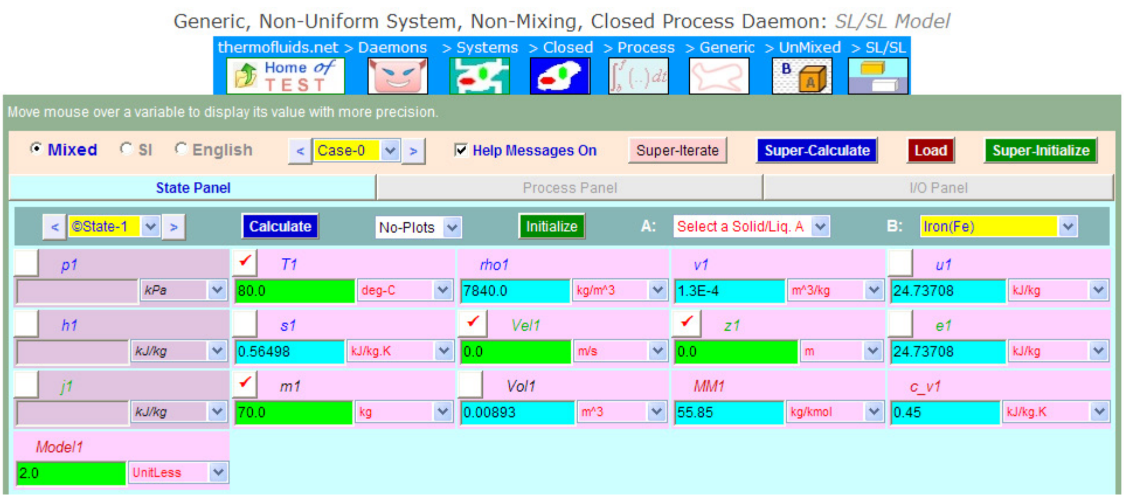
Hover the mouse pointer over 'Non-Mixing Non-Uniform' and we get the following pop-up:



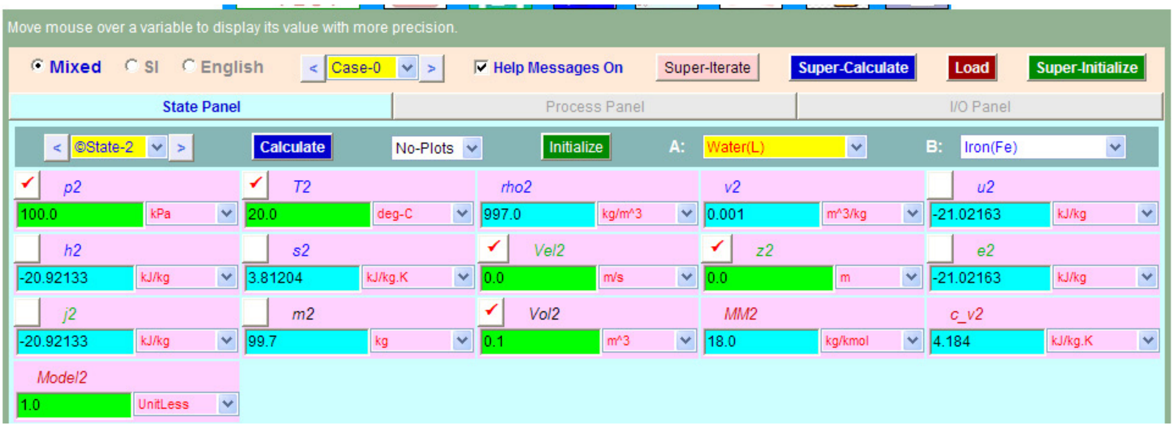
2. For material model, select (SL model + SL model) as shown below, since we are dealing with Iron / water.



3. Now, for State 1: choose Iron (Fe). See the yellow background color. Note that sp. heat value is built-in. Enter T1, m1 and hit Enter. We get:



4. Now, for State 2: Select Water. See the yellow background color which indicates that water is the selected fluid. Enter p1 = 100 kPa, T2 = 20 C, and Vol2 = 0.1 m^3. Note that sp. heat value is built-in. Hit Enter. We get:

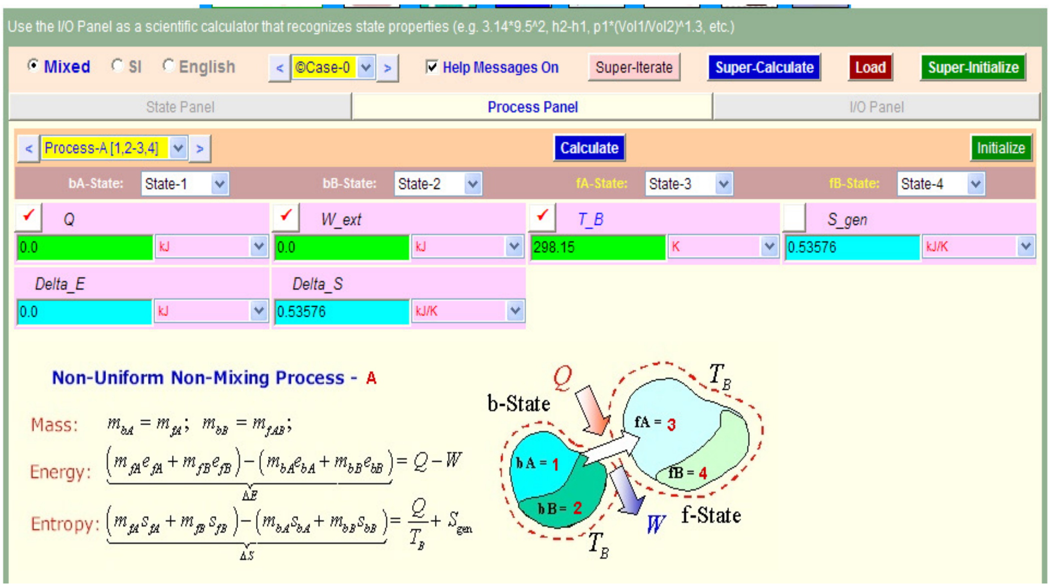


5. Next, for State 3: Select Iron. (see the yellow color). Enter m3 = m1, and T3 = (m1*c_v1*T1 + m2 *c_v2 * T2) / (m1* c_v1 + m2 * c_v2). Hit Enter. We get:

Note: Equilibrium temp, T3 = 24.213 C…..Ans.

6. Now, for State 4: Select water, see the yellow color. Enter p4 = 100 kpa,T4 = T3, and hit Enter. We get:

7. Now, go to Device Panel. Enter: State 1, State 2, State 3 and State 4 for bA-state, bB-state, fA-state and fB-state respectively, as shown below. Also, Q = 0 (since the vessel is insulated), and the external work, W_ext = 0. Click on Calculate and then SuperCalculate. We get:



8. Go to the I/O panel to see the TEST code etc. Also, make the required calculations in the I/O panel:

 # Exergy destruction: Δe = T0 * S_gen:

i.e. : Δe= (20+273) * 0.53576 = 156.978 kJ ... Ans.

See the TEST code etc in the I/O panel:

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

#Daemon Path: Systems>Closed>Process>Generic>NonUniformUnMixed>SL/SL-Model; v-10.ca09

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

States {

State-1: Water(L), Iron(Fe);

Given: { T1= 80.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 70.0 kg; Model1= 2.0 UnitLess; }

State-2: Water(L), Iron(Fe);

Given: { p2= 100.0 kPa; T2= 20.0 deg-C; Vel2= 0.0 m/s; z2= 0.0 m; Vol2= 0.1 m^3; Model2= 1.0 UnitLess; }

State-3: Water(L), Iron(Fe);

Given: { T3= "(m1*c_v1*T1 + m2*c_v2*T2)/ (m1*c_v1+m2*c_v2)" deg-C; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1" kg; Model3= 2.0 UnitLess; }

State-4: Water(L), Iron(Fe);

Given: { p4= 100.0 kPa; T4= "T3" deg-C; Vel4= 0.0 m/s; z4= 0.0 m; Model4= 1.0 UnitLess; }

}

Analysis {

Process-A: b-State = State-1, State-2; f-State = State-3, State-4;

Given: { Q= 0.0 kJ; W_ext= 0.0 kJ; T_B= 298.15 K; }

}

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

#******DETAILED OUTPUT:

 # Evaluated States:

```
#     State-1: Iron(Fe) > SL/SL Model;
#           Given: T1= 80.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m;
#           m1= 70.0 kg; Model1= 2.0 UnitLess;
#           Calculated: rho1= 7840.0 kg/m^3; v1= 1.0E-4 m^3/kg; u1= 24.7371 kJ/kg;
#           s1= 0.565 kJ/kg.K; e1= 24.7371 kJ/kg; Vol1= 0.0089 m^3;
#           MM1= 55.85 kg/kmol; c_v1= 0.45 kJ/kg.K;
#     State-2: Water(L) > SL/SL Model;
#           Given: p2= 100.0 kPa; T2= 20.0 deg-C; Vel2= 0.0 m/s;
#           z2= 0.0 m; Vol2= 0.1 m^3; Model2= 1.0 UnitLess;
#           Calculated: rho2= 997.0 kg/m^3; v2= 0.001 m^3/kg; u2= -21.0216 kJ/kg;
#           h2= -20.9213 kJ/kg; s2= 3.812 kJ/kg.K; e2= -21.0216 kJ/kg;
#           j2= -20.9213 kJ/kg; m2= 99.7 kg; MM2= 18.0 kg/kmol;
#           c_v2= 4.184 kJ/kg.K;
```

```
#        State-3: Iron(Fe) > SL/SL Model;
#        Given: T3= "(m1*c_v1*T1 + m2*c_v2*T2)/ (m1*c_v1+m2*c_v2)" deg-C; Vel3= 0.0 m/s; z3= 0.0 m;
#        m3= "m1" kg; Model3= 2.0 UnitLess;
#        Calculated: rho3= 7840.0 kg/m^3; v3= 1.0E-4 m^3/kg; u3= -0.3672 kJ/kg;
#        s3= 0.4876 kJ/kg.K; e3= -0.3672 kJ/kg; Vol3= 0.0089 m^3;
#        MM3= 55.85 kg/kmol; c_v3= 0.45 kJ/kg.K;
#        State-4: Water(L) > SL/SL Model;
#                 Given: p4= 100.0 kPa; T4= "T3" deg-C; Vel4= 0.0 m/s;
#                 z4= 0.0 m; Model4= 1.0 UnitLess;
#                 Calculated: rho4= 997.0 kg/m^3; v4= 0.001 m^3/kg; u4= -3.3958 kJ/kg;
#                 h4= -3.2954 kJ/kg; s4= 3.8717 kJ/kg.K; e4= -3.3958 kJ/kg;
#                 j4= -3.2954 kJ/kg; m4= 99.7 kg; Vol4= 0.1 m^3;
#                 MM4= 18.0 kg/kmol; c_v4= 4.184 kJ/kg.K;

#--------Property spreadsheet starts:
#        State   p(kPa)       T(K)    v(m^3/kg)    u(kJ/kg)     h(kJ/kg)     s(kJ/kg)
#        1                    353.2   1.0E-4       24.74                     0.565
#        2       100.0        293.2   0.001        -21.02       -20.92       3.812
#        3                    297.4   1.0E-4       -0.37                     0.488
#        4       100.0        297.4   0.001        -3.4         -3.3         3.872
#--------Property spreadsheet ends----------------------------------------------------------------
```

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1, State-2; f-State = State-3, State-4;

Given: Q= 0.0 kJ; W_ext= 0.0 kJ; T_B= 298.15 K;

Calculated: **S_gen= 0.535759 kJ/K;** Delta_E= "-4.5474735E-12" kJ; Delta_S= 0.535759 kJ/K;

==

8.4 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
6. *M. Thirumaleshwar*, Exergy method of analysis and its application to a helium cryorefrigerator, CRYOGENICS, June 1979
7. http://www.ecourses.ou.edu/cgi-bin/ebook.cgi?doc=&topic=th&chap_sec=07.0