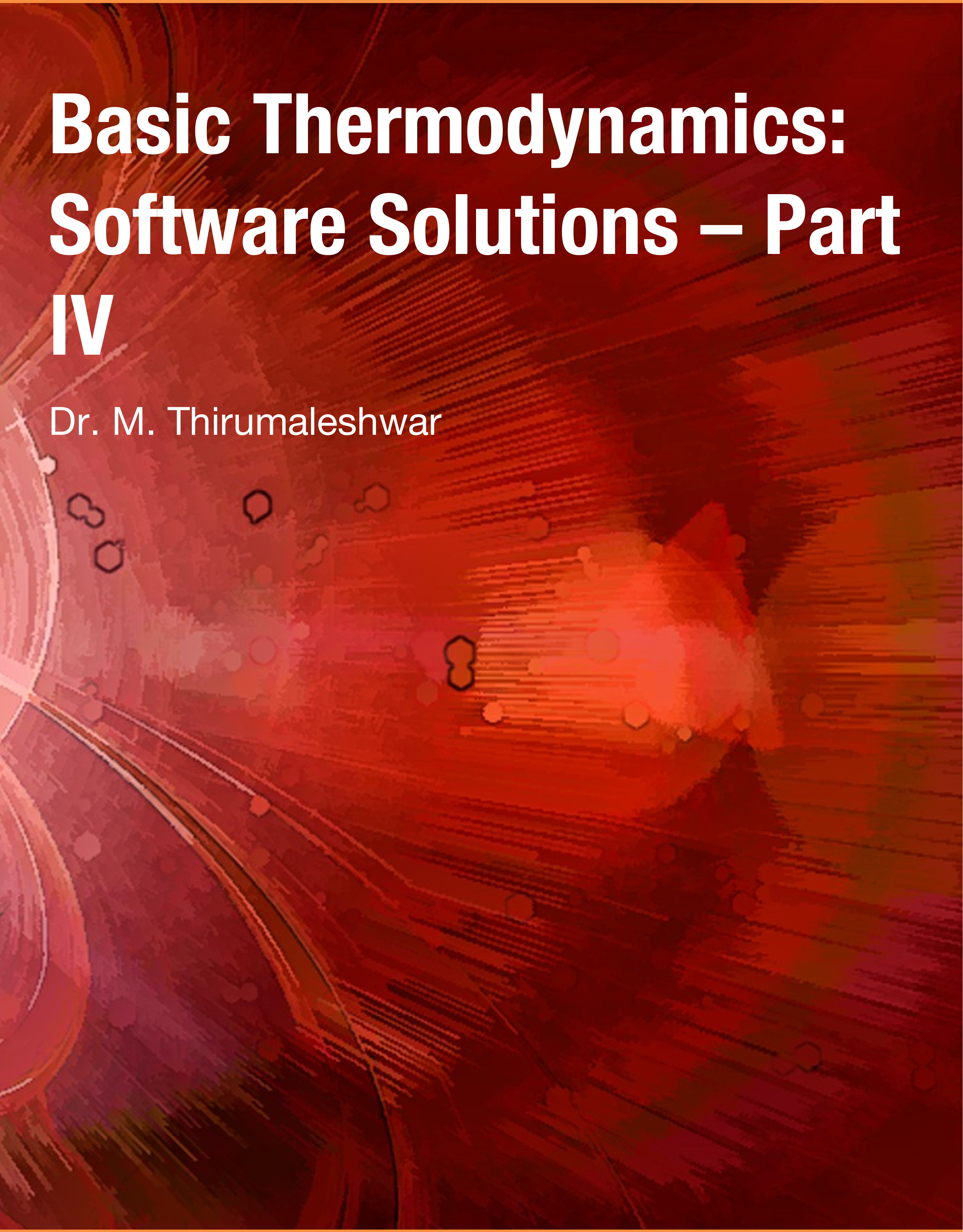

# Basic Thermodynamics: Software Solutions – Part IV

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# Basic Thermodynamics: Software Solutions – Part IV

## Availability (or 'Exergy') and Second Law analysis

Basic Thermodynamics: Software Solutions – Part IV
1st edition

ISBN 978-87-403-0704-7

# Contents


Could you think of 101 new things
to do with eggs and oil?

# 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:

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

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

where $\Delta s$ = entropy change in the process

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

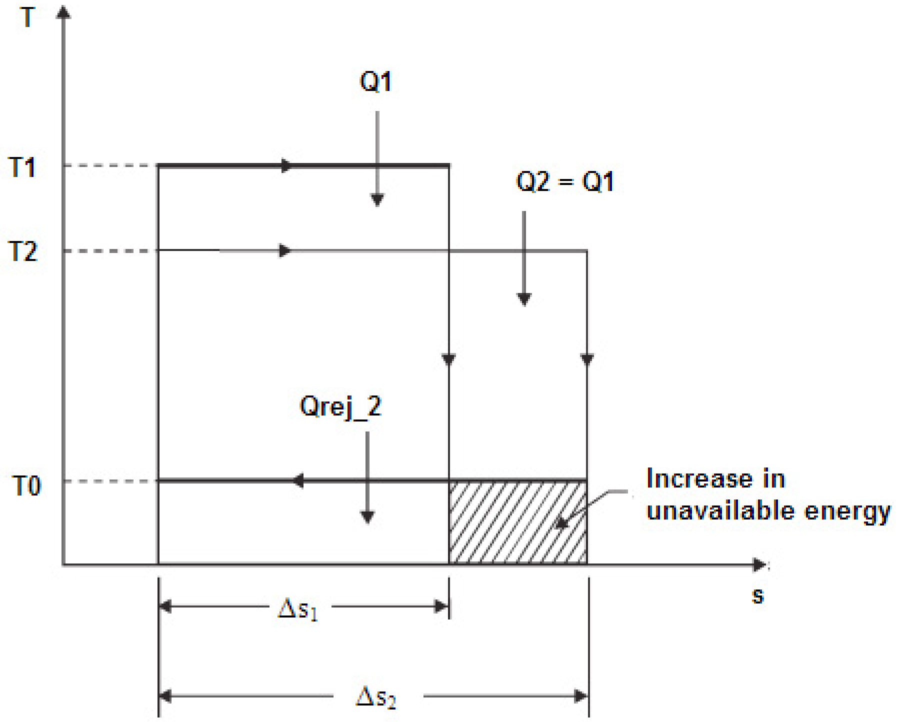
**Exergy of Work:** Exergy of work is work itself, since there is no Thermodynamic restriction on its availability.

**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: $\Delta s_1 < \Delta s_2$

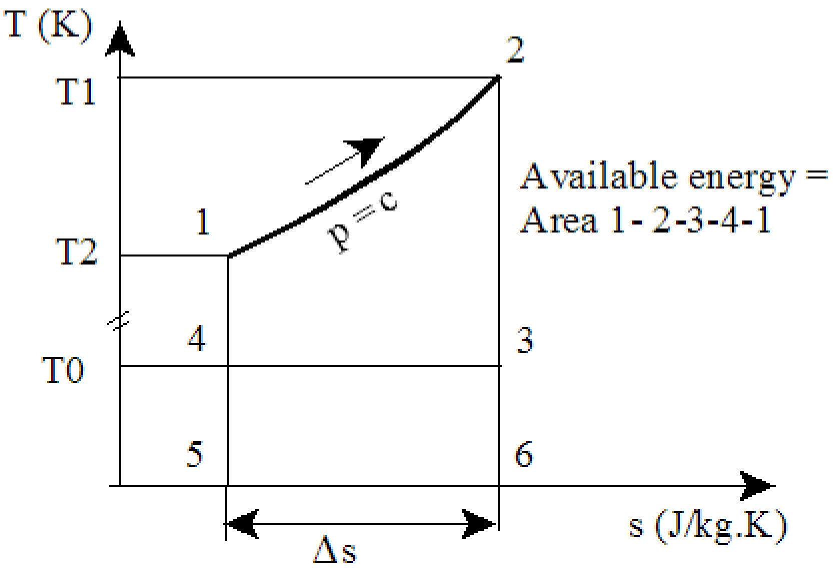
And the heat rejected in the second case: Qrej_2 = T0 . $\Delta s_2$ which is more than the heat rejected in the first case, i.e. Qrej_1 = T0 . $\Delta s_1$

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,

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

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

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

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. $W = (u_1 - T\cdot s_1) - (u_0 - T\cdot s_0)$ ....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. $W_{max} = g_1 - g_0$ ....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:

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

**Similarly, for steady flow system:**

$W_{max} = (g_1 - g_2) + (KE_1 - KE_2) + (PE_1 - PE_2)$ ...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*:**

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

i.e. $I \ge 0$

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

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

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

**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.

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

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

**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. $\eta_{II} = \dfrac{A_{min}}{A} \qquad \text{...eqn.(8.17)}$

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.

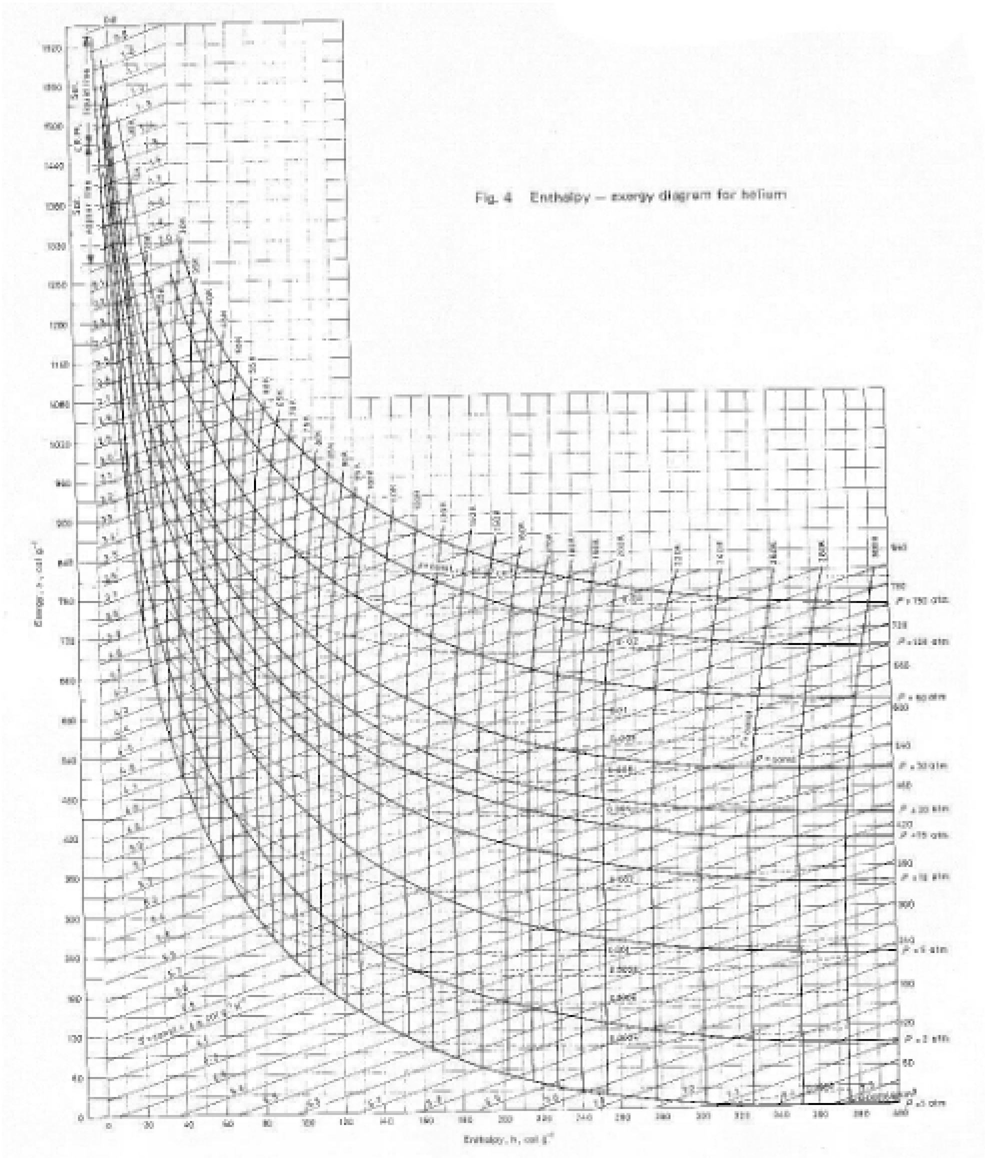


Fig. 4 Enthalpy – exergy diagram for helium

**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 $\Delta e$ 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**, Δe = 0

Therefore:

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

**If the compression is adiabatic, but irreversible, then:**

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

**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. $\Delta e_{exp} = \left(e_3 - e_4\right) - w$

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?”

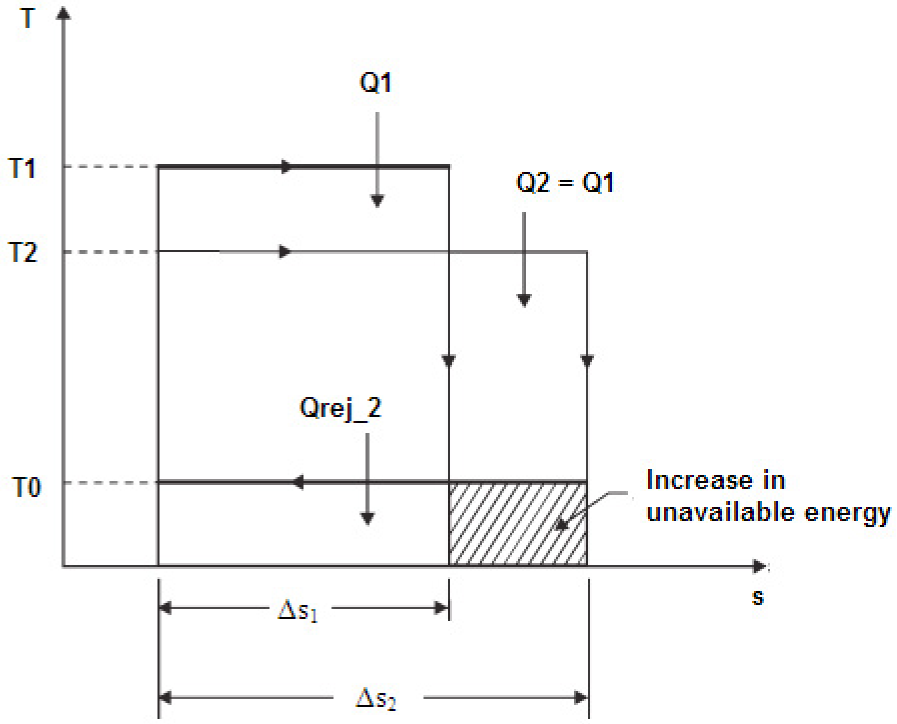
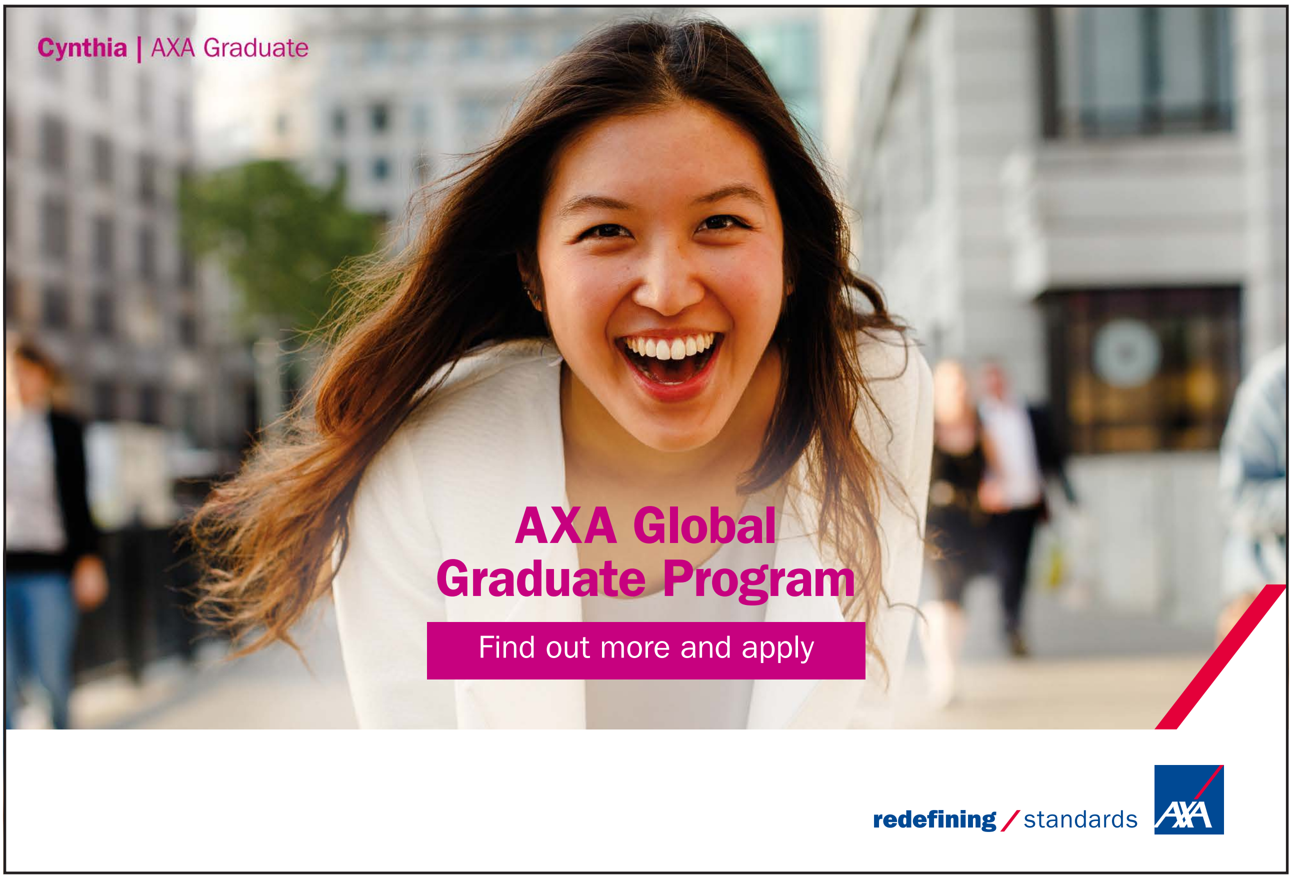


**Fig.Prob.8.1**

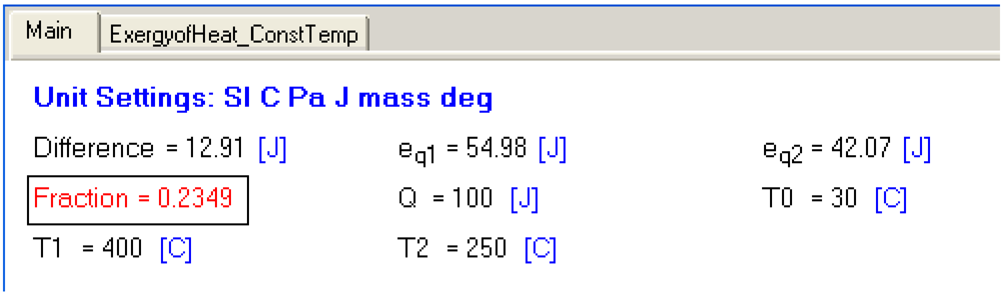
**"EES Solution:"**

"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"
```

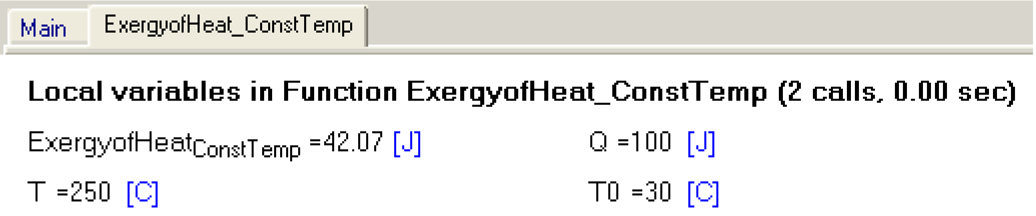


**Results:**



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]



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,**

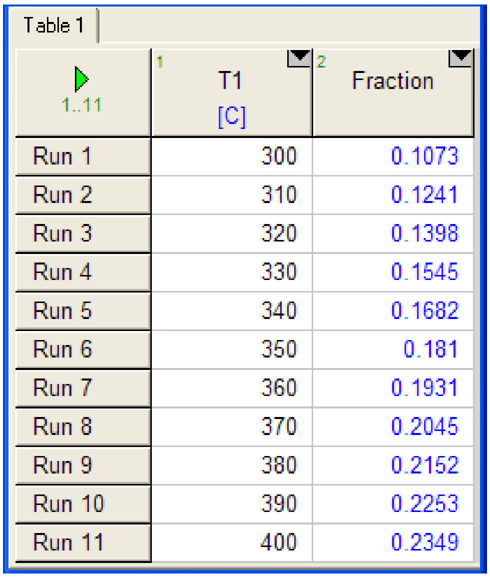
**Fraction of available energy lost due to irreversible heat transfer at 250 C = 0.2349 …Ans.**

---

**In addition:**

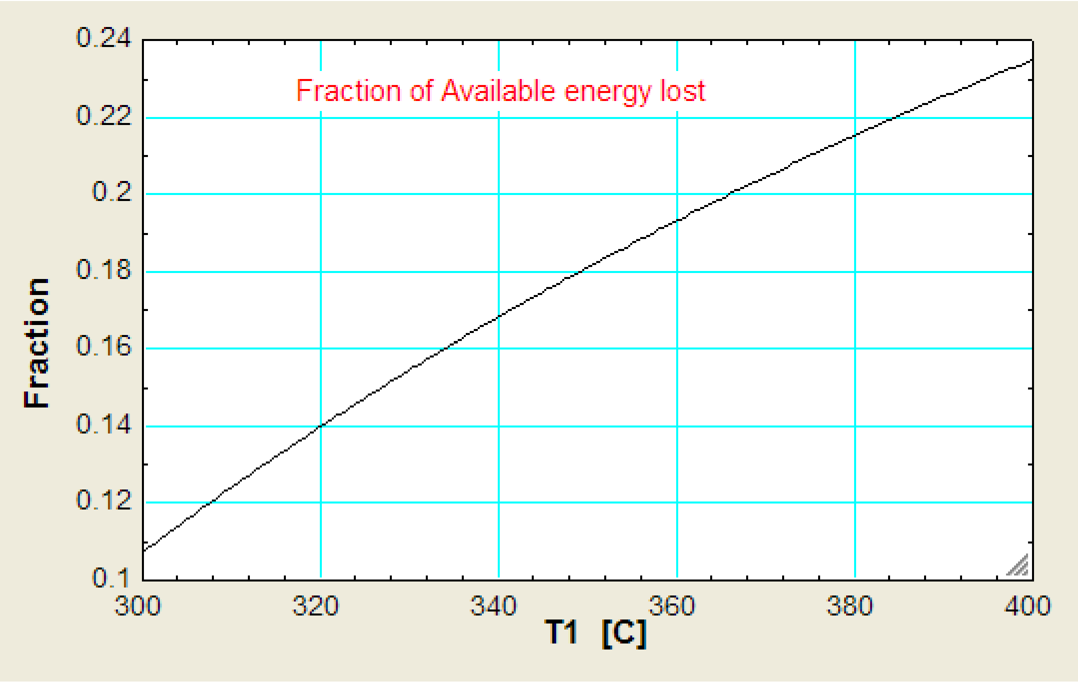
**Plot the variation of Fraction as a function of the temp of heat supplied , T1 varies from 300 C to 400 C:**

**First, compute the Parametric Table:**



| 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:**



==================================================================

"**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?"

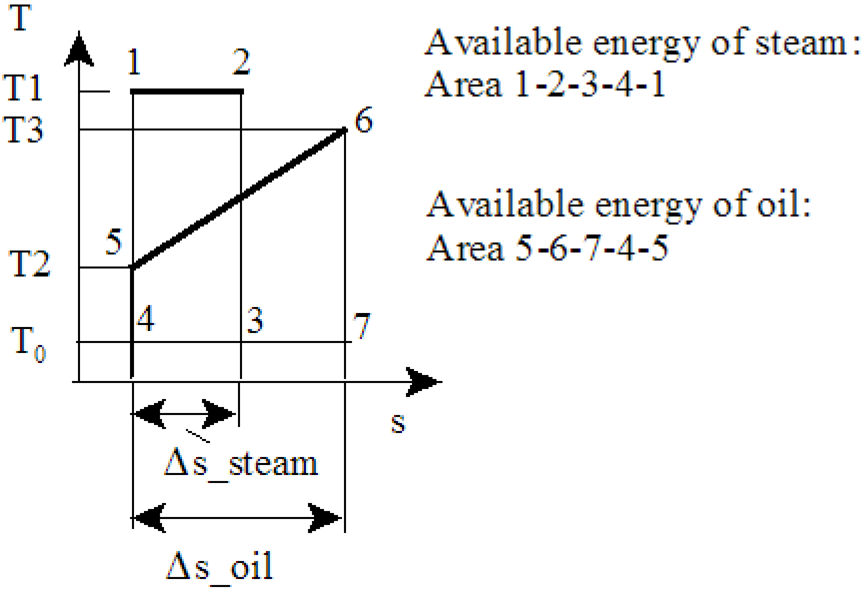


**Fig.Prob.8.2**

**"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"

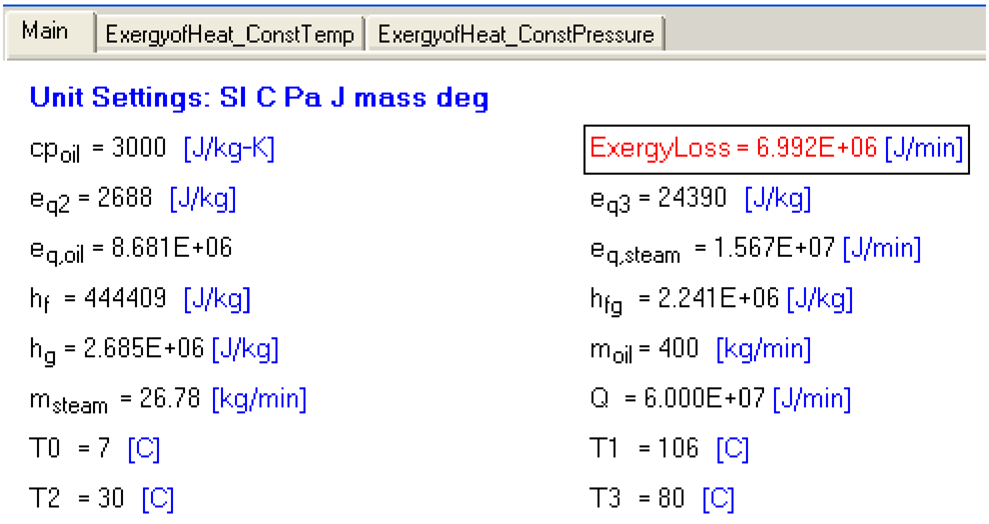
"Therefore: exergy change of oil:"

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:**



Unit Settings: SI C Pa J mass deg

$cp_{oil}$ = 3000 [J/kg-K]

$e_{q2}$ = 2688 [J/kg]

$e_{q,oil}$ = 8.681E+06

$h_f$ = 444409 [J/kg]

$h_g$ = 2.685E+06 [J/kg]

$m_{steam}$ = 26.78 [kg/min]

T0 = 7 [C]

T2 = 30 [C]

ExergyLoss = 6.992E+06 [J/min]

$e_{q3}$ = 24390 [J/kg]

$e_{q,steam}$ = 1.567E+07 [J/min]

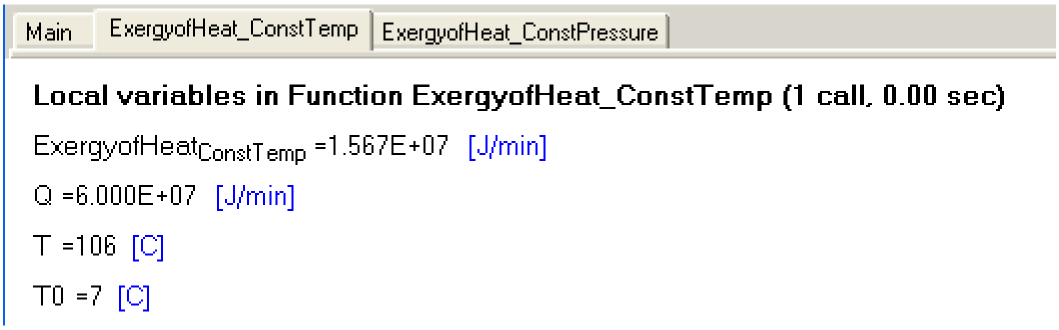
$h_{fg}$ = 2.241E+06 [J/kg]

$m_{oil}$ = 400 [kg/min]

Q = 6.000E+07 [J/min]

T1 = 106 [C]

T3 = 80 [C]



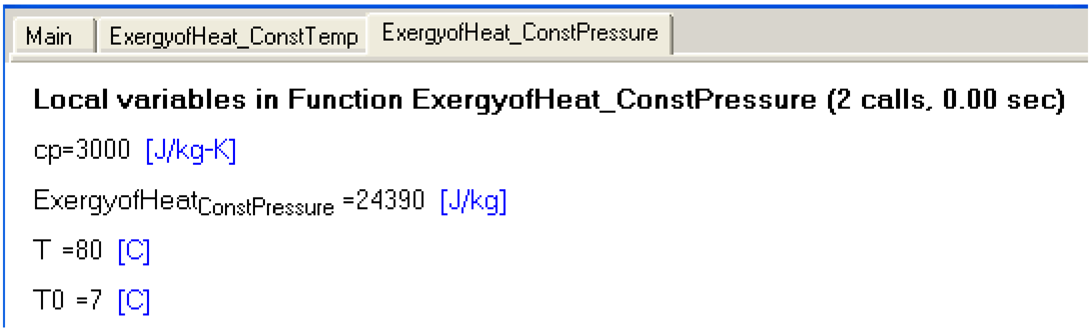
Local variables in Function ExergyofHeat_ConstTemp (1 call, 0.00 sec)

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

Q =6.000E+07 [J/min]

T =106 [C]

T0 =7 [C]



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.**

---

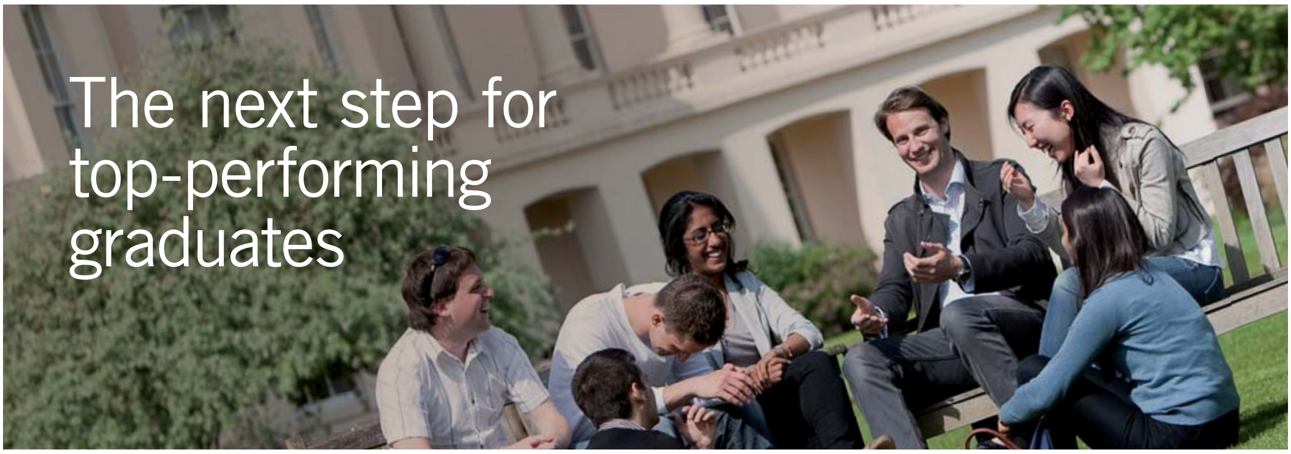
**Alternative method:**

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

**Then, Exergy loss = Irreversibility = T0 * DELTA_S_tot**

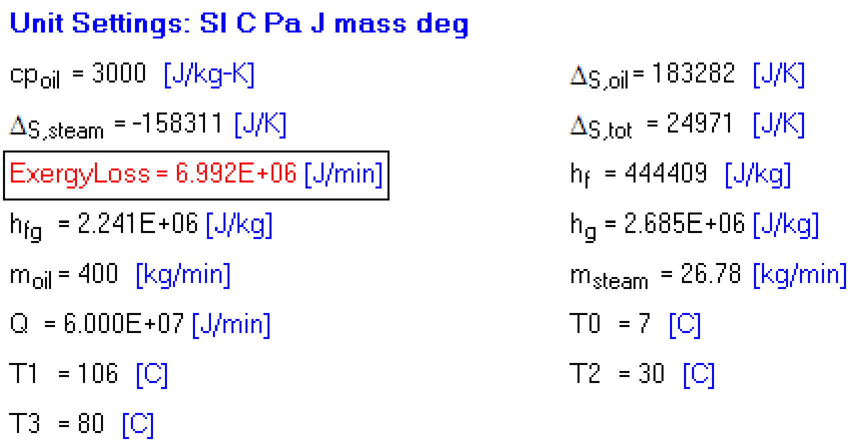
**Following is the EES program to do this:**

```
"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"

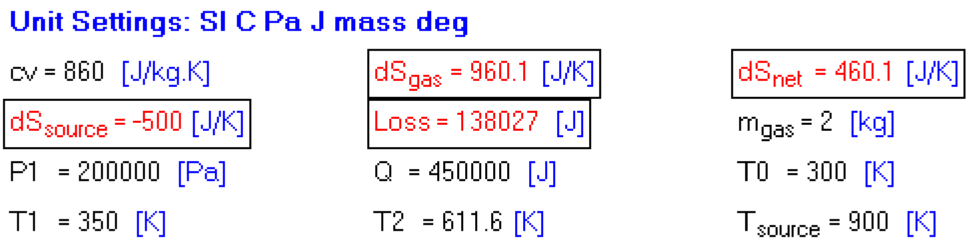
**"Therefore, dS_net:"**

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:**

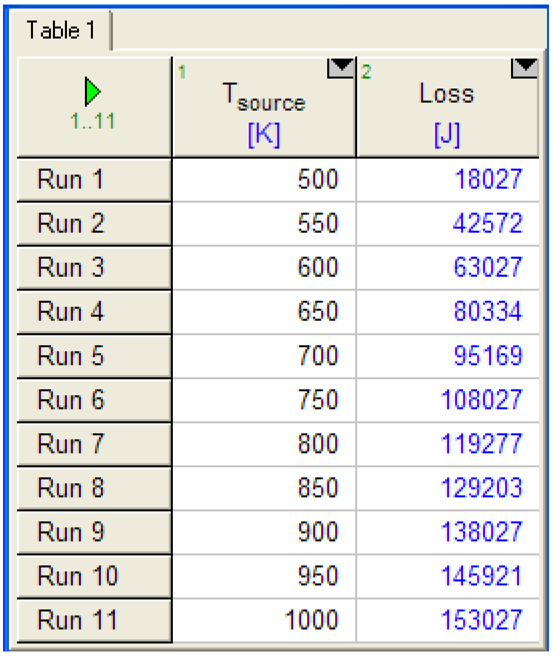
**Loss in Availability = 138.027 kJ …. Ans.**

---

**In addition:**

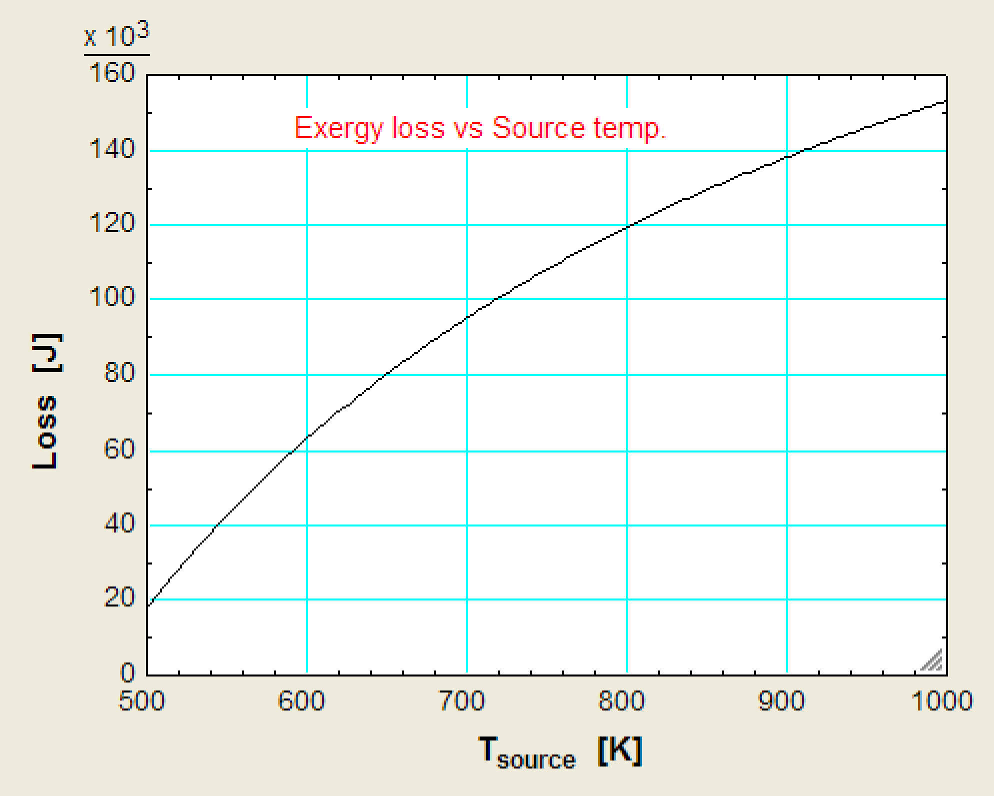
**Plot the variation of Loss in exergy as the source temp varies from 500 K to 1000 K, the amount of heat Q remaining constant:**

**First, compute the Parametric Table:**



| 1..11 | 1 $T_{source}$ [K] | 2 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"

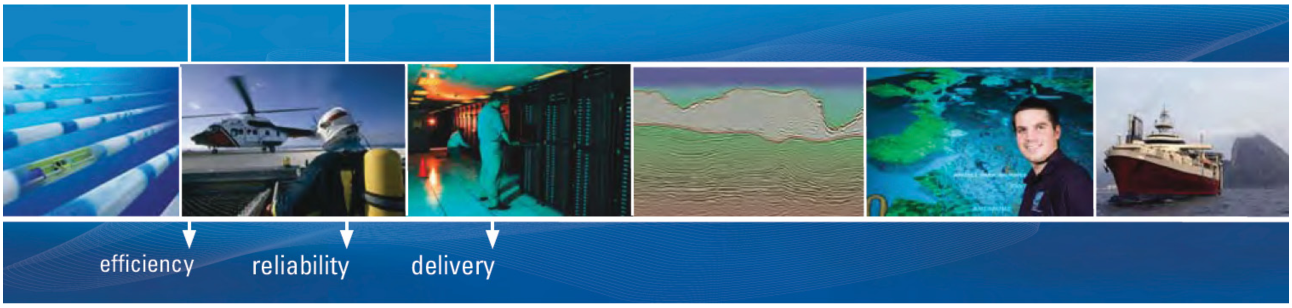
**"Change in Availability:"**

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

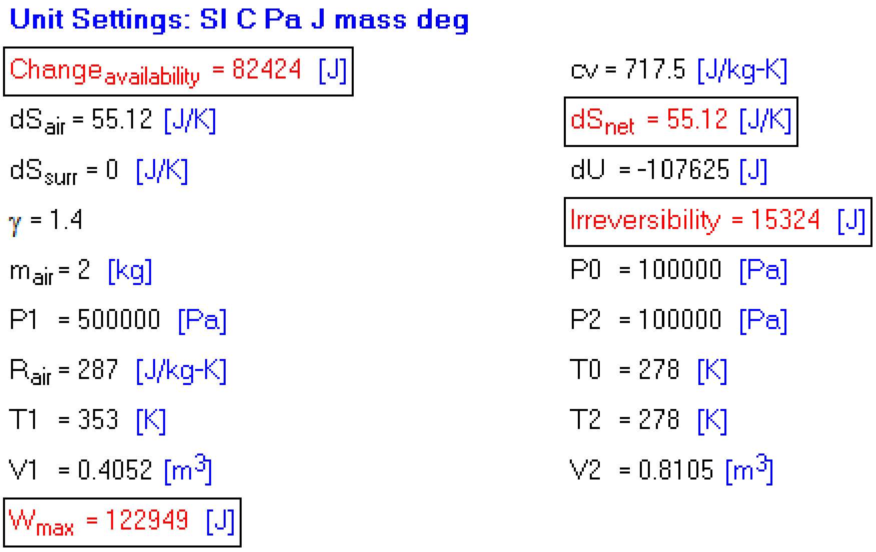
Change_availability = -dU – T0 * (-dS_air) + P0 * (V1 – V2) "J"

**"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]

$\gamma$ = 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”

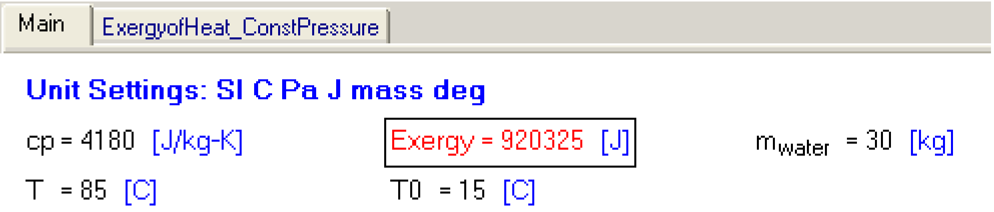
T0 = 15 “C”

cp = 4180 “J/kg.K”

m_water = 30 “kg”

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

**Results:**



**Unit Settings: SI C Pa J mass deg**

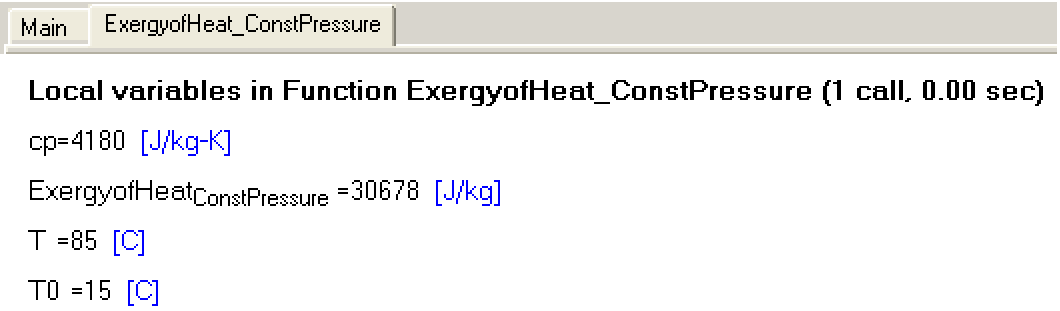
cp = 4180 [J/kg-K]

Exergy = 920325 [J]

$m_{water}$ = 30 [kg]

T = 85 [C]

T0 = 15 [C]



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

cp=4180 [J/kg-K]

$\text{ExergyofHeat}_{\text{ConstPressure}}$ =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"
```

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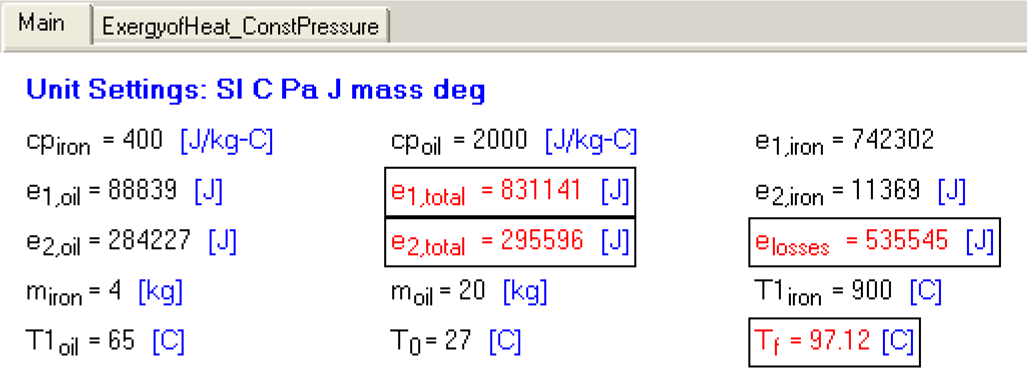
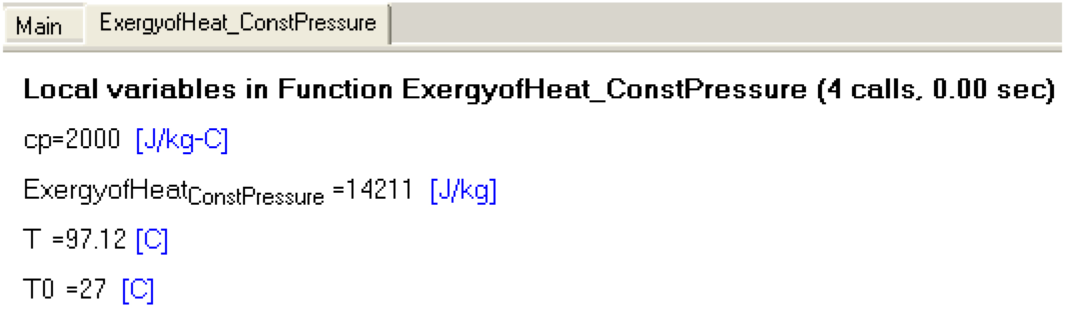


Unit Settings: SI C Pa J mass deg

$cp_{iron}$ = 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]



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"

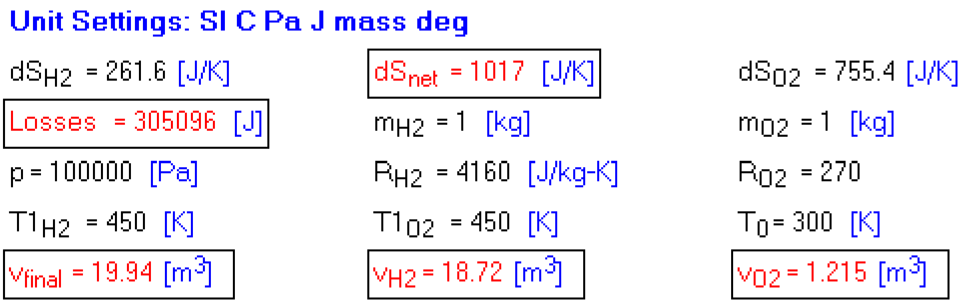
**"Therefore: total entropy change:"**

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]

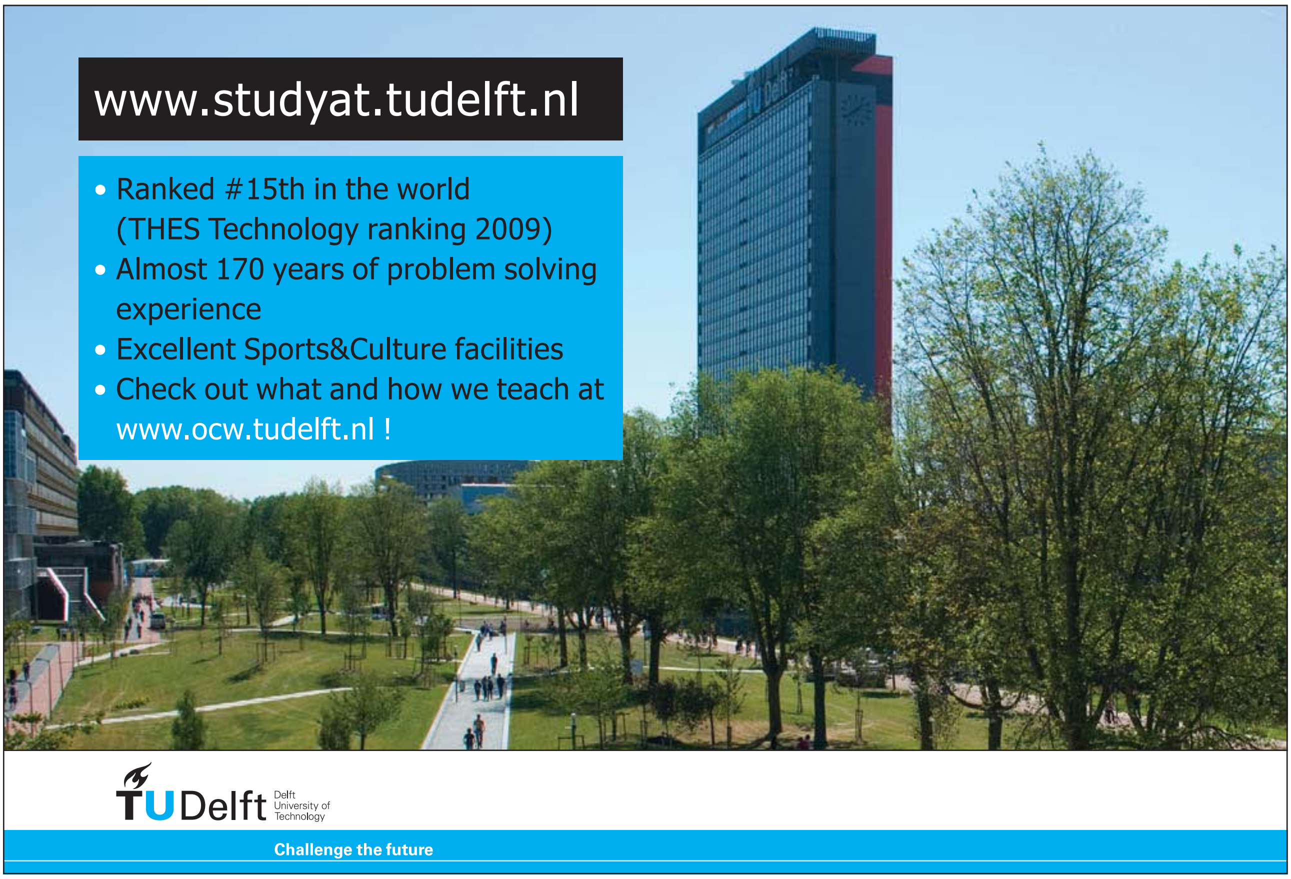
$V_{final}$ = 19.94 [m^3]    $V_{H2}$ = 18.72 [m^3]    $V_{O2}$ = 1.215 [m^3]

**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"

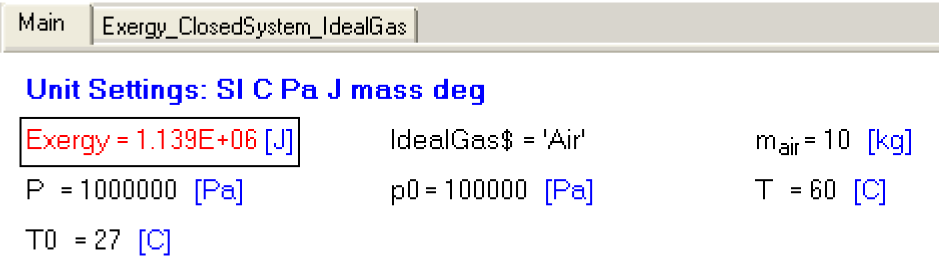
T = 60 "C"

P0 = 1E05 "Pa"

T0 = 27 "C"

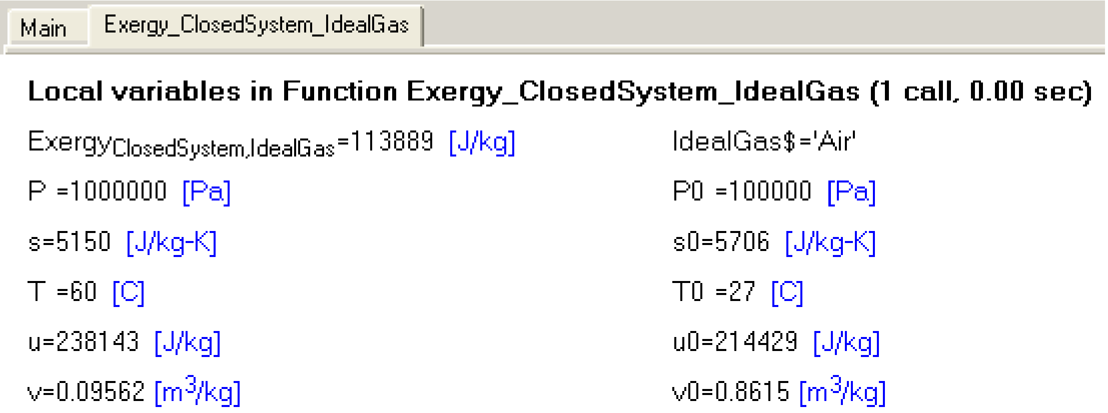
Exergy = m_air * Exergy_ClosedSystem_IdealGas(IdealGas$,T, P, T0, P0)

**Results:**



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]



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."

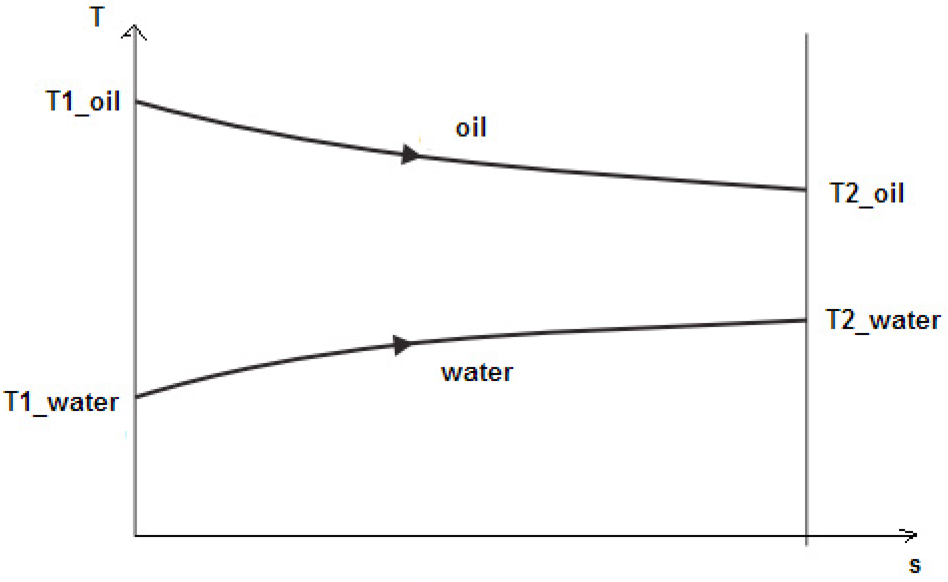


**Fig.Prob.8.10**

**"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"

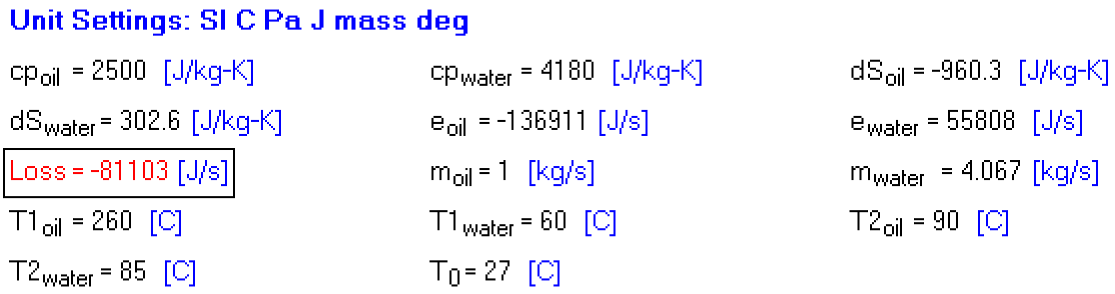
**"Change in availability of water:"**

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"

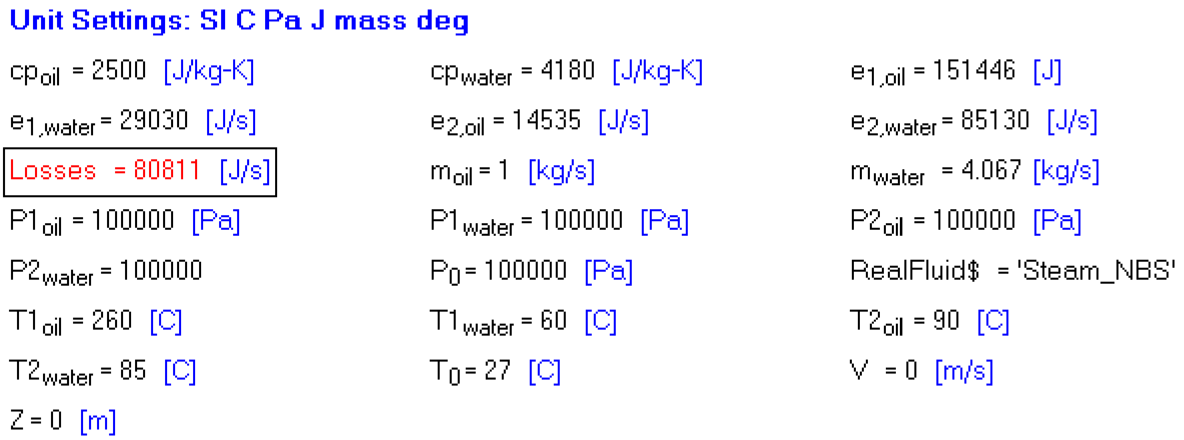
**"Exergy of oil going out:"**

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:**



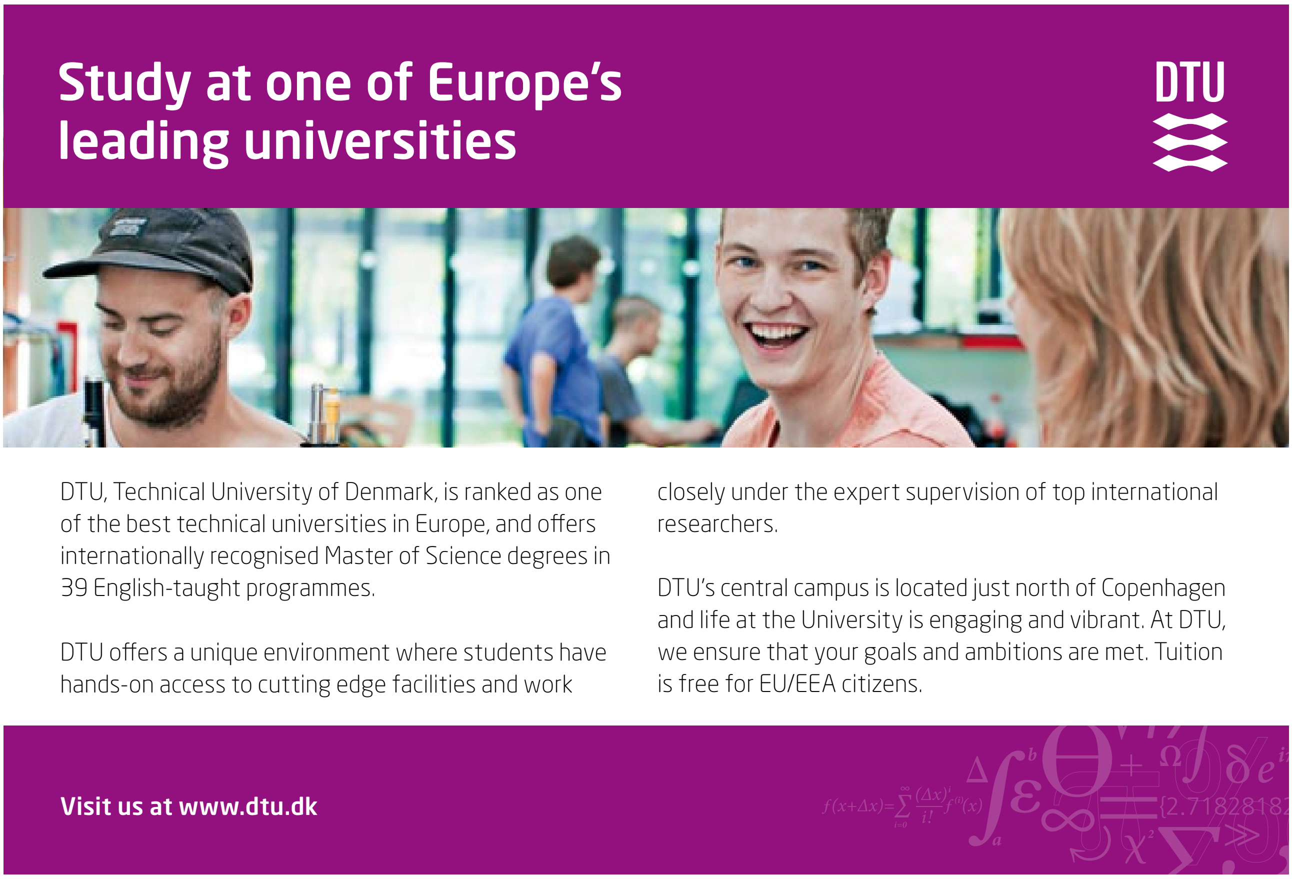
```
Unit Settings: SI C Pa J mass deg

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]"

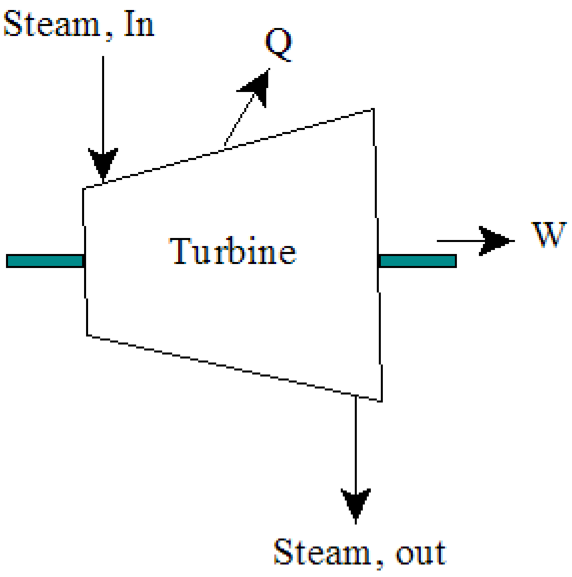


**Fig.Prob.8.11**

**"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"

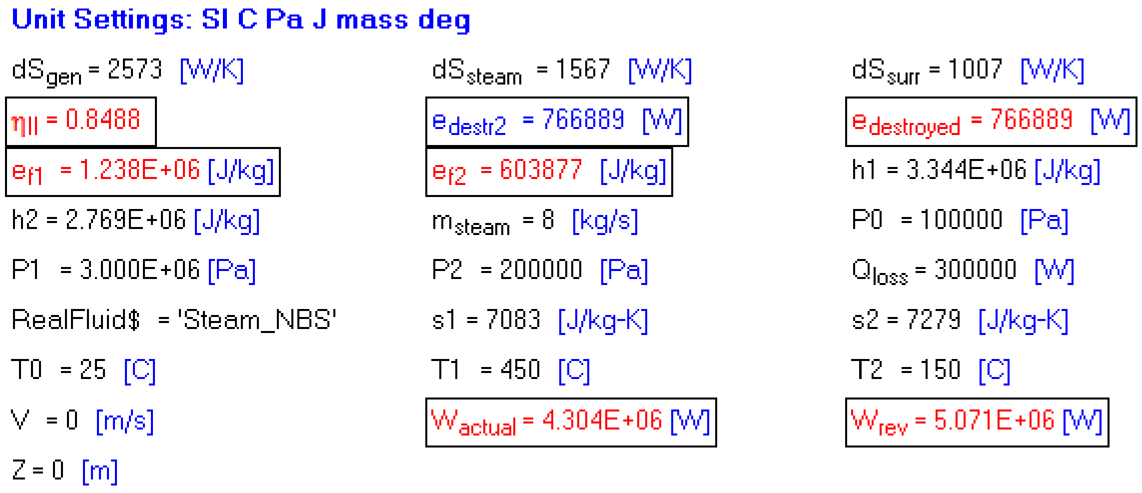
P0 = 100E03 "Pa"
T0 = 25 "C"

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

dSgen = 2573  [W/K]              dSsteam = 1567  [W/K]            dSsurr = 1007  [W/K]
ηII = 0.8488                     edestr2 = 766889  [W]            edestroyed = 766889  [W]
ef1 = 1.238E+06 [J/kg]           ef2 = 603877  [J/kg]             h1 = 3.344E+06 [J/kg]
h2 = 2.769E+06 [J/kg]            msteam = 8  [kg/s]               P0 = 100000  [Pa]
P1 = 3.000E+06 [Pa]              P2 = 200000  [Pa]                Qloss = 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]                     Wactual = 4.304E+06 [W]          Wrev = 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"

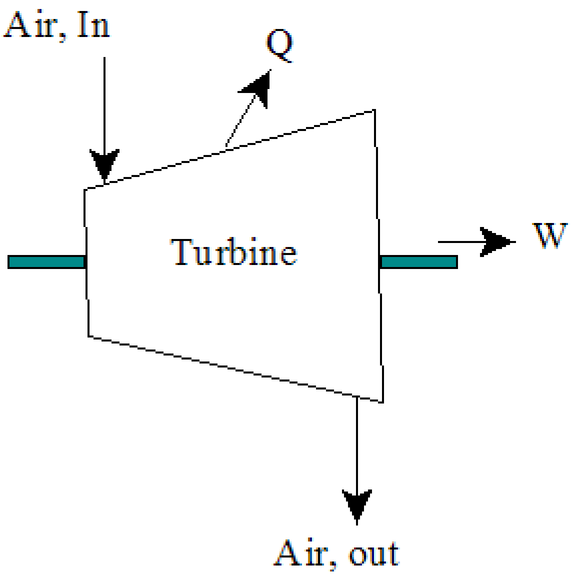


**Fig.Prob.8.12**

**"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"

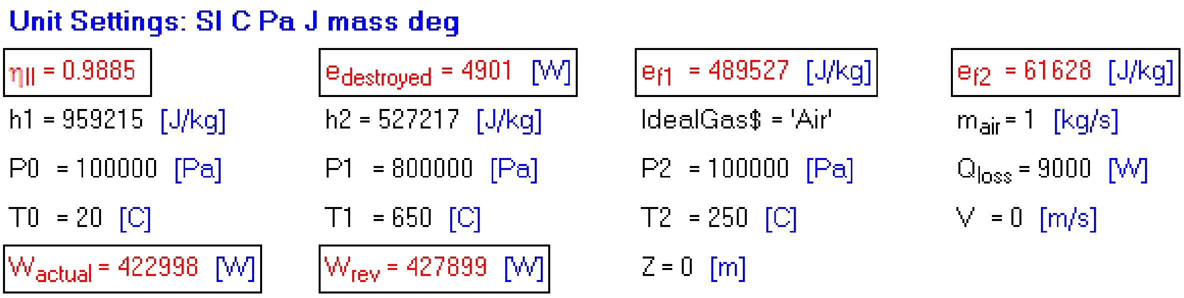
P0 = 1E05 "Pa"
T0 = 20 "C"

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
ηII = 0.9885          edestroyed = 4901  [W]   ef1  = 489527  [J/kg]   ef2  = 61628  [J/kg]
h1 = 959215  [J/kg]   h2 = 527217  [J/kg]      IdealGas$ = 'Air'       mair = 1  [kg/s]
P0  = 100000  [Pa]    P1  = 800000  [Pa]       P2  = 100000  [Pa]      Qloss = 9000  [W]
T0  = 20  [C]         T1  = 650  [C]           T2  = 250  [C]          V  = 0  [m/s]
Wactual = 422998  [W] Wrev = 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"

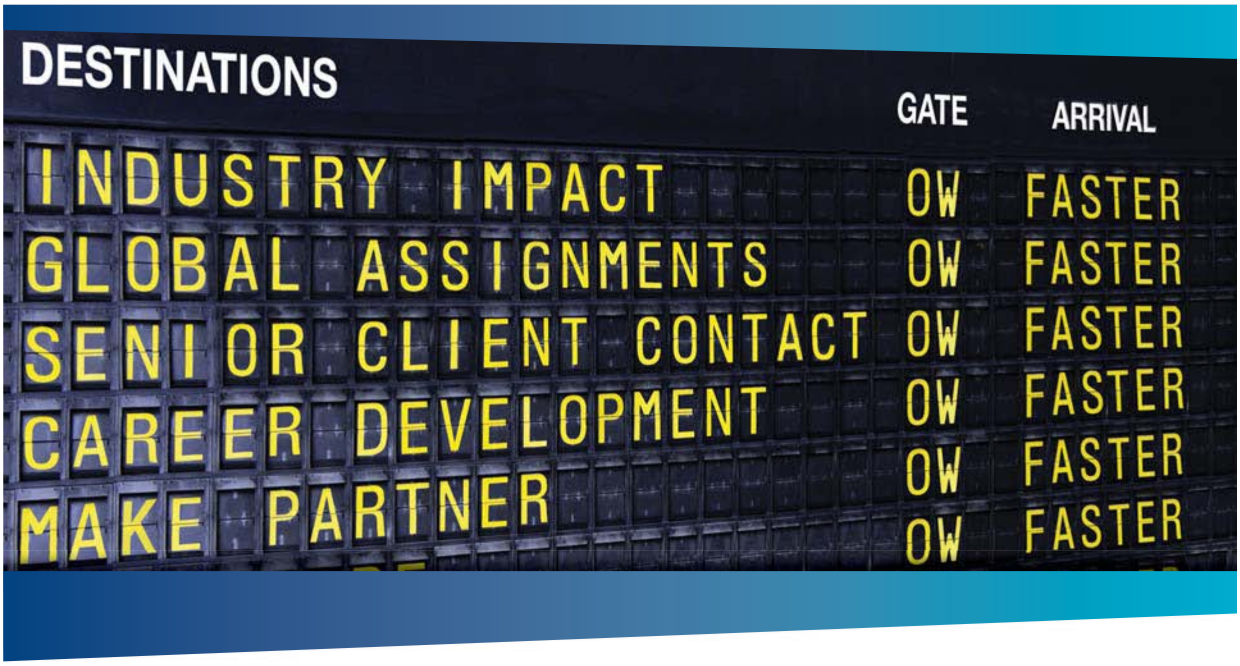
**"Then: Exergy destroyed or Loss:"**

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"**



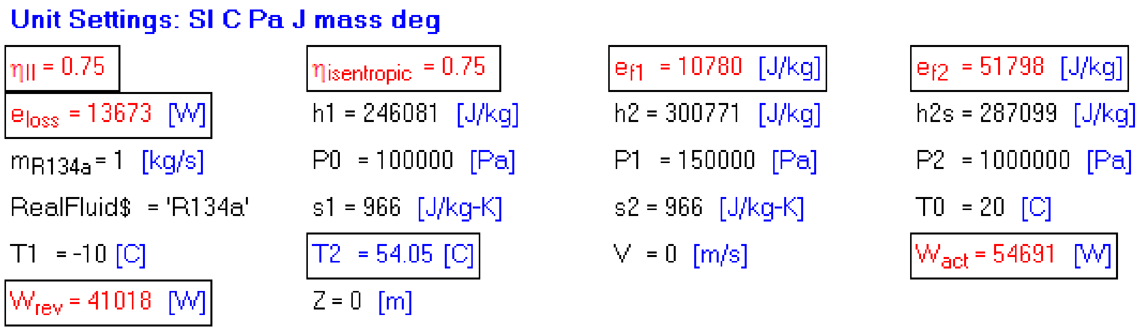
"Then:"

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

ηII = 0.75            ηisentropic = 0.75    ef1 = 10780 [J/kg]    ef2 = 51798 [J/kg]
eloss = 13673 [W]     h1 = 246081 [J/kg]    h2 = 300771 [J/kg]    h2s = 287099 [J/kg]
mR134a = 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]           Wact = 54691 [W]
Wrev = 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"

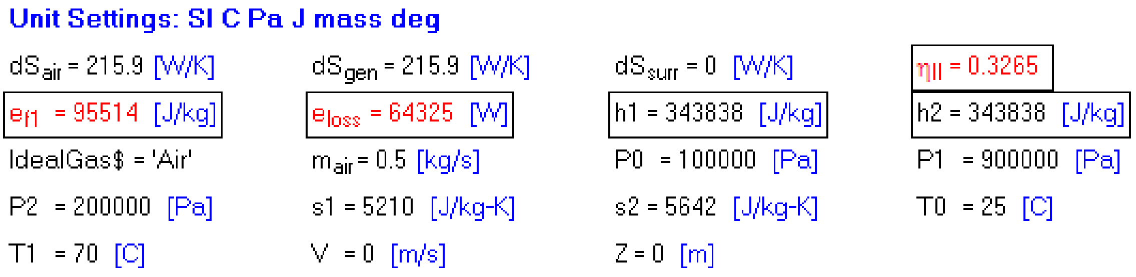
P0 = 1E05 "Pa"

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."

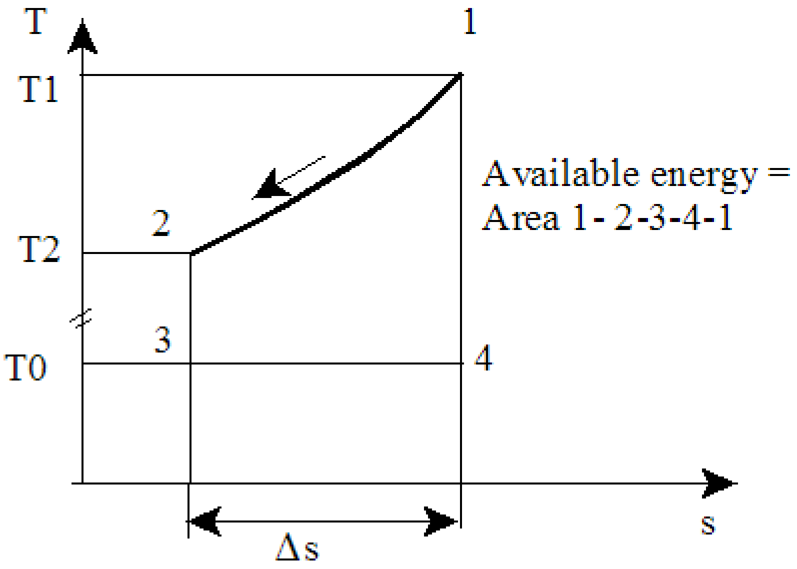


**Fig.Prob.8.15**

**"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"

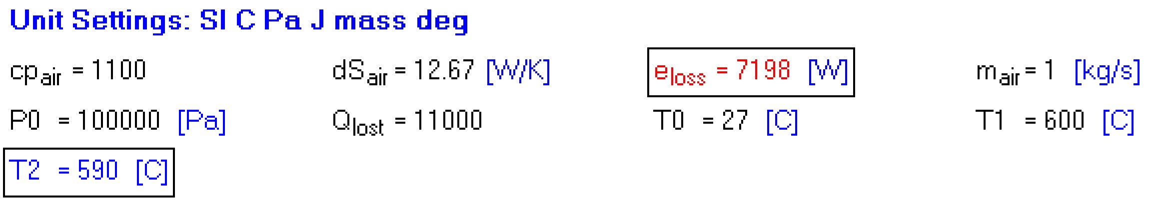
**"Calculations:"**

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.**

=====================================================================

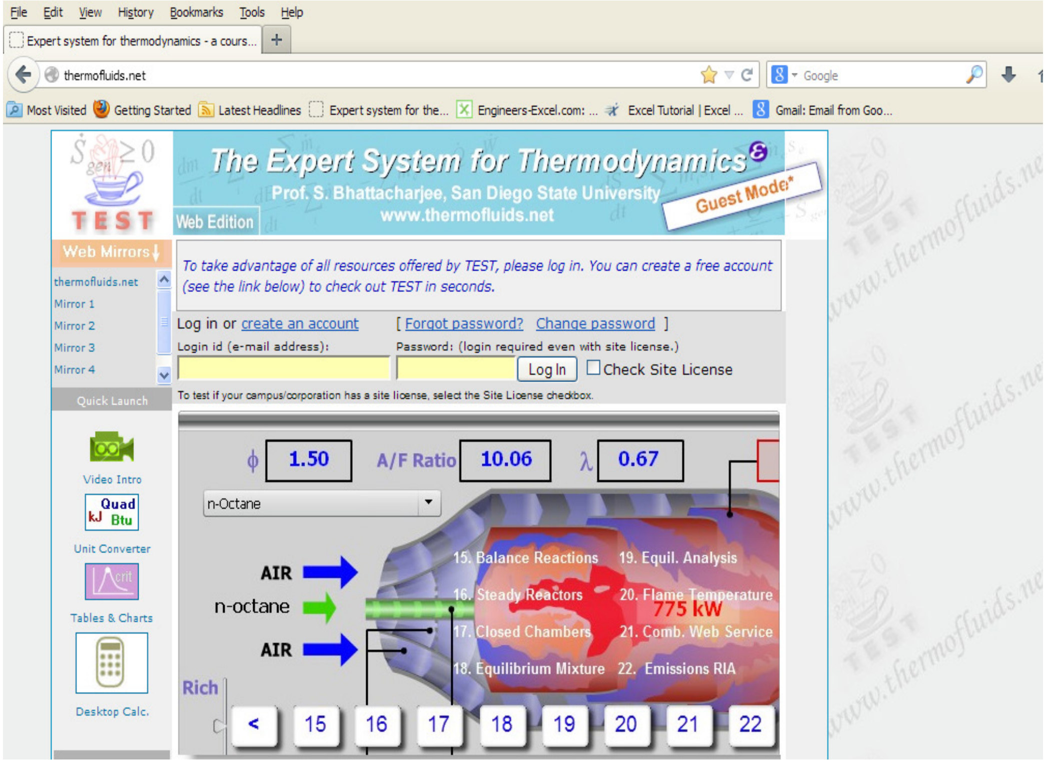
## 8.3 Problems solved with TEST:

**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:



To take advantage of all resources offered by TEST, please log in. You can create a free account (see the link below) to check out TEST in seconds.

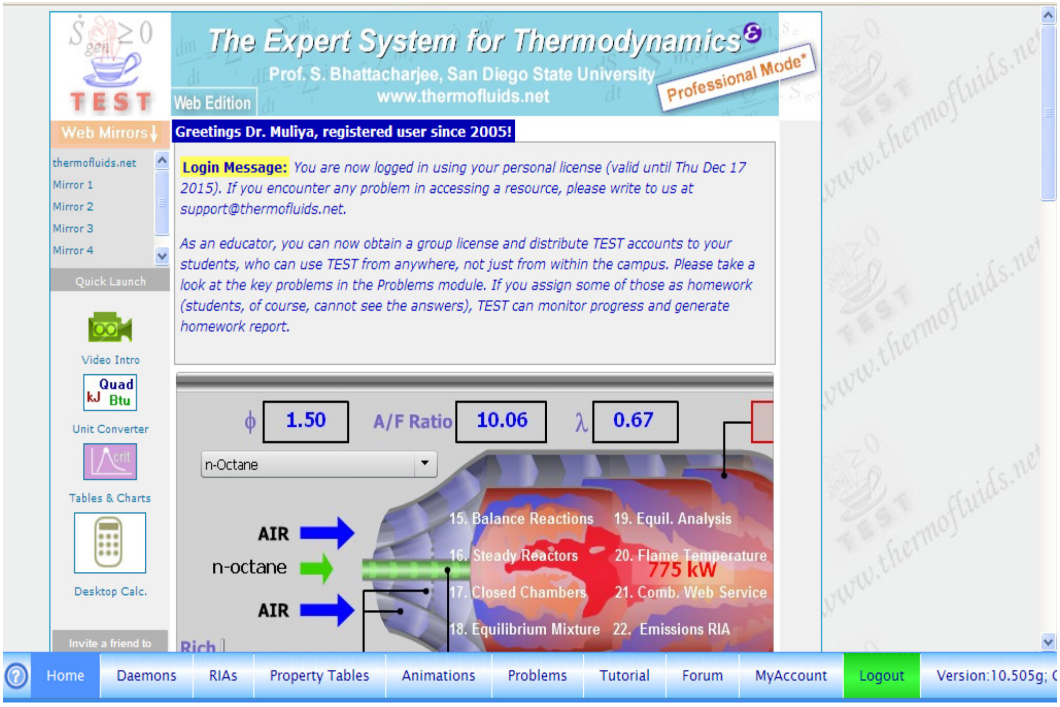
Log in or create an account [ Forgot password? Change password ]

Login id (e-mail address):

Password: (login required even with site license.)

To test if your campus/corporation has a site license, select the Site License checkbox.

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

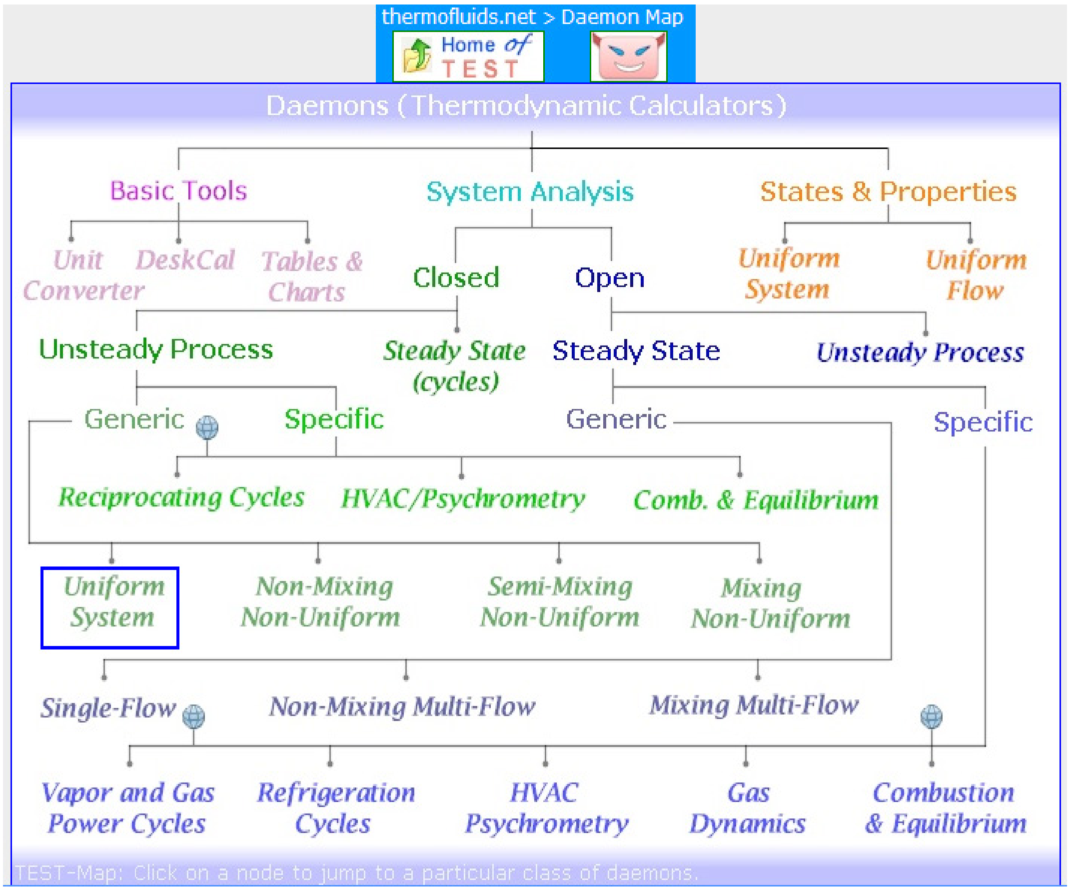


**Greetings Dr. Muliya, registered user since 2005!**

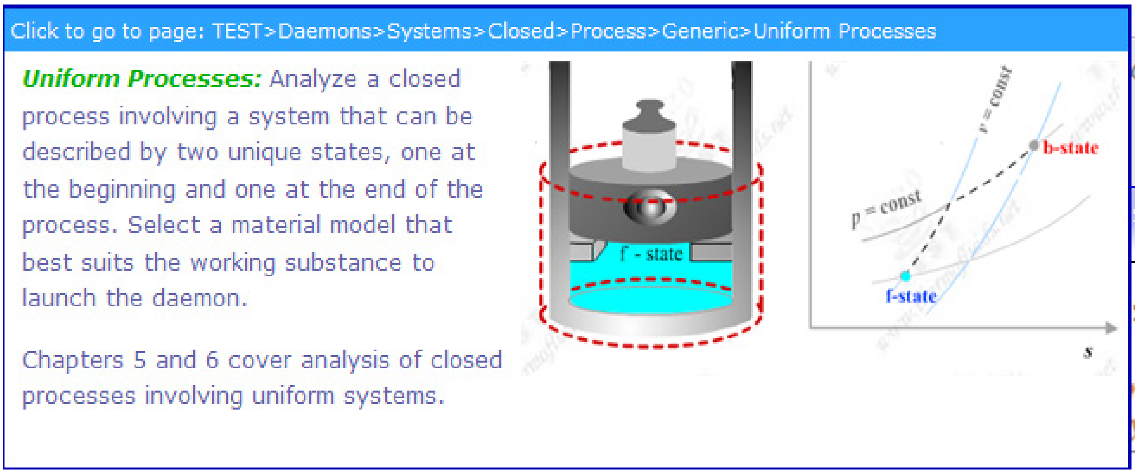
**Login Message:** *You are now logged in using your personal license (valid until Thu Dec 17 2015). If you encounter any problem in accessing a resource, please write to us at support@thermofluids.net.*

*As an educator, you can now obtain a group license and distribute TEST accounts to your students, who can use TEST from anywhere, not just from within the campus. Please take a look at the key problems in the Problems module. If you assign some of those as homework (students, of course, cannot see the answers), TEST can monitor progress and generate homework report.*

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:



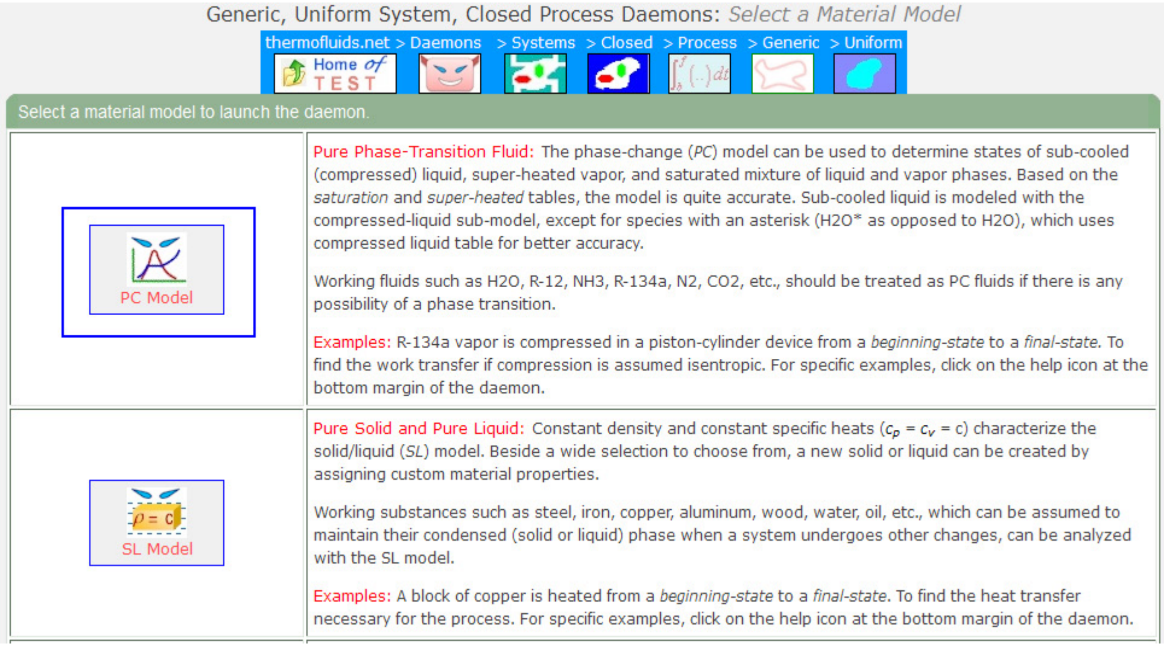
Hovering the mouse pointer over 'Uniform System' brings up the following explanatory pop up:


Click to go to page: TEST>Daemons>Systems>Closed>Process>Generic>Uniform Processes

***Uniform Processes:*** Analyze a closed process involving a system that can be described by two unique states, one at the beginning and one at the end of the process. Select a material model that best suits the working substance to launch the daemon.

Chapters 5 and 6 cover analysis of closed processes involving uniform systems.

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

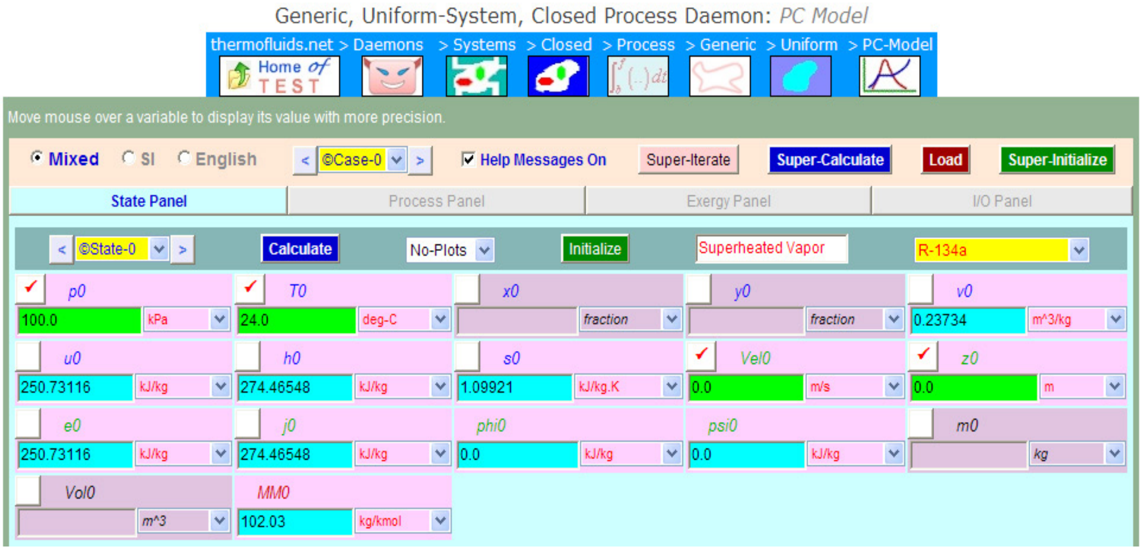


Generic, Uniform System, Closed Process Daemons: *Select a Material Model*

Select a material model to launch the daemon.

| | |
|---|---|
| PC Model | Pure Phase-Transition Fluid: The phase-change (*PC*) model can be used to determine states of sub-cooled (compressed) liquid, super-heated vapor, and saturated mixture of liquid and vapor phases. Based on the *saturation* and *super-heated* tables, the model is quite accurate. Sub-cooled liquid is modeled with the compressed-liquid sub-model, except for species with an asterisk (H2O* as opposed to H2O), which uses compressed liquid table for better accuracy.<br>Working fluids such as H2O, R-12, NH3, R-134a, N2, CO2, etc., should be treated as PC fluids if there is any possibility of a phase transition.<br>Examples: R-134a vapor is compressed in a piston-cylinder device from a *beginning-state* to a *final-state*. To find the work transfer if compression is assumed isentropic. For specific examples, click on the help icon at the bottom margin of the daemon. |
| SL Model | Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characterize the solid/liquid (*SL*) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.<br>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.<br>Examples: A block of copper is heated from a *beginning-state* to a *final-state*. To find the heat transfer necessary for the process. For specific examples, click on the help icon at the bottom margin of the daemon. |

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:



Generic, Uniform-System, Closed Process Daemon: *PC Model*

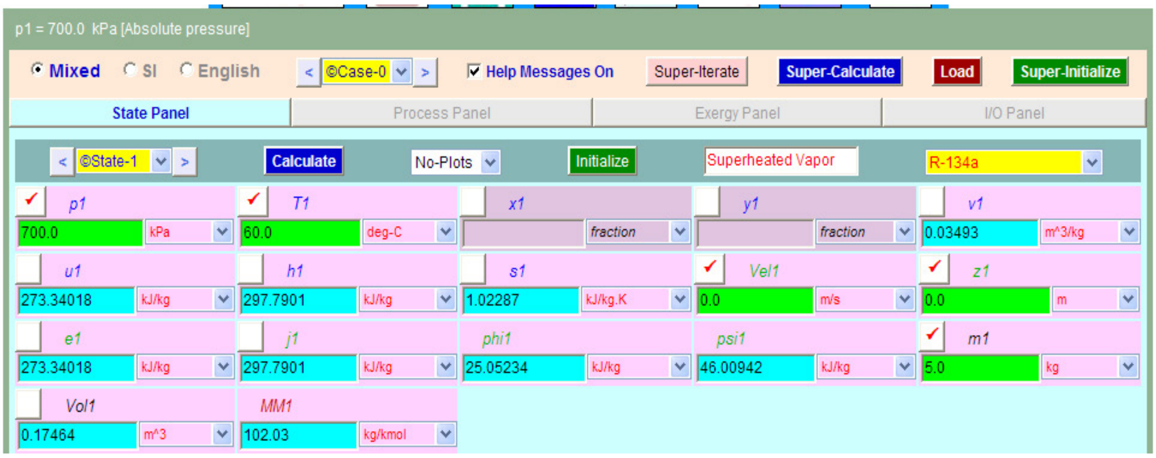
Move mouse over a variable to display its value with more precision.

Superheated Vapor

R-134a

☑ p0: 100.0 kPa
☑ T0: 24.0 deg-C
☐ x0: fraction
☐ y0: fraction
☐ v0: 0.23734 m^3/kg
☐ u0: 250.73116 kJ/kg
☐ h0: 274.46548 kJ/kg
☐ s0: 1.09921 kJ/kg.K
☑ Vel0: 0.0 m/s
☑ z0: 0.0 m
☐ e0: 250.73116 kJ/kg
☐ j0: 274.46548 kJ/kg
phi0: 0.0 kJ/kg
psi0: 0.0 kJ/kg
☐ m0: kg
☐ Vol0: m^3
MM0: 102.03 kg/kmol

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:

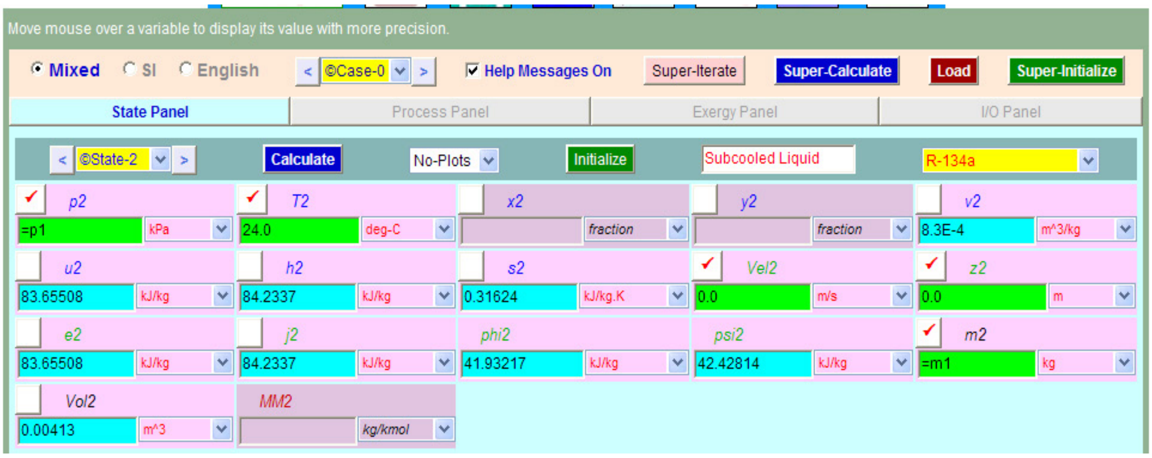


p1 = 700.0 kPa [Absolute pressure]

● Mixed ○ SI ○ English
©Case-0
☑ Help Messages On
©State-1
No-Plots
Superheated Vapor
R-134a

☑ p1 700.0 kPa
☑ T1 60.0 deg-C
☐ x1 fraction
☐ y1 fraction
☐ v1 0.03493 m^3/kg
☐ u1 273.34018 kJ/kg
☐ h1 297.7901 kJ/kg
☐ s1 1.02287 kJ/kg.K
☑ Vel1 0.0 m/s
☑ z1 0.0 m
☐ e1 273.34018 kJ/kg
☐ j1 297.7901 kJ/kg
phi1 25.05234 kJ/kg
psi1 46.00942 kJ/kg
☑ m1 5.0 kg
☐ Vol1 0.17464 m^3
MM1 102.03 kg/kmol

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:

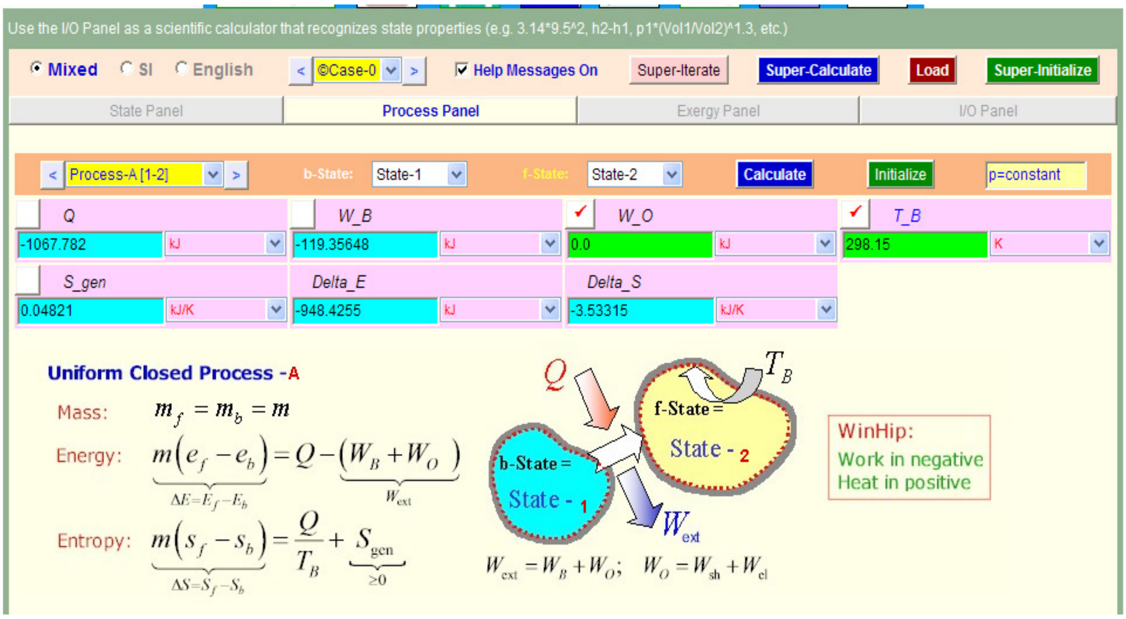


Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English
©Case-0
☑ Help Messages On
©State-2
No-Plots
Subcooled Liquid
R-134a

☑ p2 =p1 kPa
☑ T2 24.0 deg-C
☐ x2 fraction
☐ y2 fraction
☐ v2 8.3E-4 m^3/kg
☐ u2 83.65508 kJ/kg
☐ h2 84.2337 kJ/kg
☐ s2 0.31624 kJ/kg.K
☑ Vel2 0.0 m/s
☑ z2 0.0 m
☐ e2 83.65508 kJ/kg
☐ j2 84.2337 kJ/kg
phi2 41.93217 kJ/kg
psi2 42.42814 kJ/kg
☑ m2 =m1 kg
☐ Vol2 0.00413 m^3
MM2 kg/kmol

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:



Use the I/O Panel as a scientific calculator that recognizes state properties (e.g. 3.14*9.5^2, h2-h1, p1*(Vol1/Vol2)^1.3, etc.)

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

Process-A [1-2] | b-State: State-1 | f-State: State-2 | p=constant

| | | | |
|---|---|---|---|
| ☐ Q | ☐ W_B | ☑ W_O | ☑ T_B |
| -1067.782 kJ | -119.35648 kJ | 0.0 kJ | 298.15 K |
| ☐ S_gen | Delta_E | Delta_S | |
| 0.04821 kJ/K | -948.4255 kJ | -3.53315 kJ/K | |

**Uniform Closed Process -A**

Mass: $m_f = m_b = m$

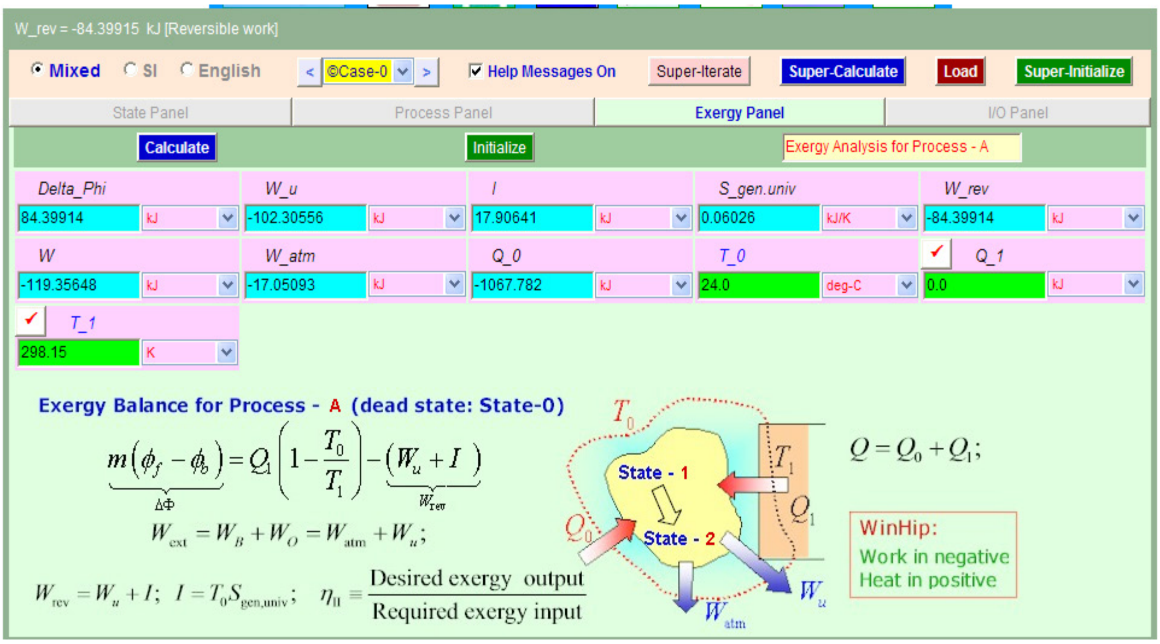
Energy: $\underbrace{m(e_f - e_b)}_{\Delta E = E_f - E_b} = Q - \underbrace{(W_B + W_O)}_{W_{\text{ext}}}$

Entropy: $\underbrace{m(s_f - s_b)}_{\Delta S = S_f - S_b} = \dfrac{Q}{T_B} + \underbrace{S_{\text{gen}}}_{\geq 0}$

$W_{\text{ext}} = W_B + W_O$; $W_O = W_{\text{sh}} + W_{\text{el}}$

WinHip:
Work in negative
Heat in positive

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



W_rev = -84.39915 kJ [Reversible work]

● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On

Exergy Analysis for Process - A

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
T_0: 24.0 deg-C
✓ Q_1: 0.0 kJ
✓ T_1: 298.15 K

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;

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

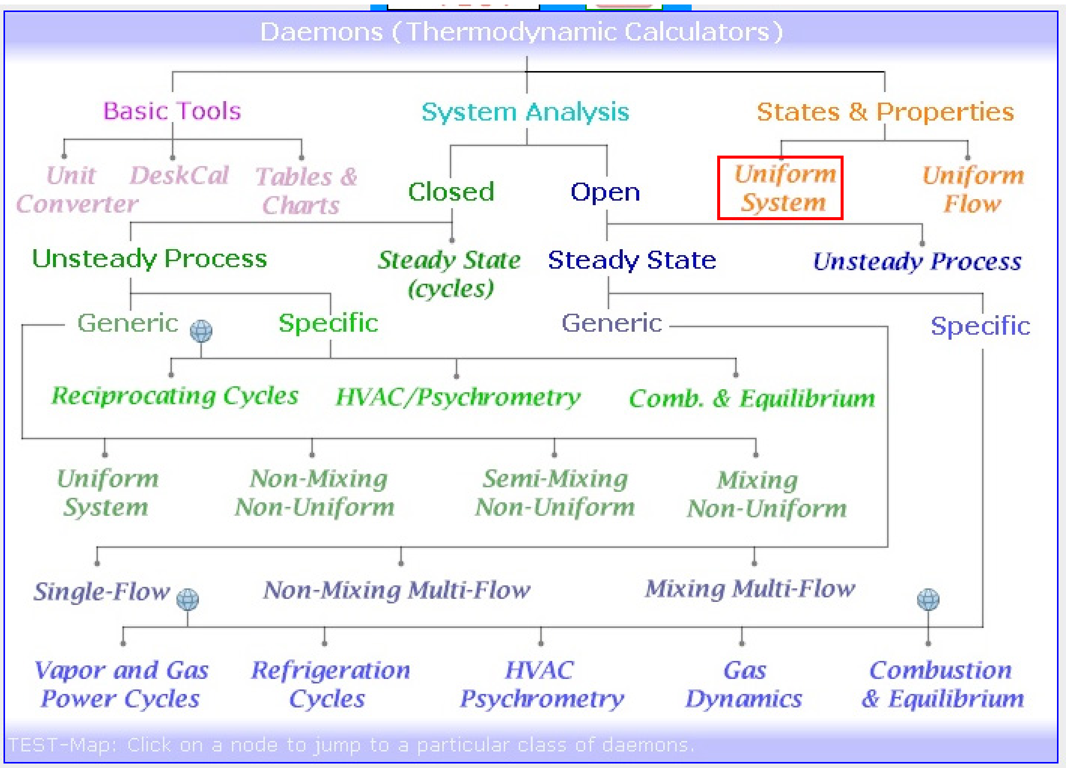
**Prob.8.17.** A rigid container with 200 L volume is divided in to two equal volumes by a partition. Both sides contain nitrogen, one side is at 2 MPa, 300 C, and the other at 1 MPa, 50 C. The partition ruptures, and the nitrogen comes to a uniform state at 100 C. Assuming the surroundings are at 25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

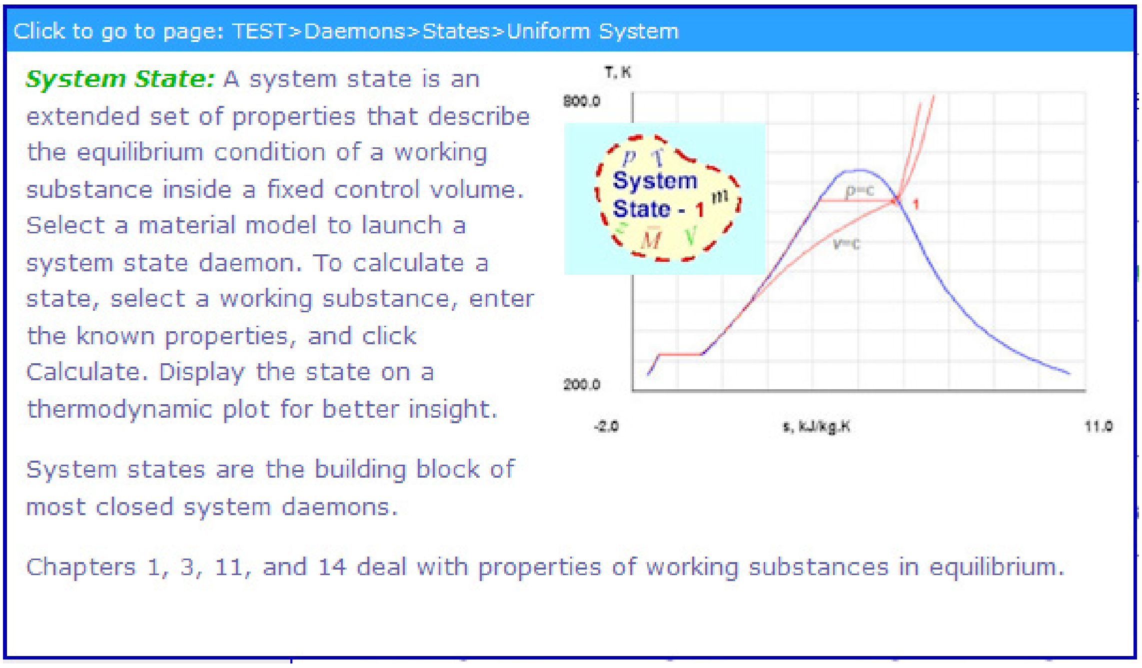
**Following are the steps:**

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



TEST-Map: Click on a node to jump to a particular class of daemons.

Hovering the mouse pointer on Uniform system brings up:



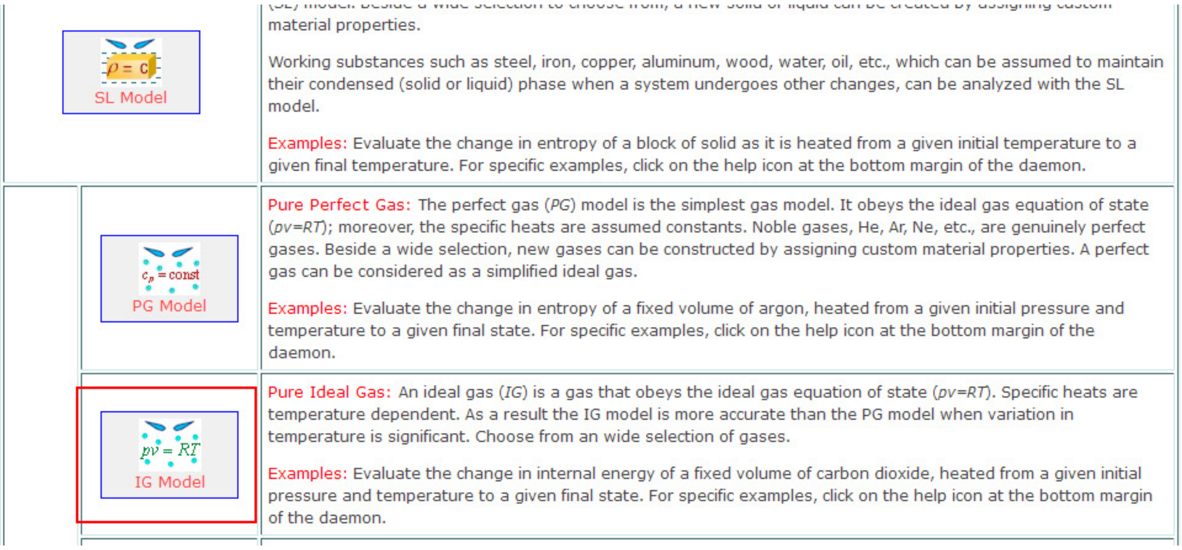
Click to go to page: TEST>Daemons>States>Uniform System

**System State:** A system state is an extended set of properties that describe the equilibrium condition of a working substance inside a fixed control volume. Select a material model to launch a system state daemon. To calculate a state, select a working substance, enter the known properties, and click Calculate. Display the state on a thermodynamic plot for better insight.

System states are the building block of most closed system daemons.

Chapters 1, 3, 11, and 14 deal with properties of working substances in equilibrium.

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



material properties.

Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.

Examples: Evaluate the change in entropy of a block of solid as it is heated from a given initial temperature to a given final temperature. For specific examples, click on the help icon at the bottom margin of the daemon.

Pure Perfect Gas: The perfect gas (*PG*) model is the simplest gas model. It obeys the ideal gas equation of state (*pv=RT*); moreover, the specific heats are assumed constants. Noble gases, He, Ar, Ne, etc., are genuinely perfect gases. Beside a wide selection, new gases can be constructed by assigning custom material properties. A perfect gas can be considered as a simplified ideal gas.

Examples: Evaluate the change in entropy of a fixed volume of argon, heated from a given initial pressure and temperature to a given final state. For specific examples, click on the help icon at the bottom margin of the daemon.

Pure Ideal Gas: An ideal gas (*IG*) is a gas that obeys the ideal gas equation of state (*pv=RT*). Specific heats are temperature dependent. As a result the IG model is more accurate than the PG model when variation in temperature is significant. Choose from an wide selection of gases.

Examples: Evaluate the change in internal energy of a fixed volume of carbon dioxide, heated from a given initial pressure and temperature to a given final state. For specific examples, click on the help icon at the bottom margin of the daemon.

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

Move mouse over a variable to display its value with more precision.

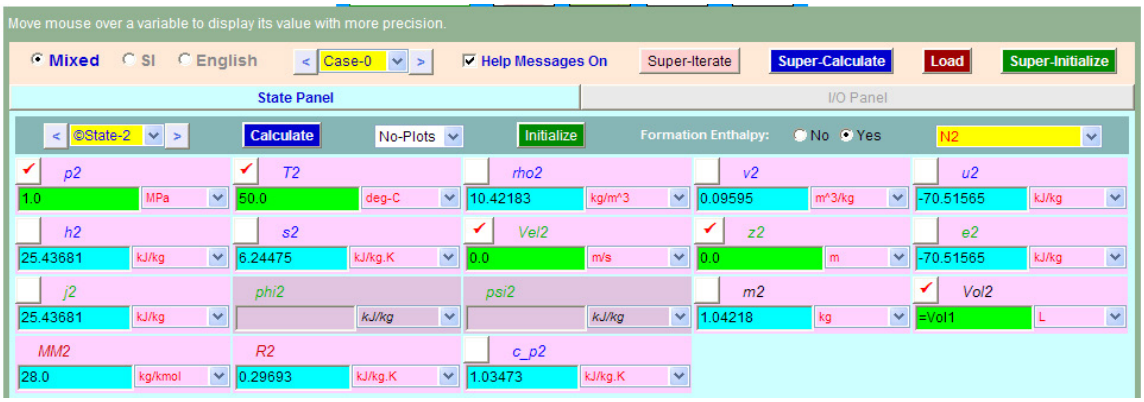
● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On

State-1 | No-Plots | Formation Enthalpy: ○ No ● Yes | N2

| | | | | |
|---|---|---|---|---|
| ☑ p1<br>2.0 MPa | ☑ T1<br>300.0 deg-C | ☐ rho1<br>11.75194 kg/m^3 | ☐ v1<br>0.08509 m^3/kg | ☐ u1<br>119.74717 kJ/kg |
| ☐ h1<br>289.9318 kJ/kg | ☐ s1<br>6.64387 kJ/kg.K | ☑ Vel1<br>0.0 m/s | ☑ z1<br>0.0 m | ☐ e1<br>119.74717 kJ/kg |
| ☐ j1<br>289.9318 kJ/kg | phi1<br>kJ/kg | psi1<br>kJ/kg | ☐ m1<br>1.17519 kg | ☑ Vol1<br>100.0 L |
| MM1<br>28.0 kg/kmol | R1<br>0.29693 kJ/kg.K | ☐ c_p1<br>1.08281 kJ/kg.K | | |

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:



Move mouse over a variable to display its value with more precision.

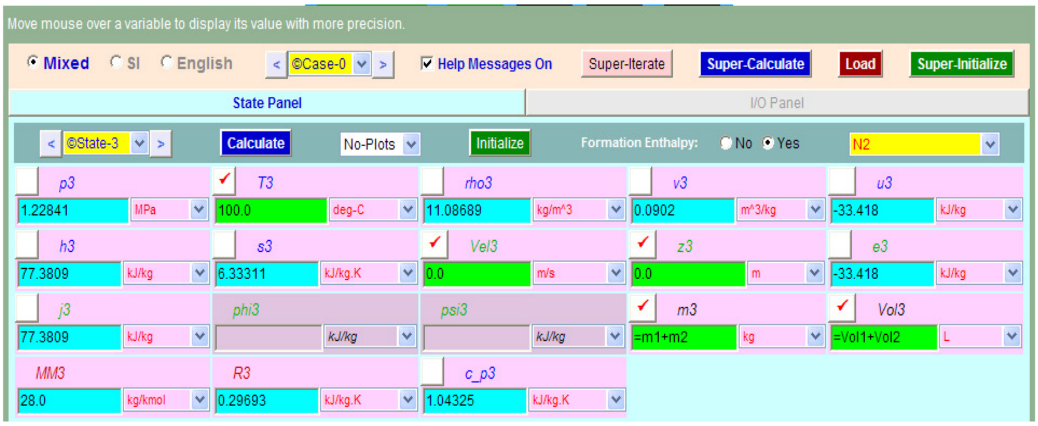
● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On

State-2 | No-Plots | Formation Enthalpy: ○ No ● Yes | N2

| | | | | |
|---|---|---|---|---|
| ☑ p2<br>1.0 MPa | ☑ T2<br>50.0 deg-C | ☐ rho2<br>10.42183 kg/m^3 | ☐ v2<br>0.09595 m^3/kg | ☐ u2<br>-70.51565 kJ/kg |
| ☐ h2<br>25.43681 kJ/kg | ☐ s2<br>6.24475 kJ/kg.K | ☑ Vel2<br>0.0 m/s | ☑ z2<br>0.0 m | ☐ e2<br>-70.51565 kJ/kg |
| ☐ j2<br>25.43681 kJ/kg | phi2<br>kJ/kg | psi2<br>kJ/kg | ☐ m2<br>1.04218 kg | ☑ Vol2<br>=Vol1 L |
| MM2<br>28.0 kg/kmol | R2<br>0.29693 kJ/kg.K | ☐ c_p2<br>1.03473 kJ/kg.K | | |

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:



| | | | | |
|---|---|---|---|---|
| ☐ p3<br>1.22841 MPa | ✓ T3<br>100.0 deg-C | ☐ rho3<br>11.08689 kg/m^3 | ☐ v3<br>0.0902 m^3/kg | ☐ u3<br>-33.418 kJ/kg |
| ☐ h3<br>77.3809 kJ/kg | ☐ s3<br>6.33311 kJ/kg.K | ✓ Vel3<br>0.0 m/s | ✓ z3<br>0.0 m | ☐ e3<br>-33.418 kJ/kg |
| ☐ j3<br>77.3809 kJ/kg | phi3<br>kJ/kg | psi3<br>kJ/kg | ✓ m3<br>=m1+m2 kg | ✓ Vol3<br>=Vol1+Vol2 L |
| MM3<br>28.0 kg/kmol | R3<br>0.29693 kJ/kg.K | ☐ c_p3<br>1.04325 kJ/kg.K | | |

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

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

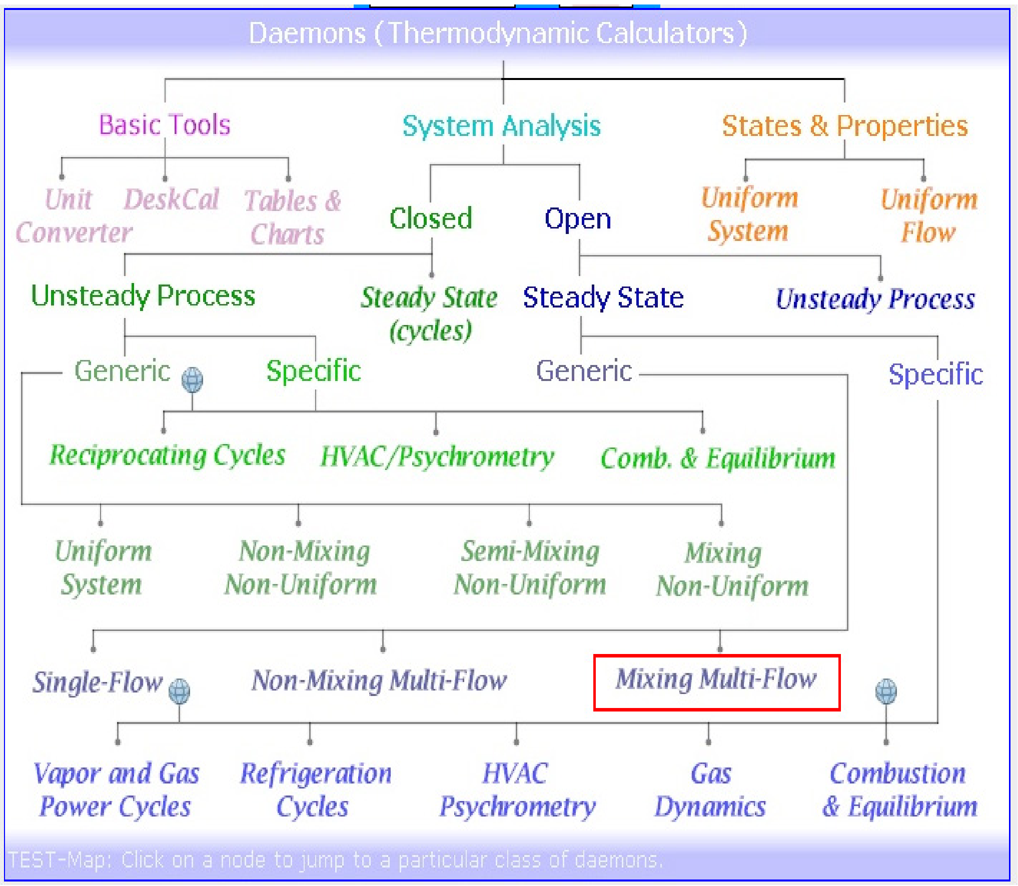
**Prob.8.18.** Two flows of air, both at 200 kPa, of equal flow rates mix in an insulated mixing chamber. One flow is at 1500 K, and the other at 300 K. Find the Irreversibility in the process per kg of air flowing out. [Ref: 2]

**TEST Solution:**

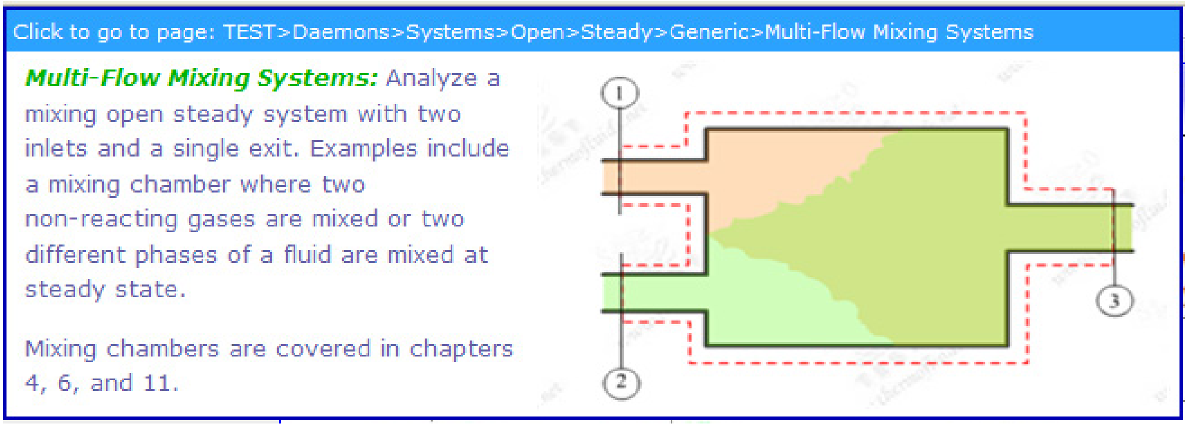
**We shall assume the two flow rates as 0.5 kg/s each.**

**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:

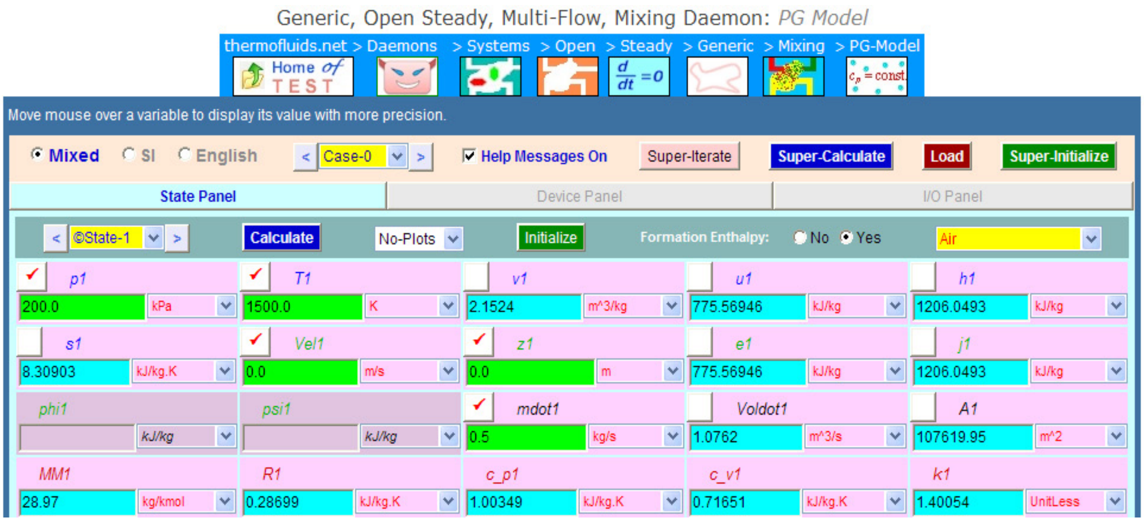


Click to go to page: TEST>Daemons>Systems>Open>Steady>Generic>Multi-Flow Mixing Systems

**Multi-Flow Mixing Systems:** Analyze a mixing open steady system with two inlets and a single exit. Examples include a mixing chamber where two non-reacting gases are mixed or two different phases of a fluid are mixed at steady state.

Mixing chambers are covered in chapters 4, 6, and 11.

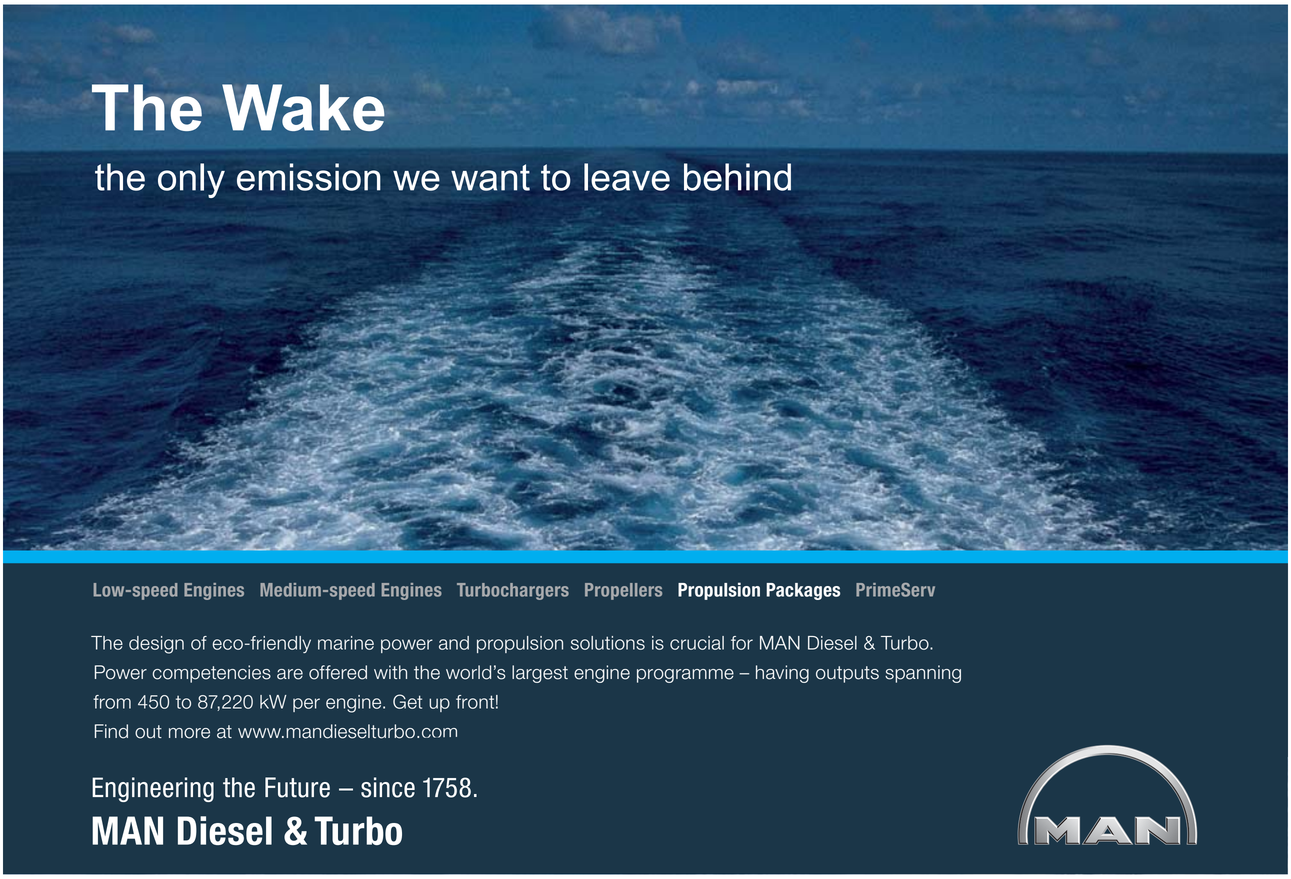
2. Choose PG model for material model, select Air as the substance, and enter p1, T1 and mdot1 for State 1. Hit Enter. We get:


Generic, Open Steady, Multi-Flow, Mixing Daemon: *PG Model*

Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English
Case-0
☑ Help Messages On
©State-1
No-Plots
Formation Enthalpy: ○ No ● Yes
Air

| | | | | |
|---|---|---|---|---|
| ✓ p1 | ✓ T1 | ☐ v1 | ☐ u1 | ☐ h1 |
| 200.0 kPa | 1500.0 K | 2.1524 m^3/kg | 775.56946 kJ/kg | 1206.0493 kJ/kg |
| ☐ s1 | ✓ Vel1 | ✓ z1 | ☐ e1 | ☐ j1 |
| 8.30903 kJ/kg.K | 0.0 m/s | 0.0 m | 775.56946 kJ/kg | 1206.0493 kJ/kg |
| phi1 | psi1 | ✓ mdot1 | ☐ Voldot1 | ☐ A1 |
| kJ/kg | kJ/kg | 0.5 kg/s | 1.0762 m^3/s | 107619.95 m^2 |
| MM1 | R1 | c_p1 | c_v1 | k1 |
| 28.97 kg/kmol | 0.28699 kJ/kg.K | 1.00349 kJ/kg.K | 0.71651 kJ/kg.K | 1.40054 UnitLess |



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

● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On

State-2 | No-Plots | Formation Enthalpy: ○ No ● Yes | Air

- ☑ p2: 200.0 kPa
- ☑ T2: 300.0 K
- ☐ v2: 0.43048 m^3/kg
- ☐ u2: -84.2395 kJ/kg
- ☐ h2: 1.85646 kJ/kg
- ☐ s2: 6.69397 kJ/kg.K
- ☑ Vel2: 0.0 m/s
- ☑ z2: 0.0 m
- ☐ e2: -84.2395 kJ/kg
- ☐ j2: 1.85646 kJ/kg
- phi2: kJ/kg
- psi2: kJ/kg
- ☑ mdot2: 0.5 kg/s
- ☐ Voldot2: 0.21524 m^3/s
- ☐ A2: 21523.99 m^2
- MM2: 28.97 kg/kmol
- R2: 0.28699 kJ/kg.K
- c_p2: 1.00349 kJ/kg.K
- c_v2: 0.71651 kJ/kg.K
- k2: 1.40054 UnitLess

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

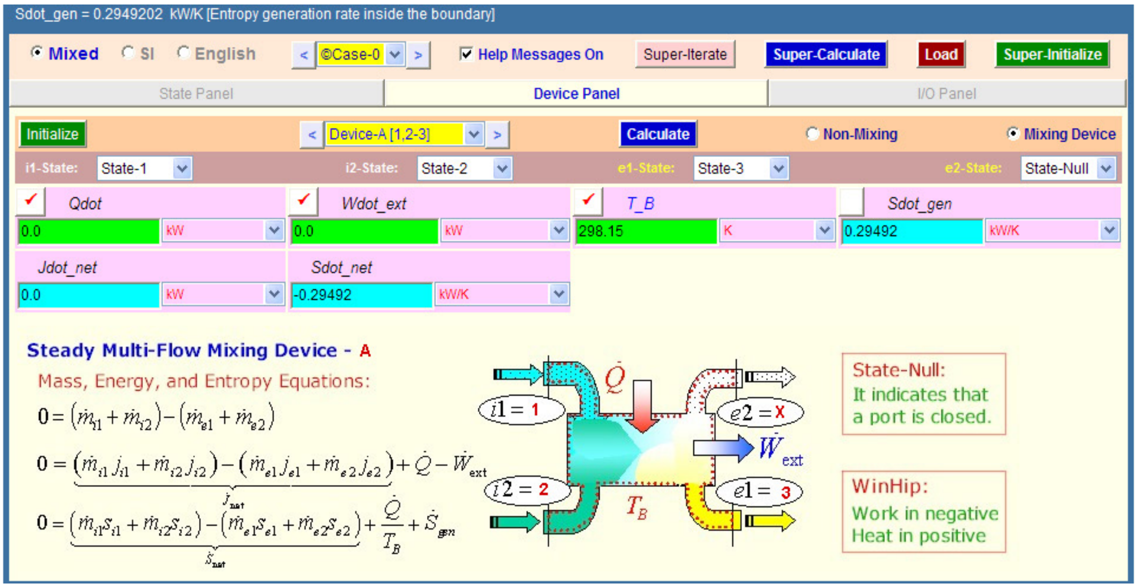
● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On

State-3 | No-Plots | Formation Enthalpy: ○ No ● Yes | Air

- ☑ p3: 200.0 kPa
- ☐ T3: 900.0 K
- ☐ v3: 1.29144 m^3/kg
- ☐ u3: 345.66498 kJ/kg
- ☑ h3: =(m1*h1+m2*h2 kJ/kg
- ☐ s3: 7.79642 kJ/kg.K
- ☑ Vel3: 0.0 m/s
- ☑ z3: 0.0 m
- ☐ e3: 345.66498 kJ/kg
- ☐ j3: 603.9529 kJ/kg
- phi3: kJ/kg
- psi3: kJ/kg
- ☑ mdot3: =mdot1+mdot2 kg/s
- ☐ Voldot3: 1.29144 m^3/s
- ☐ A3: 129143.945 m^2
- MM3: 28.97 kg/kmol
- R3: 0.28699 kJ/kg.K
- c_p3: 1.00349 kJ/kg.K
- c_v3: 0.71651 kJ/kg.K
- k3: 1.40054 UnitLess

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:


Sdot_gen = 0.2949202 kW/K [Entropy generation rate inside the boundary]

● Mixed ○ SI ○ English

©Case-0

☑ Help Messages On

Device-A [1,2-3]

○ Non-Mixing ● Mixing Device

i1-State: State-1

i2-State: State-2

e1-State: State-3

e2-State: State-Null

✓ Qdot: 0.0 kW

✓ Wdot_ext: 0.0 kW

✓ T_B: 298.15 K

☐ Sdot_gen: 0.29492 kW/K

Jdot_net: 0.0 kW

Sdot_net: -0.29492 kW/K

Steady Multi-Flow Mixing Device - A

Mass, Energy, and Entropy Equations:

$$0=(\dot{m}_{i1}+\dot{m}_{i2})-(\dot{m}_{e1}+\dot{m}_{e2})$$

$$0=\underbrace{(\dot{m}_{i1}j_{i1}+\dot{m}_{i2}j_{i2})-(\dot{m}_{e1}j_{e1}+\dot{m}_{e2}j_{e2})}_{\dot{J}_{net}}+\dot{Q}-\dot{W}_{ext}$$

$$0=\underbrace{(\dot{m}_{i1}s_{i1}+\dot{m}_{i2}s_{i2})-(\dot{m}_{e1}s_{e1}+\dot{m}_{e2}s_{e2})}_{\dot{S}_{net}}+\frac{\dot{Q}}{T_B}+\dot{S}_{gen}$$

State-Null:
It indicates that a port is closed.

WinHip:
Work in negative
Heat in positive

**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;
```

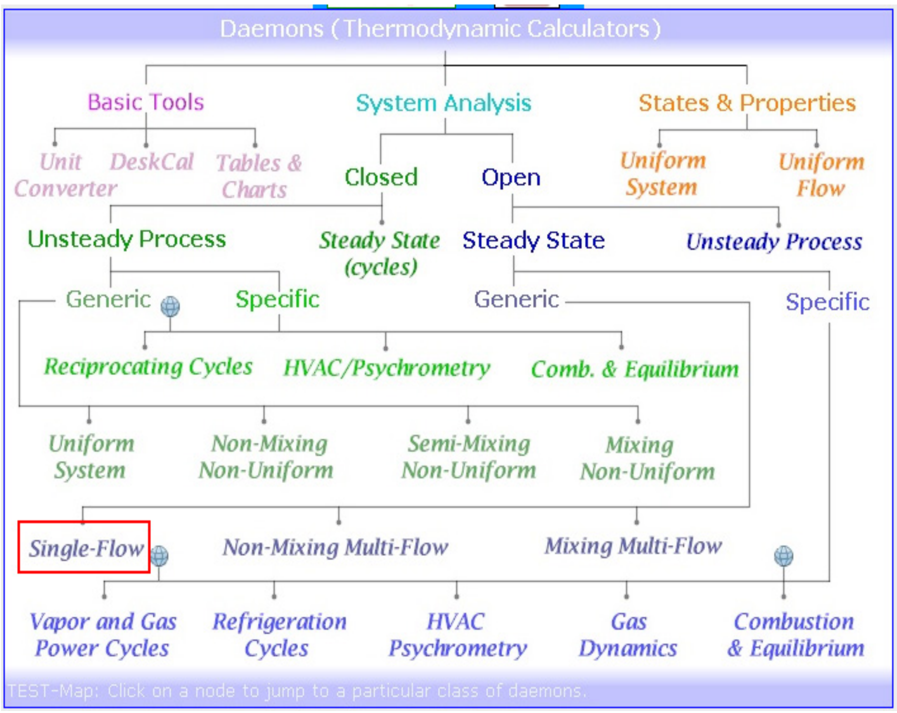
```
#--------Property spreadsheet starts: #

#    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]

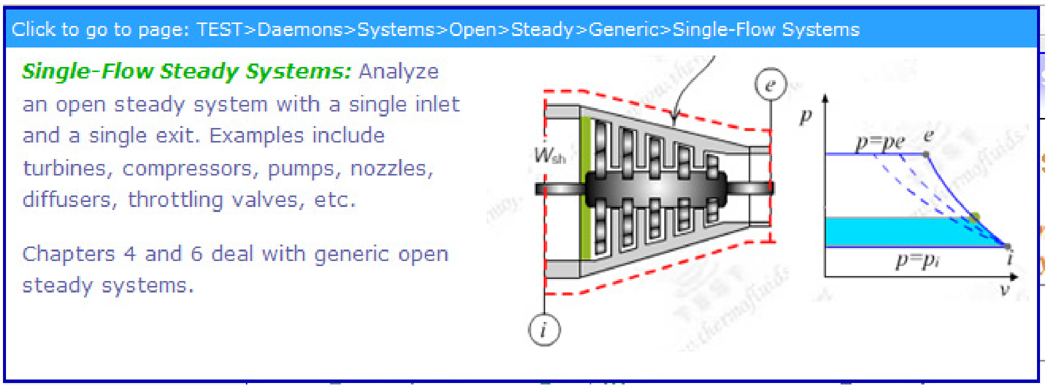
**TEST Solution:**

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:

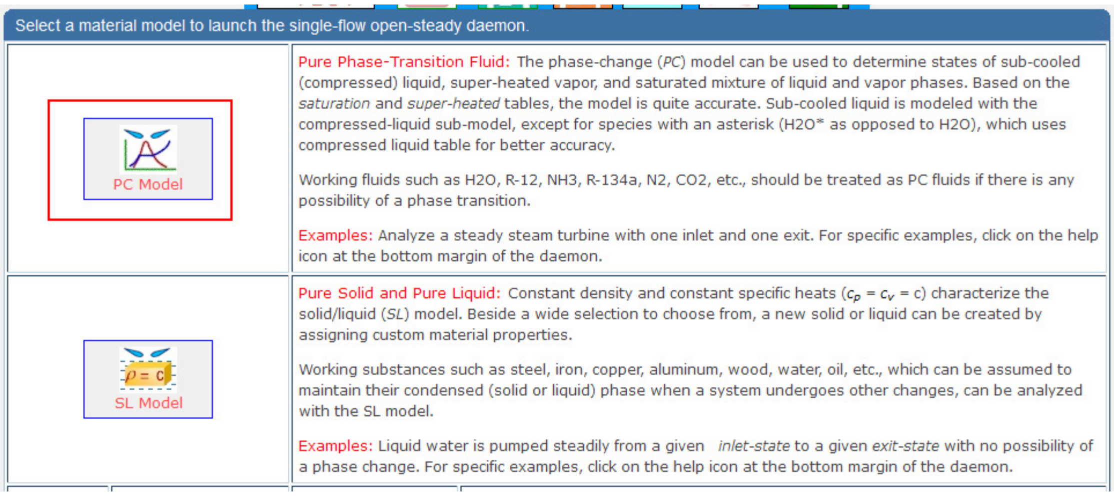


Click to go to page: TEST>Daemons>Systems>Open>Steady>Generic>Single-Flow Systems

***Single-Flow Steady Systems:*** Analyze an open steady system with a single inlet and a single exit. Examples include turbines, compressors, pumps, nozzles, diffusers, throttling valves, etc.

Chapters 4 and 6 deal with generic open steady systems.

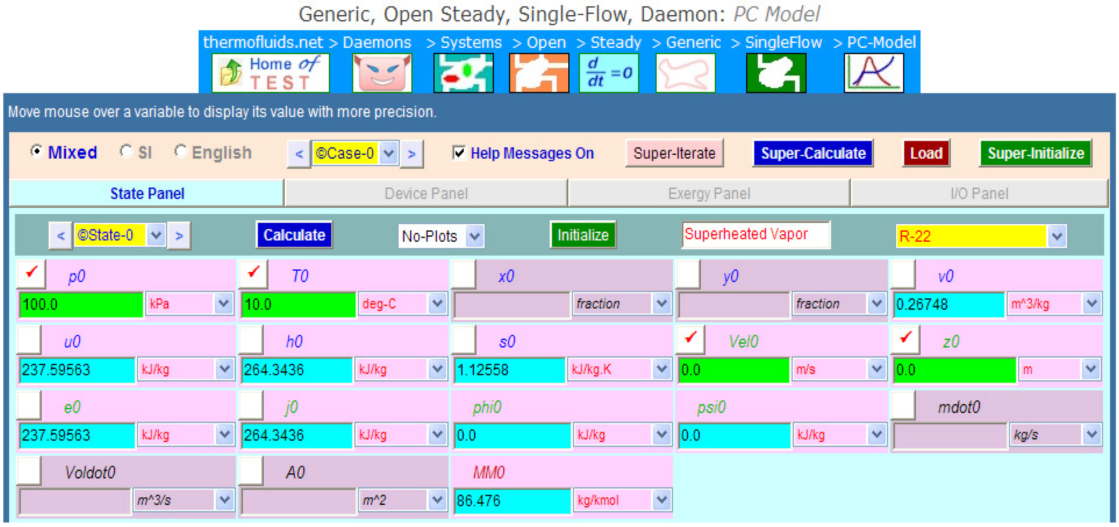
2. Choose PC model for material model:



Select a material model to launch the single-flow open-steady daemon.

| | |
|---|---|
| PC Model | Pure Phase-Transition Fluid: The phase-change (*PC*) model can be used to determine states of sub-cooled (compressed) liquid, super-heated vapor, and saturated mixture of liquid and vapor phases. Based on the *saturation* and *super-heated* tables, the model is quite accurate. Sub-cooled liquid is modeled with the compressed-liquid sub-model, except for species with an asterisk (H2O* as opposed to H2O), which uses compressed liquid table for better accuracy.<br>Working fluids such as H2O, R-12, NH3, R-134a, N2, CO2, etc., should be treated as PC fluids if there is any possibility of a phase transition.<br>Examples: Analyze a steady steam turbine with one inlet and one exit. For specific examples, click on the help icon at the bottom margin of the daemon. |
| SL Model | Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characterize the solid/liquid (*SL*) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.<br>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.<br>Examples: Liquid water is pumped steadily from a given *inlet-state* to a given *exit-state* with no possibility of a phase change. For specific examples, click on the help icon at the bottom margin of the daemon. |

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:



Generic, Open Steady, Single-Flow, Daemon: *PC Model*

thermofluids.net > Daemons > Systems > Open > Steady > Generic > SingleFlow > PC-Model

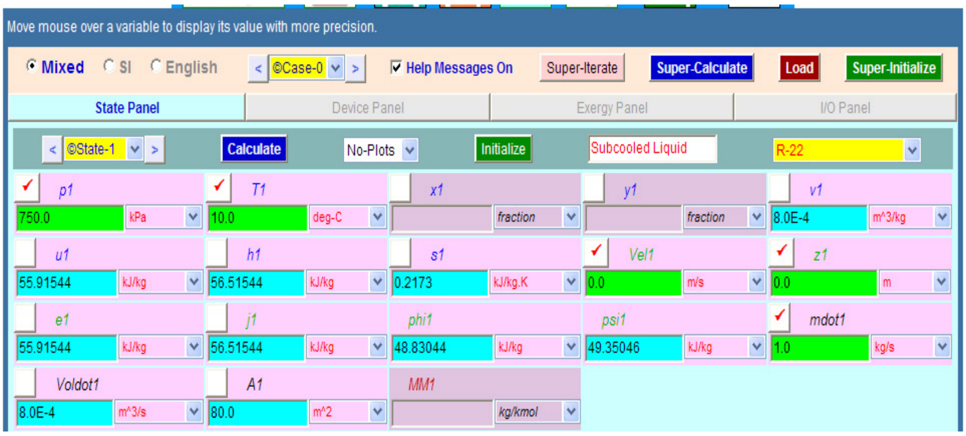
Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

State Panel | ©State-0 | No-Plots | Superheated Vapor | R-22

| | | | | |
|---|---|---|---|---|
| ☑ p0<br>100.0 kPa | ☑ T0<br>10.0 deg-C | ☐ x0<br>fraction | ☐ y0<br>fraction | ☐ v0<br>0.26748 m^3/kg |
| ☐ u0<br>237.59563 kJ/kg | ☐ h0<br>264.3436 kJ/kg | ☐ s0<br>1.12558 kJ/kg.K | ☑ Vel0<br>0.0 m/s | ☑ z0<br>0.0 m |
| ☐ e0<br>237.59563 kJ/kg | ☐ j0<br>264.3436 kJ/kg | phi0<br>0.0 kJ/kg | psi0<br>0.0 kJ/kg | ☐ mdot0<br>kg/s |
| ☐ Voldot0<br>m^3/s | ☐ A0<br>m^2 | MM0<br>86.476 kg/kmol | | |

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



● Mixed ○ SI ○ English

©Case-0

☑ Help Messages On

©State-1

No-Plots

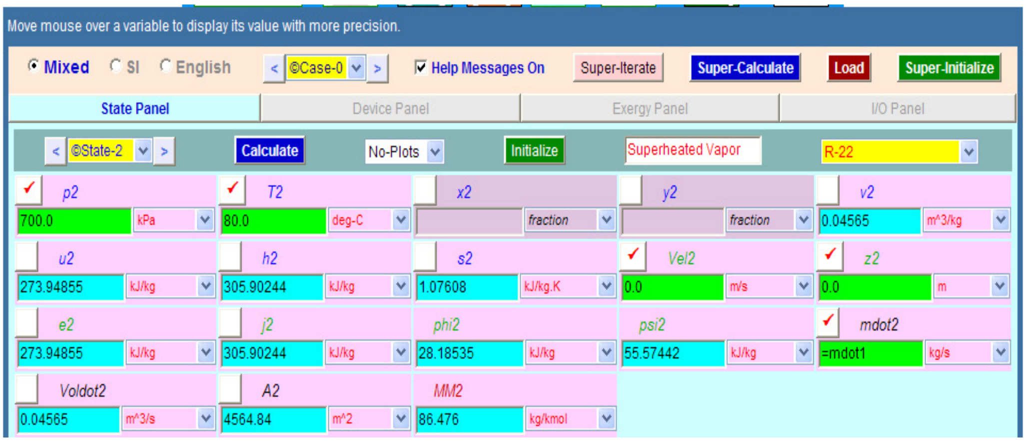
Subcooled Liquid

R-22

☑ p1 750.0 kPa
☑ T1 10.0 deg-C
☐ x1 fraction
☐ y1 fraction
☐ v1 8.0E-4 m^3/kg
☐ u1 55.91544 kJ/kg
☐ h1 56.51544 kJ/kg
☐ s1 0.2173 kJ/kg.K
☑ Vel1 0.0 m/s
☑ z1 0.0 m
☐ e1 55.91544 kJ/kg
☐ j1 56.51544 kJ/kg
phi1 48.83044 kJ/kg
psi1 49.35046 kJ/kg
☑ mdot1 1.0 kg/s
☐ Voldot1 8.0E-4 m^3/s
☐ A1 80.0 m^2
MM1 kg/kmol

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:



● Mixed ○ SI ○ English

©Case-0

☑ Help Messages On

©State-2

No-Plots

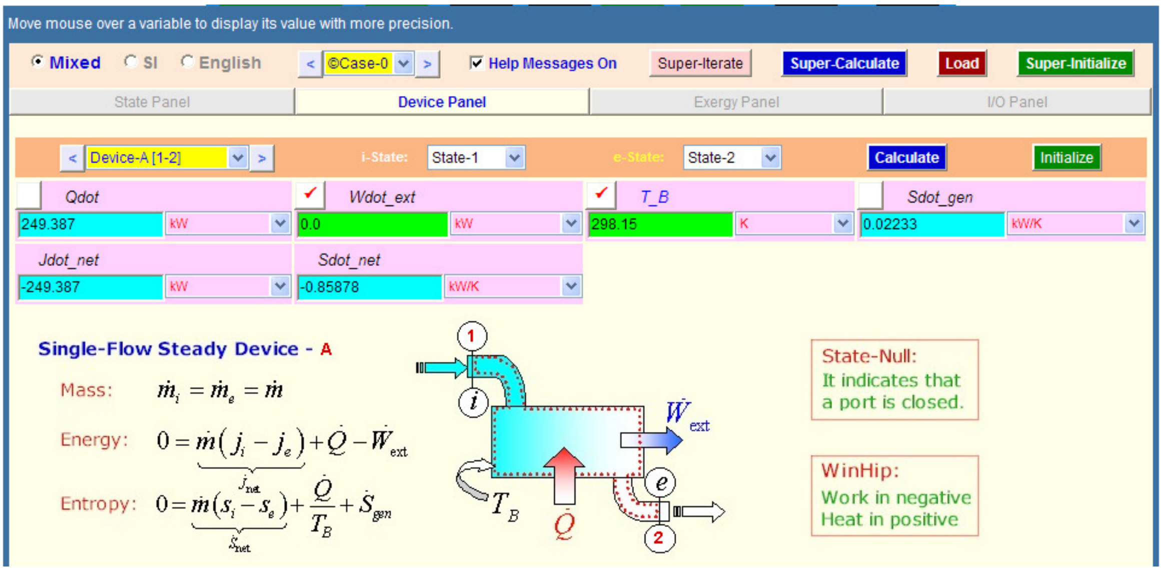
Superheated Vapor

R-22

☑ p2 700.0 kPa
☑ T2 80.0 deg-C
☐ x2 fraction
☐ y2 fraction
☐ v2 0.04565 m^3/kg
☐ u2 273.94855 kJ/kg
☐ h2 305.90244 kJ/kg
☐ s2 1.07608 kJ/kg.K
☑ Vel2 0.0 m/s
☑ z2 0.0 m
☐ e2 273.94855 kJ/kg
☐ j2 305.90244 kJ/kg
phi2 28.18535 kJ/kg
psi2 55.57442 kJ/kg
☑ mdot2 =mdot1 kg/s
☐ Voldot2 0.04565 m^3/s
☐ A2 4564.84 m^2
MM2 86.476 kg/kmol

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:



Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

Device-A [1-2] | i-State: State-1 | e-State: State-2

Qdot: 249.387 kW
Wdot_ext: 0.0 kW
T_B: 298.15 K
Sdot_gen: 0.02233 kW/K
Jdot_net: -249.387 kW
Sdot_net: -0.85878 kW/K

**Single-Flow Steady Device - A**

Mass: $\dot{m}_i = \dot{m}_e = \dot{m}$

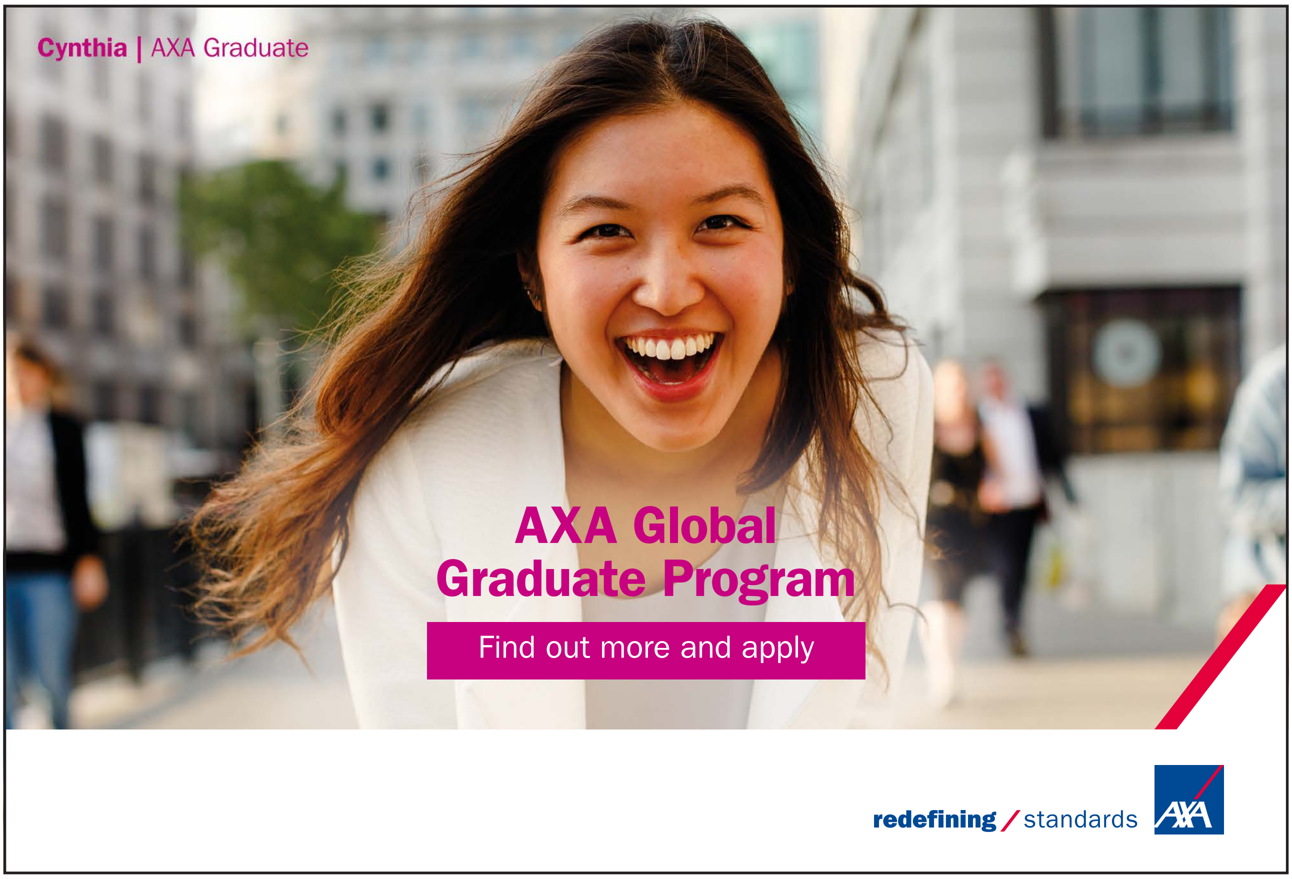
Energy: $0 = \underbrace{\dot{m}(j_i - j_e)}_{\dot{J}_{net}} + \dot{Q} - \dot{W}_{ext}$

Entropy: $0 = \underbrace{\dot{m}(s_i - s_e)}_{\dot{S}_{net}} + \frac{\dot{Q}}{T_B} + \dot{S}_{gen}$

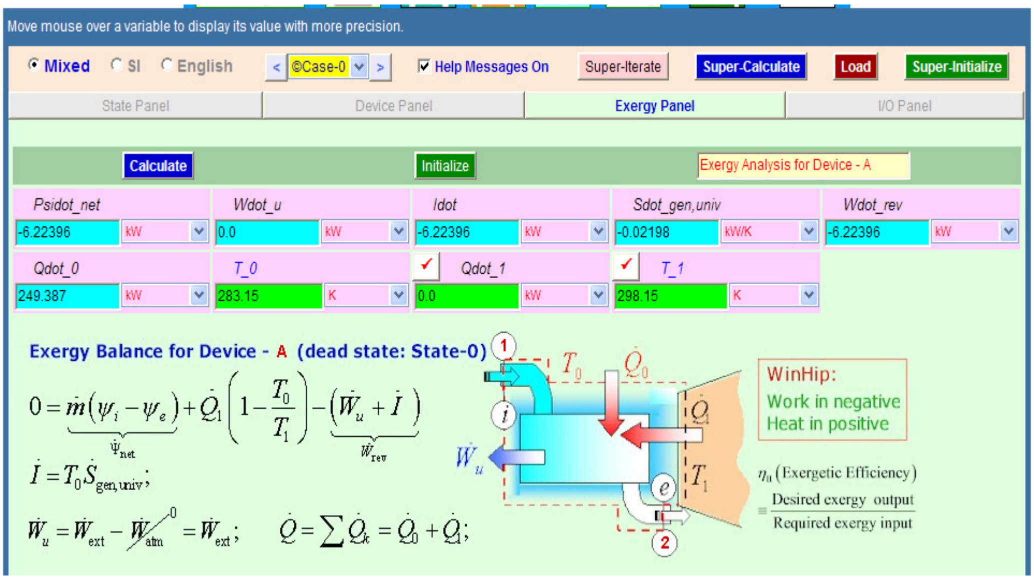
State-Null: It indicates that a port is closed.

WinHip: Work in negative Heat in positive

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.



● Mixed ○ SI ○ English

☑ Help Messages On

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

T_0: 283.15 K

✓ Qdot_1: 0.0 kW

✓ T_1: 298.15 K

Exergy Balance for Device - A (dead state: State-0)

$$0=\underbrace{\dot{m}(\psi_i-\psi_e)}_{\dot{\Psi}_{\text{net}}}+\dot{Q}_1\left(1-\frac{T_0}{T_1}\right)-\underbrace{(\dot{W}_u+\dot{I})}_{\dot{W}_{\text{rev}}}$$

$$\dot{I}=T_0\dot{S}_{\text{gen,univ}};$$

$$\dot{W}_u=\dot{W}_{\text{ext}}-\cancel{\dot{W}_{\text{atm}}}^{0}=\dot{W}_{\text{ext}};\qquad \dot{Q}=\sum\dot{Q}_k=\dot{Q}_0+\dot{Q}_1;$$

$$\eta_{II}\,(\text{Exergetic Efficiency})\equiv\frac{\text{Desired exergy output}}{\text{Required exergy input}}$$

$T_0$ $\dot{Q}_0$ $\dot{Q}_1$ $T_1$ $\dot{W}_u$

**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; }

          }
```

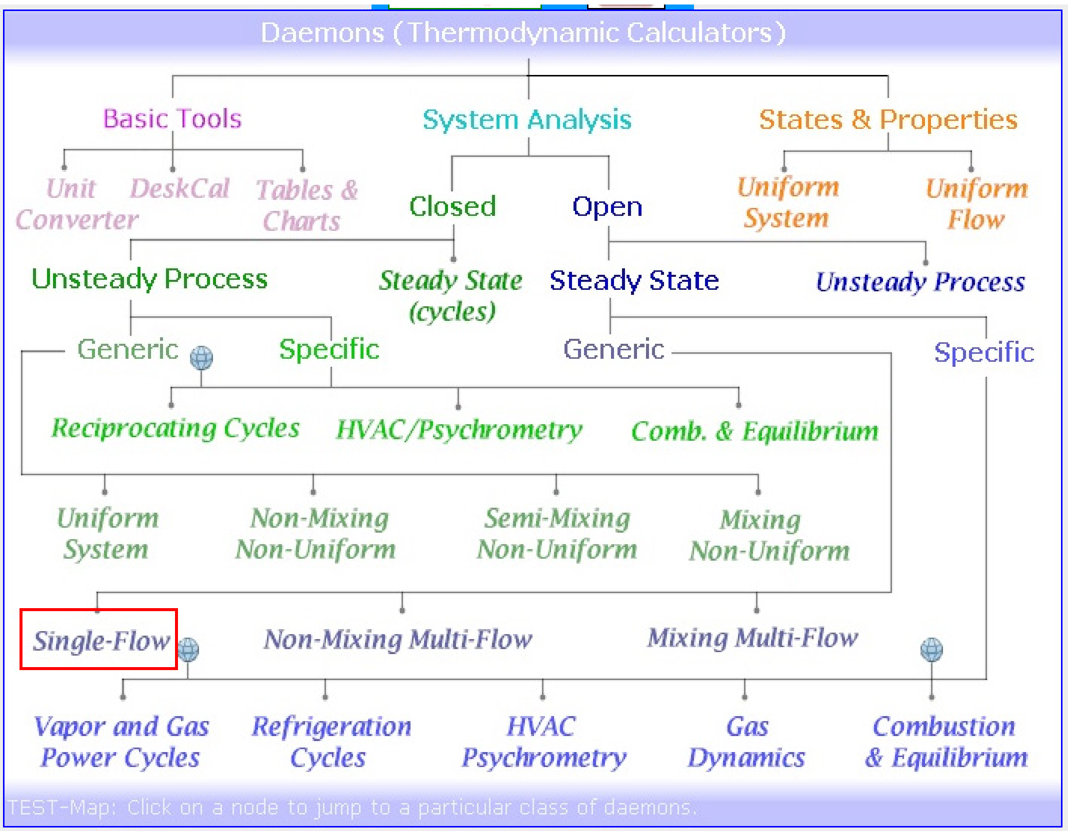
```
Analysis {

        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]

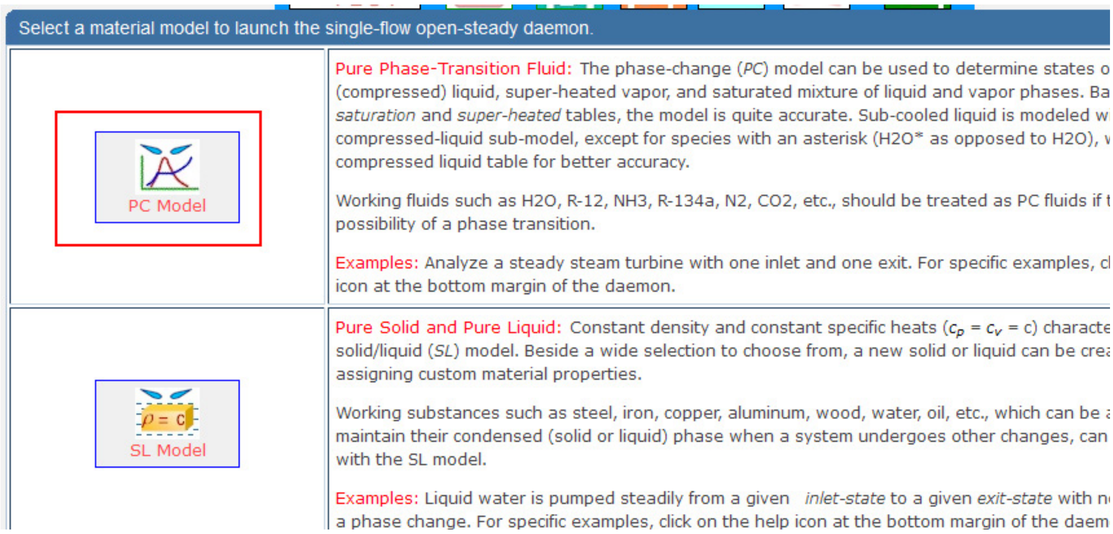
**TEST Solution:**

Following are the steps:

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



2. Choose PC model for material model:



Select a material model to launch the single-flow open-steady daemon.

Pure Phase-Transition Fluid: The phase-change (*PC*) model can be used to determine states o (compressed) liquid, super-heated vapor, and saturated mixture of liquid and vapor phases. Ba *saturation* and *super-heated* tables, the model is quite accurate. Sub-cooled liquid is modeled w compressed-liquid sub-model, except for species with an asterisk (H2O* as opposed to H2O), w compressed liquid table for better accuracy.

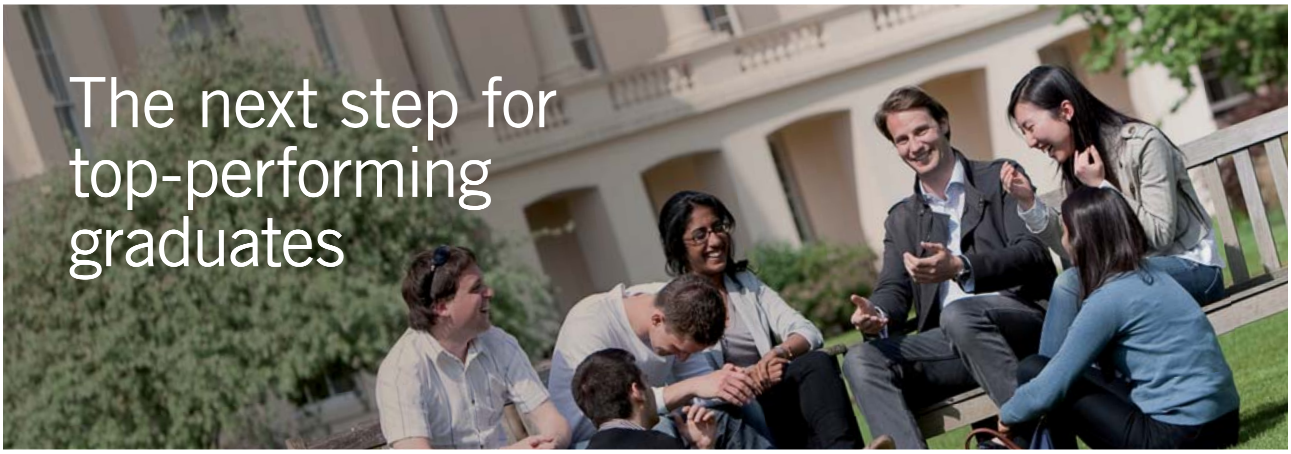
Working fluids such as H2O, R-12, NH3, R-134a, N2, CO2, etc., should be treated as PC fluids if t possibility of a phase transition.

Examples: Analyze a steady steam turbine with one inlet and one exit. For specific examples, cl icon at the bottom margin of the daemon.

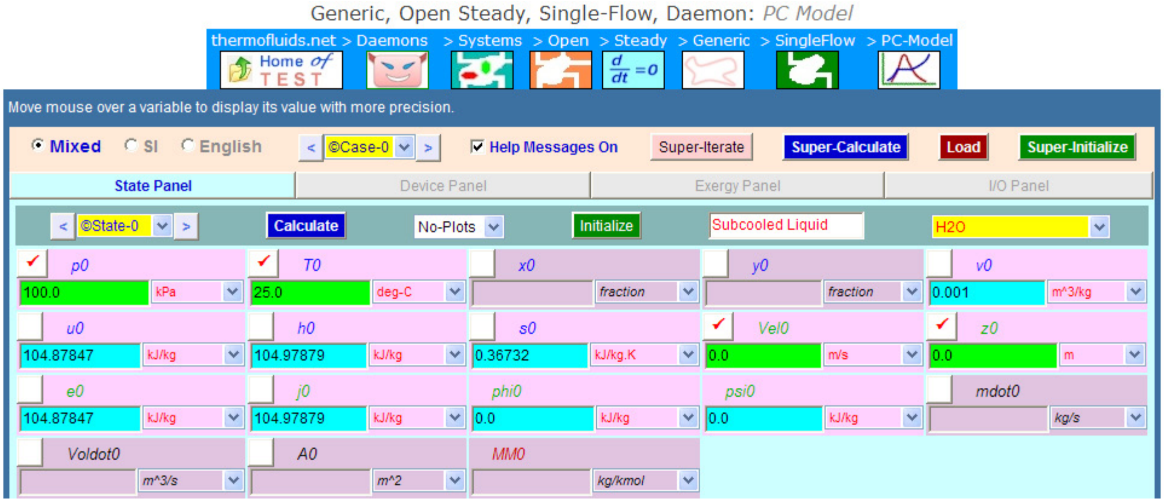
Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characte solid/liquid (*SL*) model. Beside a wide selection to choose from, a new solid or liquid can be crea assigning custom material properties.

Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be a maintain their condensed (solid or liquid) phase when a system undergoes other changes, can with the SL model.

Examples: Liquid water is pumped steadily from a given *inlet-state* to a given *exit-state* with n a phase change. For specific examples, click on the help icon at the bottom margin of the daem



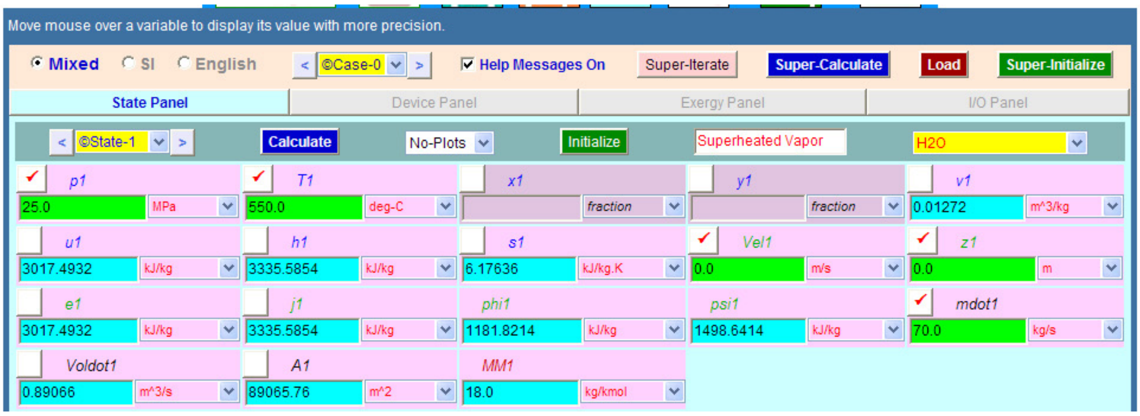
3. And, select H2O for substance, enter for State – '0' values of p0, T0 (for exergy calculations). Hit Enter:



● Mixed ○ SI ○ English
Case-0
☑ Help Messages On
State-0
No-Plots
Subcooled Liquid
H2O

p0 = 100.0 kPa
T0 = 25.0 deg-C
x0 = fraction
y0 = fraction
v0 = 0.001 m^3/kg
u0 = 104.87847 kJ/kg
h0 = 104.97879 kJ/kg
s0 = 0.36732 kJ/kg.K
Vel0 = 0.0 m/s
z0 = 0.0 m
e0 = 104.87847 kJ/kg
j0 = 104.97879 kJ/kg
phi0 = 0.0 kJ/kg
psi0 = 0.0 kJ/kg
mdot0 = kg/s
Voldot0 = m^3/s
A0 = m^2
MM0 = kg/kmol

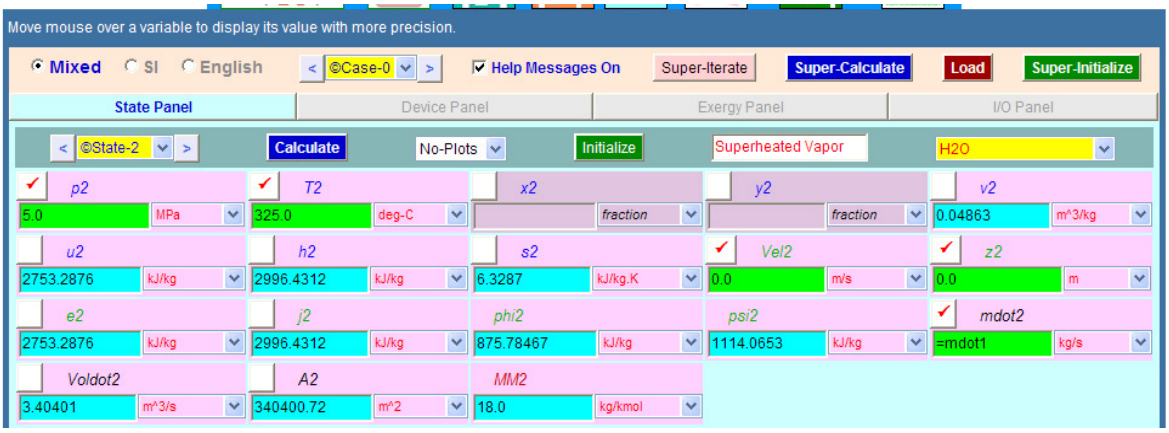
4. Enter p1, T1 and mdot1 for State 1, hit Enter. We get:



● Mixed ○ SI ○ English
Case-0
☑ Help Messages On
State-1
No-Plots
Superheated Vapor
H2O

p1 = 25.0 MPa
T1 = 550.0 deg-C
x1 = fraction
y1 = fraction
v1 = 0.01272 m^3/kg
u1 = 3017.4932 kJ/kg
h1 = 3335.5854 kJ/kg
s1 = 6.17636 kJ/kg.K
Vel1 = 0.0 m/s
z1 = 0.0 m
e1 = 3017.4932 kJ/kg
j1 = 3335.5854 kJ/kg
phi1 = 1181.8214 kJ/kg
psi1 = 1498.6414 kJ/kg
mdot1 = 70.0 kg/s
Voldot1 = 0.89066 m^3/s
A1 = 89065.76 m^2
MM1 = 18.0 kg/kmol

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



● Mixed ○ SI ○ English
Case-0
☑ Help Messages On
State-2
No-Plots
Superheated Vapor
H2O

p2 = 5.0 MPa
T2 = 325.0 deg-C
x2 = fraction
y2 = fraction
v2 = 0.04863 m^3/kg
u2 = 2753.2876 kJ/kg
h2 = 2996.4312 kJ/kg
s2 = 6.3287 kJ/kg.K
Vel2 = 0.0 m/s
z2 = 0.0 m
e2 = 2753.2876 kJ/kg
j2 = 2996.4312 kJ/kg
phi2 = 875.78467 kJ/kg
psi2 = 1114.0653 kJ/kg
mdot2 = =mdot1 kg/s
Voldot2 = 3.40401 m^3/s
A2 = 340400.72 m^2
MM2 = 18.0 kg/kmol

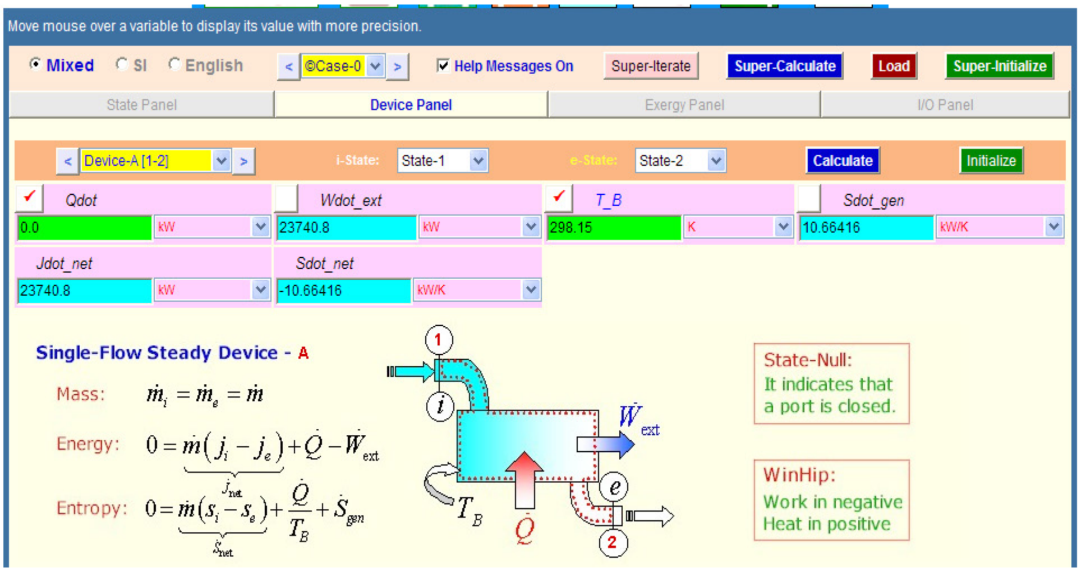
6. Have a State 3 where we get properties if the expansion in the turbine is isentropic. i.e. Enter for State 3: p3 = p2, s3 = s1 and mdot3 = mdot1. Hit Enter. We get:

● Mixed ○ SI ○ English
©Case-0
☑ Help Messages On
©State-3
No-Plots
Superheated Vapor
H2O

| | Variable | Value | Unit |
|---|---|---|---|
| ✓ | p3 | =p2 | MPa |
| ☐ | T3 | 295.11386 | deg-C |
| ☐ | x3 | | fraction |
| ☐ | y3 | | fraction |
| ☐ | v3 | 0.04452 | m^3/kg |
| ☐ | u3 | 2684.2283 | kJ/kg |
| ☐ | h3 | 2906.832 | kJ/kg |
| ✓ | s3 | =s1 | kJ/kg.K |
| ✓ | Vel3 | 0.0 | m/s |
| ✓ | z3 | 0.0 | m |
| ☐ | e3 | 2684.2283 | kJ/kg |
| ☐ | j3 | 2906.832 | kJ/kg |
| | phi3 | 851.73627 | kJ/kg |
| | psi3 | 1069.888 | kJ/kg |
| ✓ | mdot3 | =mdot1 | kg/s |
| ☐ | Voldot3 | 3.11645 | m^3/s |
| ☐ | A3 | 311645.16 | m^2 |
| | MM3 | 18.0 | kg/kmol |

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:



i-State: State-1
e-State: State-2

| Field | Value | Unit |
|---|---|---|
| ✓ Qdot | 0.0 | kW |
| Wdot_ext | 23740.8 | kW |
| ✓ T_B | 298.15 | K |
| Sdot_gen | 10.66416 | kW/K |
| Jdot_net | 23740.8 | kW |
| Sdot_net | -10.66416 | kW/K |

**Single-Flow Steady Device - A**

Mass: $\dot{m}_i = \dot{m}_e = \dot{m}$

Energy: $0 = \underbrace{\dot{m}(j_i - j_e)}_{\dot{J}_{net}} + \dot{Q} - \dot{W}_{ext}$

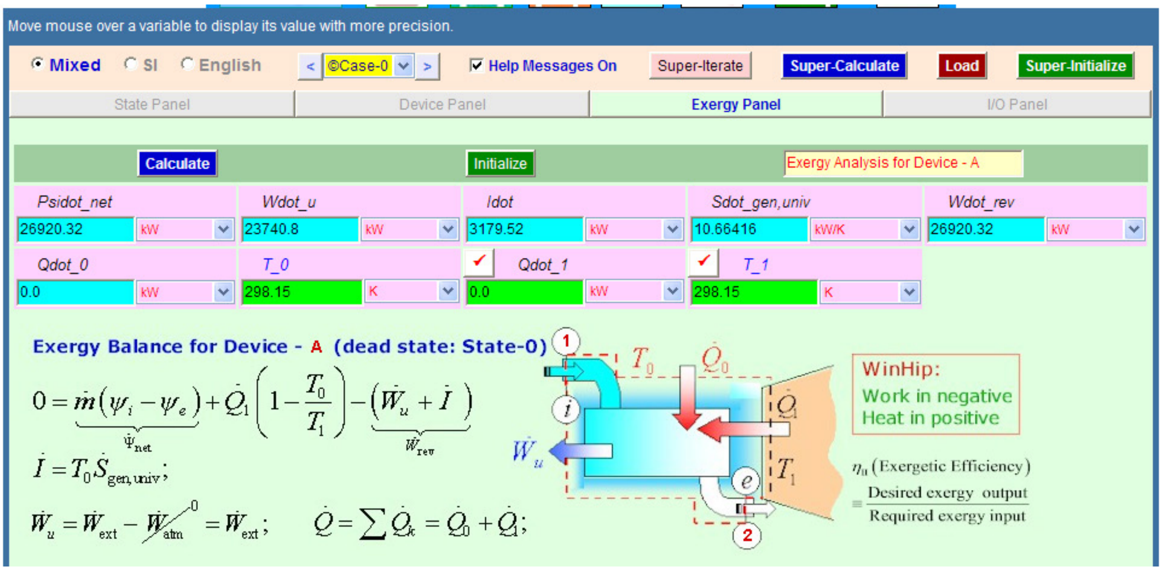
Entropy: $0 = \underbrace{\dot{m}(s_i - s_e)}_{\dot{S}_{net}} + \frac{\dot{Q}}{T_B} + \dot{S}_{gen}$

State-Null: It indicates that a port is closed.

WinHip: Work in negative Heat in positive

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

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



| Field | Value | Unit |
|---|---|---|
| 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 |
| T_0 | 298.15 | K |
| ✓ Qdot_1 | 0.0 | kW |
| ✓ T_1 | 298.15 | K |

**Exergy Balance for Device - A (dead state: State-0)**

$$0 = \underbrace{\dot{m}(\psi_i - \psi_e)}_{\dot{\Psi}_{net}} + \dot{Q}_1\left(1 - \frac{T_0}{T_1}\right) - \underbrace{(\dot{W}_u + \dot{I})}_{\dot{W}_{rev}}$$

$$\dot{I} = T_0 \dot{S}_{gen,univ};$$

$$\dot{W}_u = \dot{W}_{ext} - \cancel{\dot{W}_{atm}}^{0} = \dot{W}_{ext}; \quad \dot{Q} = \sum \dot{Q}_k = \dot{Q}_0 + \dot{Q}_1;$$

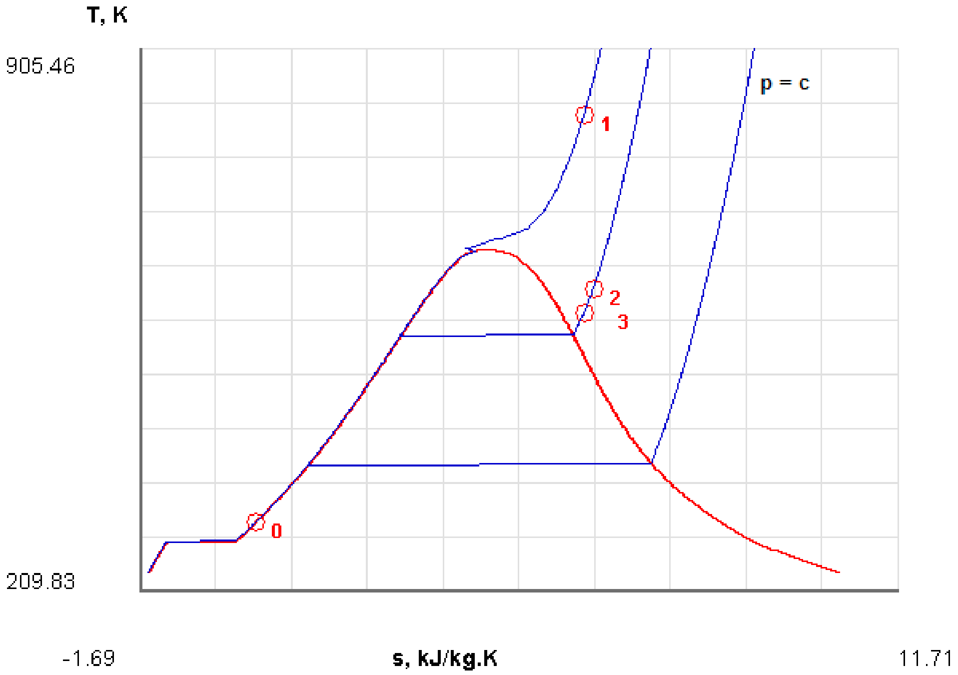
WinHip: Work in negative Heat in positive

$\eta_{II}$ (Exergetic Efficiency) $= \frac{\text{Desired exergy output}}{\text{Required exergy input}}$

**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;

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

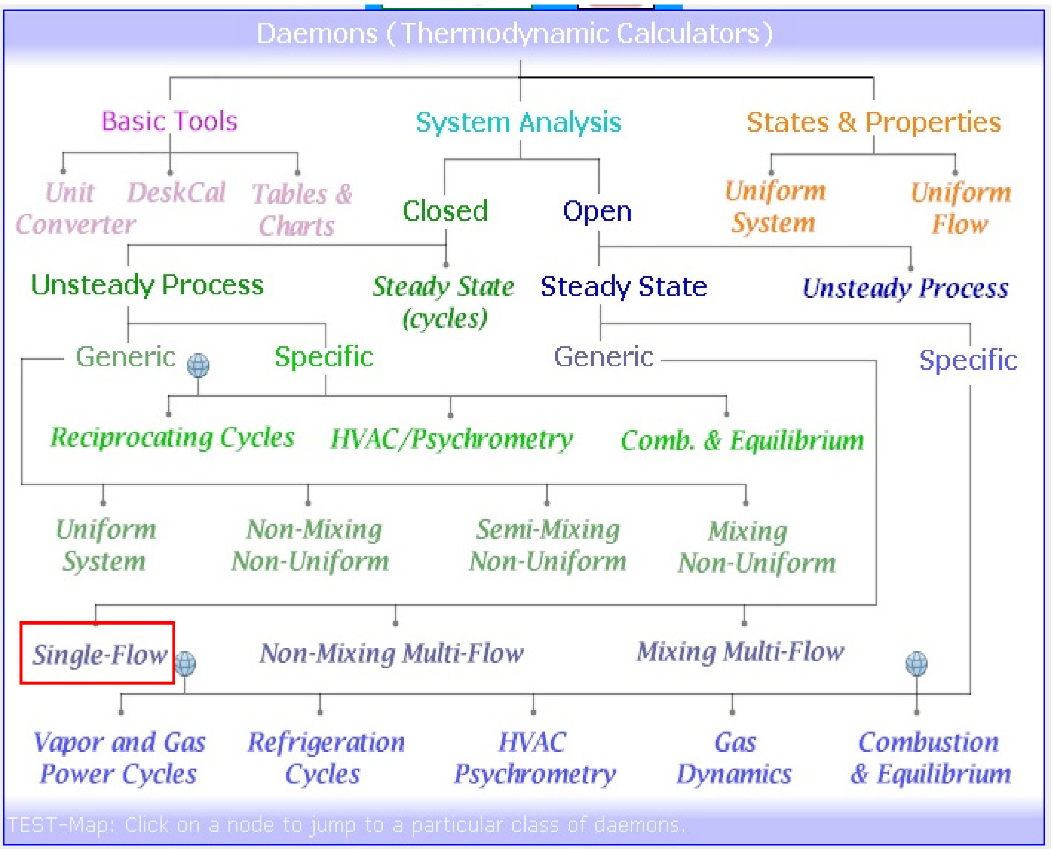
**Prob.8.21**. Air is compressed by a compressor from 101 kPa and 27 C to 400 kPa and 220 C at a rate of 0.15 kg/s. Neglecting the changes in K.E. and P.E. and assuming the surroundings to be at 25 C, determine the reversible power input for this process

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

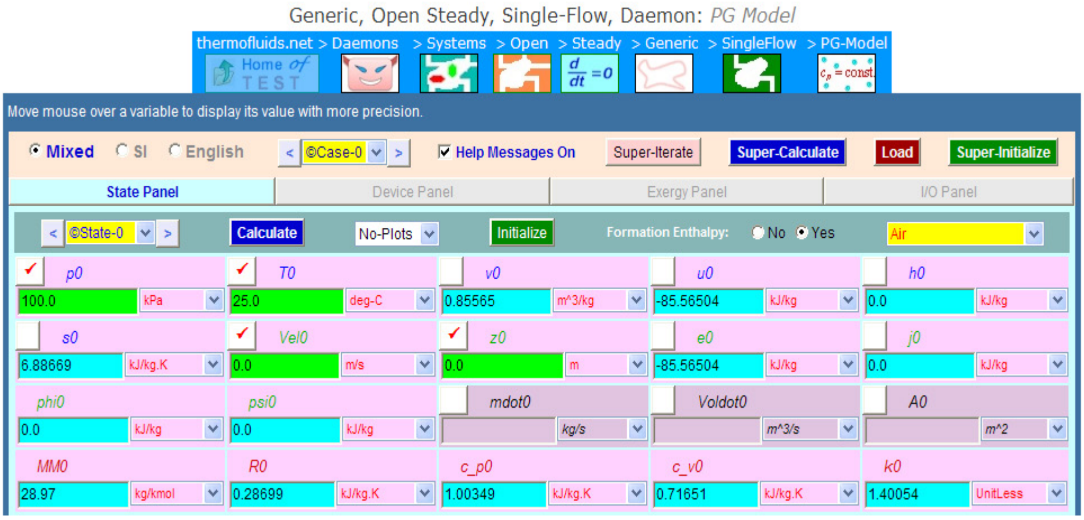
**TEST Solution:**

**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:



Generic, Open Steady, Single-Flow, Daemon: *PG Model*

Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English   ©Case-0   ☑ Help Messages On

©State-0   No-Plots   Formation Enthalpy: ○ No ● Yes   Air

| | | | | |
|---|---|---|---|---|
| ☑ p0 | ☑ T0 | ☐ v0 | ☐ u0 | ☐ h0 |
| 100.0 kPa | 25.0 deg-C | 0.85565 m^3/kg | -85.56504 kJ/kg | 0.0 kJ/kg |
| ☐ s0 | ☑ Vel0 | ☑ z0 | ☐ e0 | ☐ j0 |
| 6.88669 kJ/kg.K | 0.0 m/s | 0.0 m | -85.56504 kJ/kg | 0.0 kJ/kg |
| phi0 | psi0 | ☐ mdot0 | ☐ Voldot0 | ☐ A0 |
| 0.0 kJ/kg | 0.0 kJ/kg | kg/s | m^3/s | m^2 |
| MM0 | R0 | c_p0 | c_v0 | k0 |
| 28.97 kg/kmol | 0.28699 kJ/kg.K | 1.00349 kJ/kg.K | 0.71651 kJ/kg.K | 1.40054 UnitLess |

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

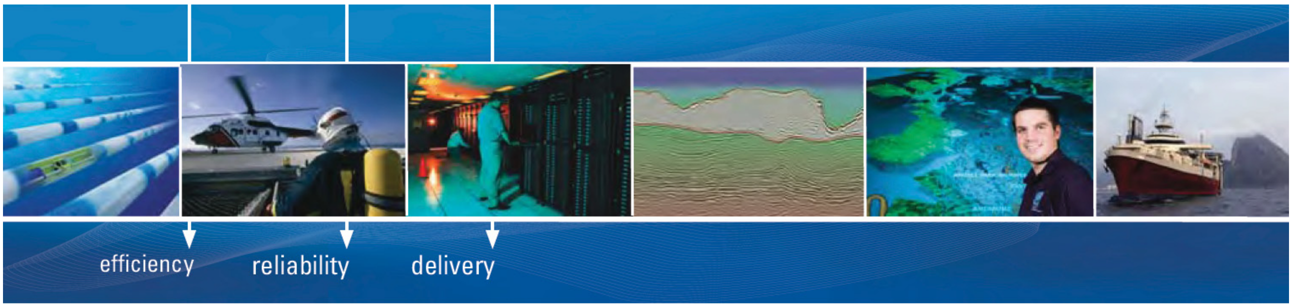

p1 = 101.0 kPa [Absolute pressure]

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

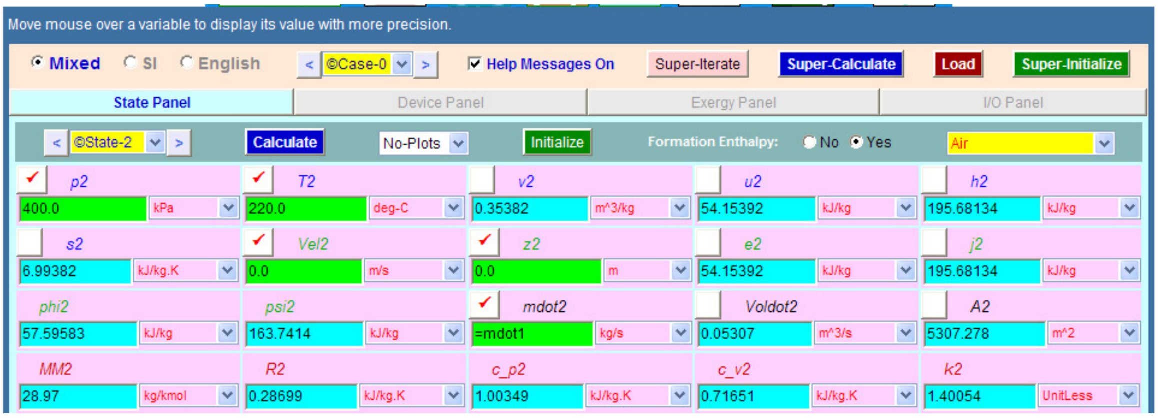
©State-1 | No-Plots | Formation Enthalpy: ○ No ● Yes | Air

| | | | | |
|---|---|---|---|---|
| ☑ p1 | ☑ T1 | ☐ v1 | ☐ u1 | ☐ h1 |
| 101.0 kPa | 27.0 deg-C | 0.85286 m^3/kg | -84.13202 kJ/kg | 2.00699 kJ/kg |
| ☐ s1 | ☑ Vel1 | ☑ z1 | ☐ e1 | ☐ j1 |
| 6.89054 kJ/kg.K | 0.0 m/s | 0.0 m | -84.13202 kJ/kg | 2.00699 kJ/kg |
| phi1 | psi1 | ☑ mdot1 | ☐ Voldot1 | ☐ A1 |
| 0.00524 kJ/kg | 0.8581 kJ/kg | 0.15 kg/s | 0.12793 m^3/s | 12792.922 m^2 |
| MM1 | R1 | c_p1 | c_v1 | k1 |
| 28.97 kg/kmol | 0.28699 kJ/kg.K | 1.00349 kJ/kg.K | 0.71651 kJ/kg.K | 1.40054 UnitLess |

Note that all properties at State 1 are immediately calculated.



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


Move mouse over a variable to display its value with more precision.

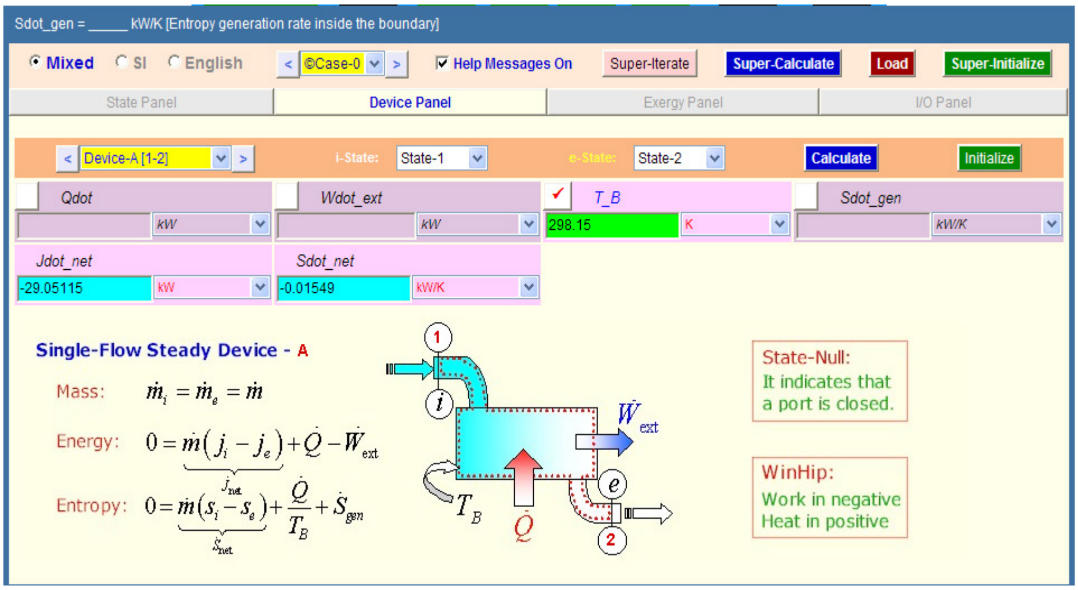
● Mixed ○ SI ○ English — ©Case-0 — ☑ Help Messages On

©State-2 — Formation Enthalpy: ○ No ● Yes — Air

☑ p2: 400.0 kPa
☑ T2: 220.0 deg-C
v2: 0.35382 m^3/kg
u2: 54.15392 kJ/kg
h2: 195.68134 kJ/kg
s2: 6.99382 kJ/kg.K
☑ Vel2: 0.0 m/s
☑ z2: 0.0 m
e2: 54.15392 kJ/kg
j2: 195.68134 kJ/kg
phi2: 57.59583 kJ/kg
psi2: 163.7414 kJ/kg
☑ mdot2: =mdot1 kg/s
Voldot2: 0.05307 m^3/s
A2: 5307.278 m^2
MM2: 28.97 kg/kmol
R2: 0.28699 kJ/kg.K
c_p2: 1.00349 kJ/kg.K
c_v2: 0.71651 kJ/kg.K
k2: 1.40054 UnitLess

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:


Sdot_gen = _____ kW/K [Entropy generation rate inside the boundary]

● Mixed ○ SI ○ English — ©Case-0 — ☑ Help Messages On

Device-A [1-2] — i-State: State-1 — e-State: State-2

Qdot: kW
Wdot_ext: kW
☑ T_B: 298.15 K
Sdot_gen: kW/K
Jdot_net: -29.05115 kW
Sdot_net: -0.01549 kW/K

Single-Flow Steady Device - A

Mass: $\dot m_i = \dot m_e = \dot m$

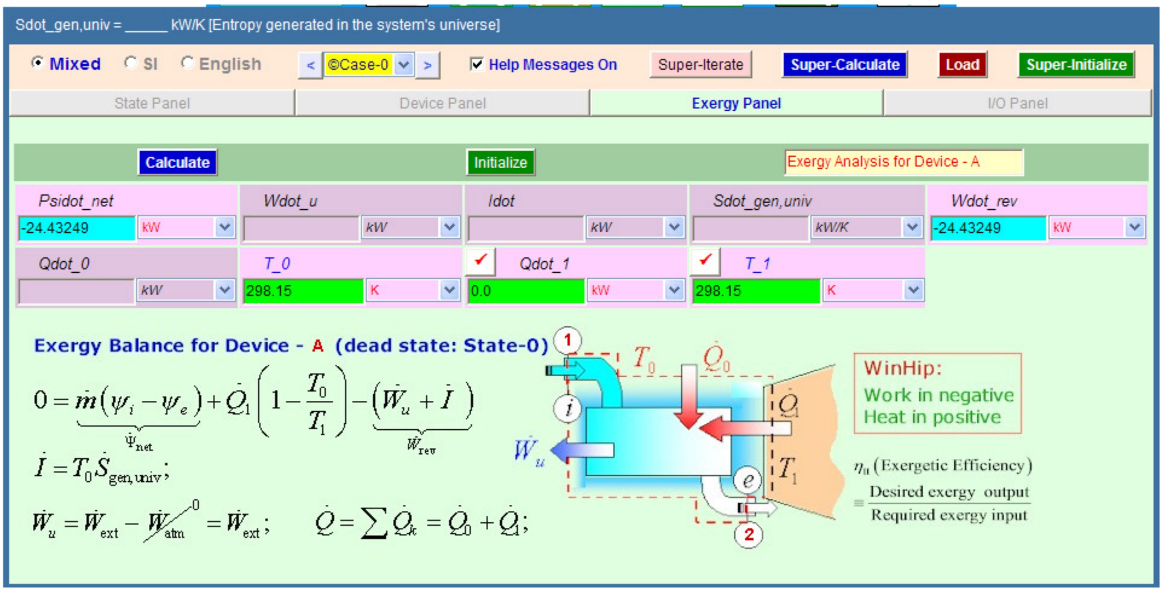
Energy: $0 = \underbrace{\dot m\left(j_i - j_e\right)}_{\dot J_{net}} + \dot Q - \dot W_{ext}$

Entropy: $0 = \underbrace{\dot m\left(s_i - s_e\right)}_{\dot S_{net}} + \frac{\dot Q}{T_B} + \dot S_{gen}$

State-Null:
It indicates that a port is closed.

WinHip:
Work in negative
Heat in positive

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



Sdot_gen,univ = _____ kW/K [Entropy generated in the system's universe]

● Mixed ○ SI ○ English  < ©Case-0 >  ☑ Help Messages On

Exergy Analysis for Device - A

Psidot_net: -24.43249 kW
Wdot_u: kW
Idot: kW
Sdot_gen,univ: kW/K
Wdot_rev: -24.43249 kW
Qdot_0: kW
T_0: 298.15 K
✓ Qdot_1: 0.0 kW
✓ T_1: 298.15 K

Exergy Balance for Device - A (dead state: State-0)

$$0=\dot{m}\underbrace{(\psi_i-\psi_e)}_{\dot{\Psi}_{\text{net}}}+\dot{Q}_1\left(1-\frac{T_0}{T_1}\right)-\underbrace{(\dot{W}_u+\dot{I})}_{\dot{W}_{\text{rev}}}$$

$$\dot{I}=T_0\dot{S}_{\text{gen,univ}};$$

$$\dot{W}_u=\dot{W}_{\text{ext}}-\cancel{\dot{W}_{\text{atm}}}^{0}=\dot{W}_{\text{ext}};\qquad \dot{Q}=\sum\dot{Q}_k=\dot{Q}_0+\dot{Q}_1;$$

WinHip:
Work in negative
Heat in positive

$$\eta_{II}\text{ (Exergetic Efficiency)}=\frac{\text{Desired exergy output}}{\text{Required exergy input}}$$

**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:**

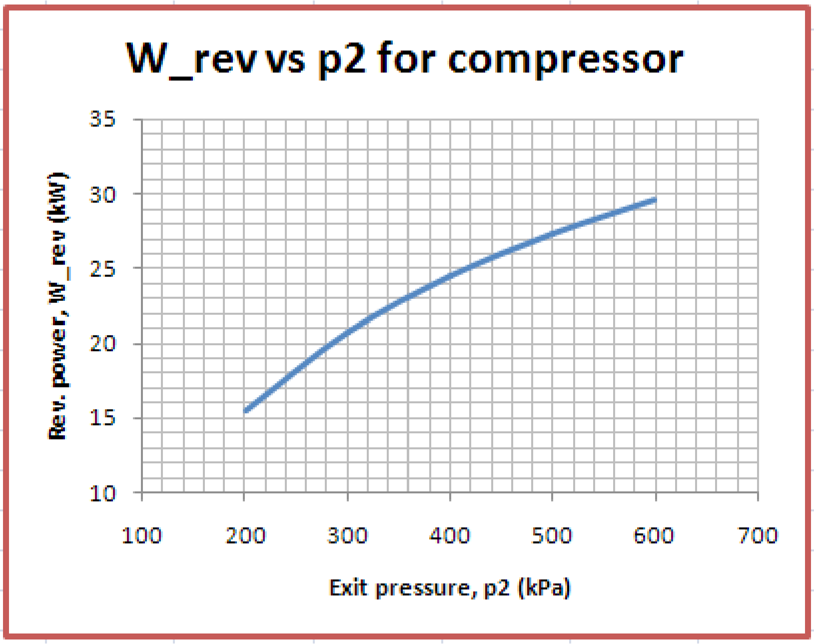
To do this, following are the simple steps:

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.



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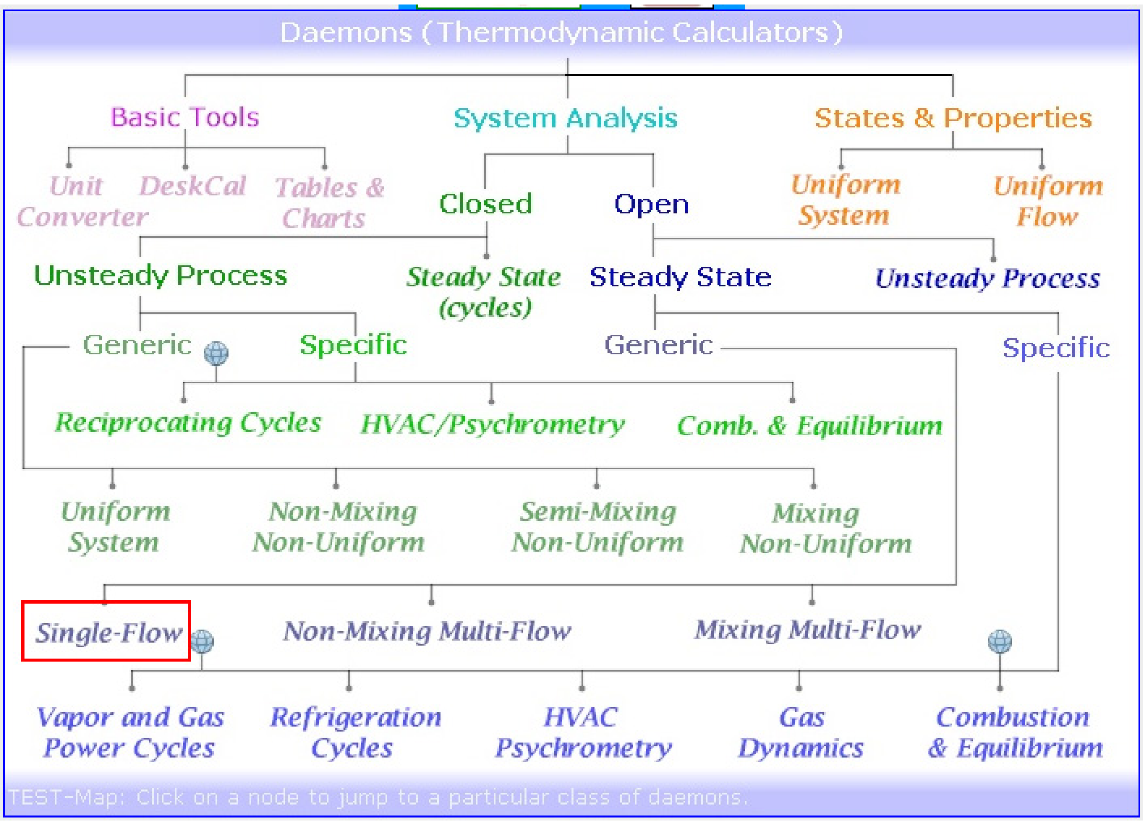
**Prob.8.22.** Air enters a compressor t ambient conditions of 100 kPa and 17 C with a low velocity and exits at 1 MPa, 327 C, and 105 m/s. The compressor is cooled by the ambient air at 17 C at a rate of 1500 kJ/min. The power input to the compressor is 300 kW. Determine (a) the mass flow rate of air,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

**TEST Solution:**

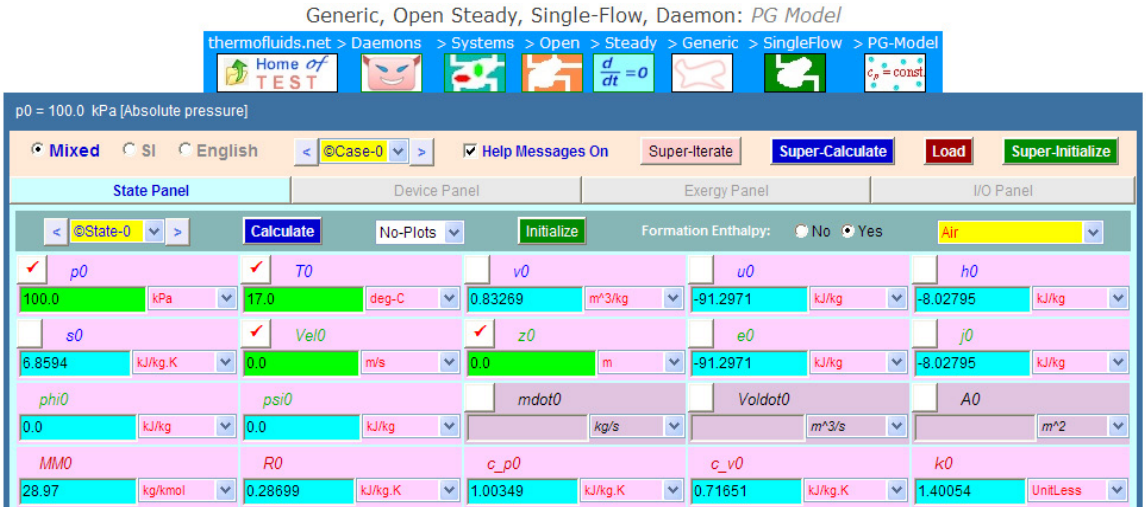
**Following are the steps:**

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



TEST-Map: Click on a node to jump to a particular class of daemons.

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:


Generic, Open Steady, Single-Flow, Daemon: *PG Model*

p0 = 100.0 kPa [Absolute pressure]

● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On

State-0 | No-Plots | Formation Enthalpy: ○ No ● Yes | Air

|  |  |  |  |  |
|---|---|---|---|---|
| ☑ p0 | ☑ T0 | ☐ v0 | ☐ u0 | ☐ h0 |
| 100.0 kPa | 17.0 deg-C | 0.83269 m^3/kg | -91.2971 kJ/kg | -8.02795 kJ/kg |
| ☐ s0 | ☑ Vel0 | ☑ z0 | ☐ e0 | ☐ j0 |
| 6.8594 kJ/kg.K | 0.0 m/s | 0.0 m | -91.2971 kJ/kg | -8.02795 kJ/kg |
| phi0 | psi0 | ☐ mdot0 | ☐ Voldot0 | ☐ A0 |
| 0.0 kJ/kg | 0.0 kJ/kg | kg/s | m^3/s | m^2 |
| MM0 | R0 | c_p0 | c_v0 | k0 |
| 28.97 kg/kmol | 0.28699 kJ/kg.K | 1.00349 kJ/kg.K | 0.71651 kJ/kg.K | 1.40054 UnitLess |

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:

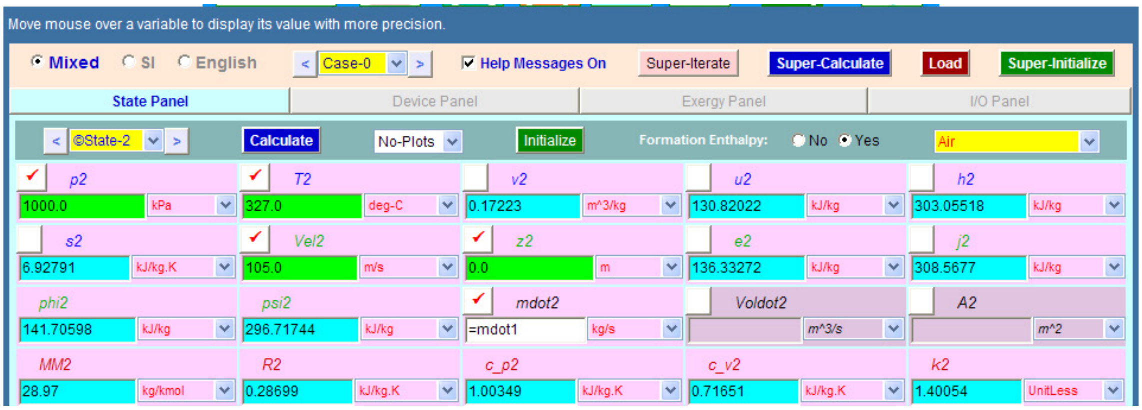

Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On

State-1 | No-Plots | Formation Enthalpy: ○ No ● Yes | Air

|  |  |  |  |  |
|---|---|---|---|---|
| ☑ p1 | ☑ T1 | ☐ v1 | ☐ u1 | ☐ h1 |
| 100.0 kPa | 17.0 deg-C | 0.83269 m^3/kg | -91.2971 kJ/kg | -8.02795 kJ/kg |
| ☐ s1 | ☑ Vel1 | ☑ z1 | ☐ e1 | ☐ j1 |
| 6.8594 kJ/kg.K | 0.0 m/s | 0.0 m | -91.2971 kJ/kg | -8.02795 kJ/kg |
| phi1 | psi1 | ☑ mdot1 | ☐ Voldot1 | ☐ A1 |
| 0.0 kJ/kg | 0.0 kJ/kg | 0.86861587 kg/s | 0.72329 m^3/s | 72328.9 m^2 |
| MM1 | R1 | c_p1 | c_v1 | k1 |
| 28.97 kg/kmol | 0.28699 kJ/kg.K | 1.00349 kJ/kg.K | 0.71651 kJ/kg.K | 1.40054 UnitLess |

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:



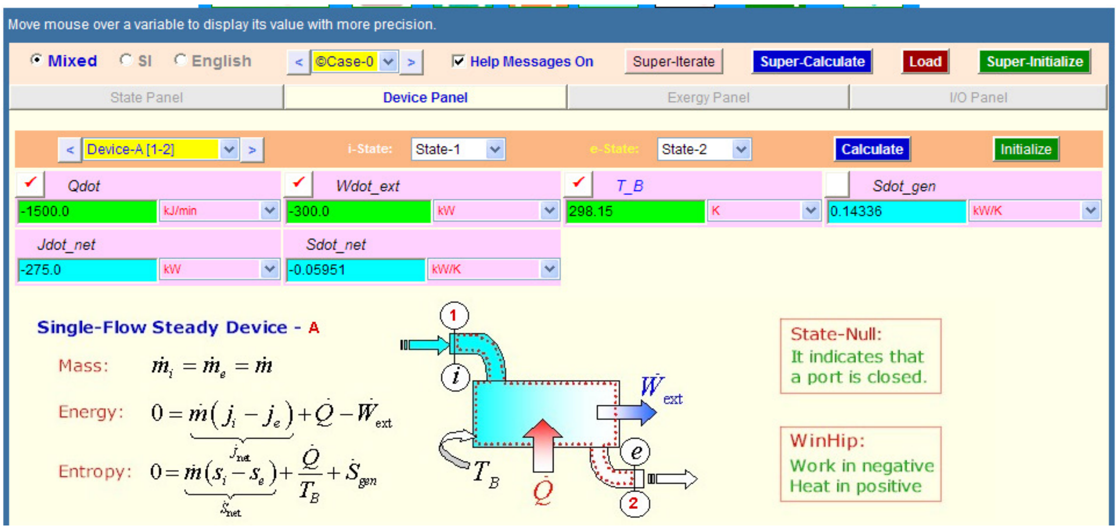
Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English   Case-0   ☑ Help Messages On

©State-2   No-Plots   Formation Enthalpy: ○ No ● Yes   Air

| | | | | |
|---|---|---|---|---|
| ☑ p2<br>1000.0 kPa | ☑ T2<br>327.0 deg-C | ☐ v2<br>0.17223 m^3/kg | ☐ u2<br>130.82022 kJ/kg | ☐ h2<br>303.05518 kJ/kg |
| ☐ s2<br>6.92791 kJ/kg.K | ☑ Vel2<br>105.0 m/s | ☑ z2<br>0.0 m | ☐ e2<br>136.33272 kJ/kg | ☐ j2<br>308.5677 kJ/kg |
| phi2<br>141.70598 kJ/kg | psi2<br>296.71744 kJ/kg | ☑ mdot2<br>=mdot1 kg/s | ☐ Voldot2<br>m^3/s | ☐ A2<br>m^2 |
| MM2<br>28.97 kg/kmol | R2<br>0.28699 kJ/kg.K | c_p2<br>1.00349 kJ/kg.K | c_v2<br>0.71651 kJ/kg.K | k2<br>1.40054 UnitLess |

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:



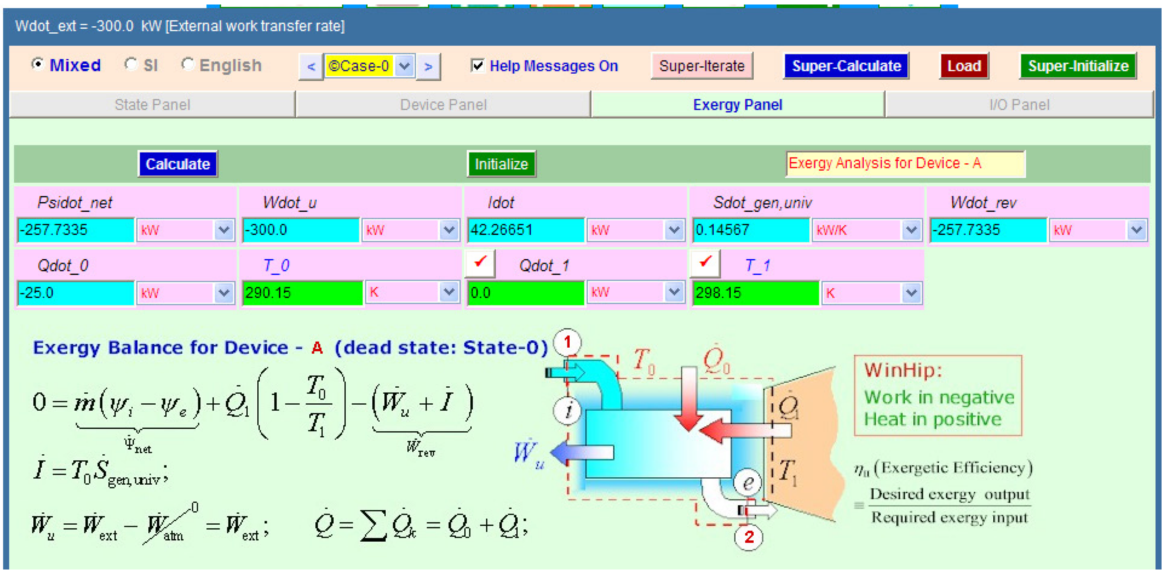
Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

Device Panel: Device-A [1-2], i-State: State-1, e-State: State-2

☑ Qdot: -1500.0 kJ/min
☑ Wdot_ext: -300.0 kW
☑ T_B: 298.15 K
☐ Sdot_gen: 0.14336 kW/K
Jdot_net: -275.0 kW
Sdot_net: -0.05951 kW/K

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



Wdot_ext = -300.0 kW [External work transfer rate]

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

Exergy Analysis for Device - A

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
T_0: 290.15 K
☑ Qdot_1: 0.0 kW
☑ T_1: 298.15 K

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:**

| | | | | |
|---|---|---|---|---|
| ☑ p2 | ☑ T2 | ☐ v2 | ☐ u2 | ☐ h2 |
| 1000.0 kPa | 327.0 deg-C | 0.17223 m^3/kg | 130.82022 kJ/kg | 303.05518 kJ/kg |
| ☐ s2 | ☑ Vel2 | ☑ z2 | ☐ e2 | ☐ j2 |
| 6.92791 kJ/kg.K | 105.0 m/s | 0.0 m | 136.33272 kJ/kg | 308.5677 kJ/kg |
| phi2 | psi2 | ☑ mdot2 | ☐ Voldot2 | ☐ A2 |
| 141.70598 kJ/kg | 296.71744 kJ/kg | 0.86861587 kg/s | 0.14961 m^3/s | 0.00142 m^2 |
| MM2 | R2 | c_p2 | c_v2 | k2 |
| 28.97 kg/kmol | 0.28699 kJ/kg.K | 1.00349 kJ/kg.K | 0.71651 kJ/kg.K | 1.40054 UnitLess |

**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------------------------------------------------------------------
```

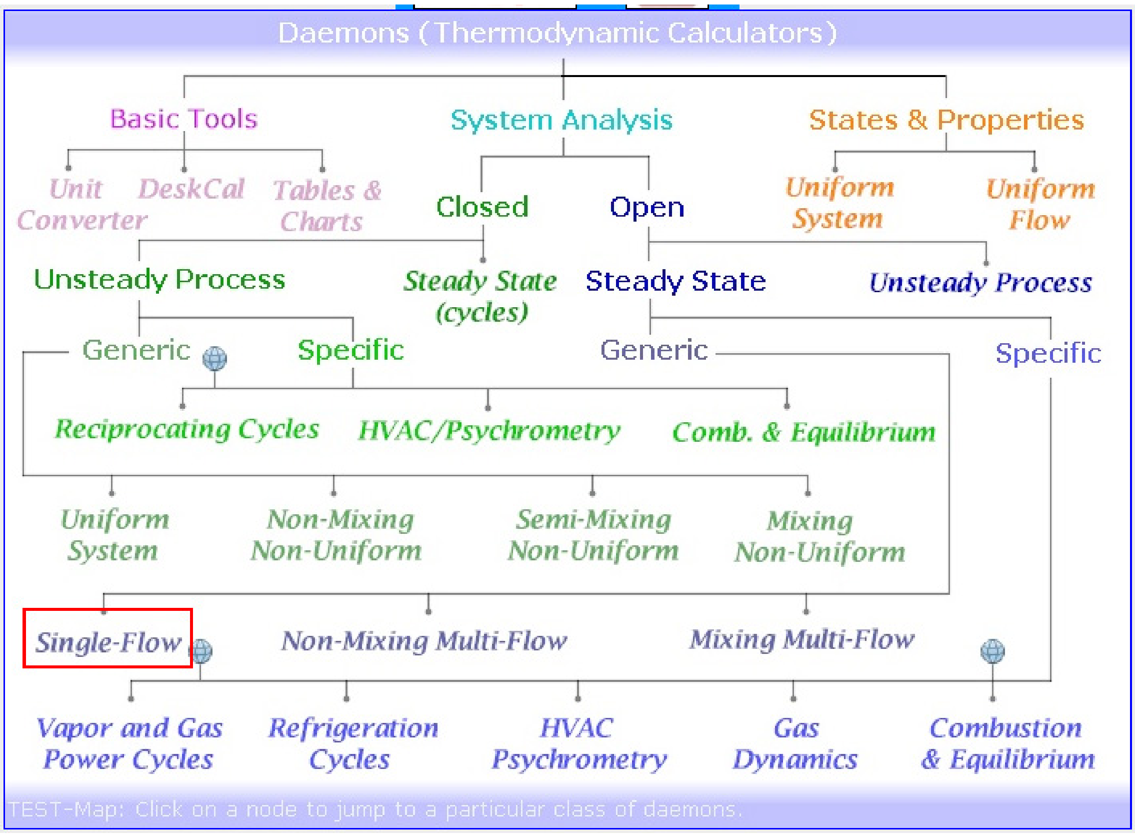
```
# Mass, Energy, and Entropy Analysis Results:

#          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]

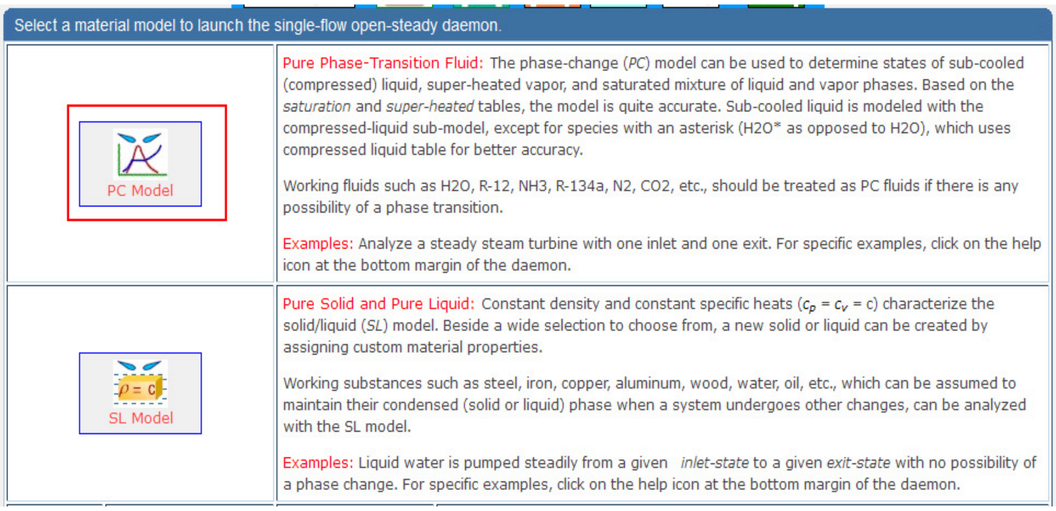
**TEST Solution:**

**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.



Select a material model to launch the single-flow open-steady daemon.

Pure Phase-Transition Fluid: The phase-change (*PC*) model can be used to determine states of sub-cooled (compressed) liquid, super-heated vapor, and saturated mixture of liquid and vapor phases. Based on the *saturation* and *super-heated* tables, the model is quite accurate. Sub-cooled liquid is modeled with the compressed-liquid sub-model, except for species with an asterisk (H2O* as opposed to H2O), which uses compressed liquid table for better accuracy.

Working fluids such as H2O, R-12, NH3, R-134a, N2, CO2, etc., should be treated as PC fluids if there is any possibility of a phase transition.

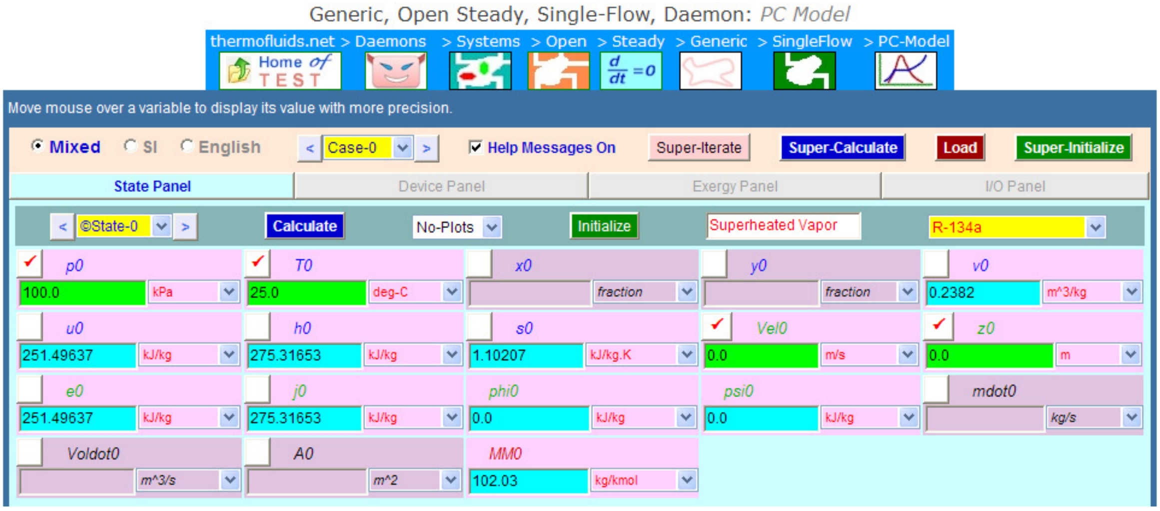
Examples: Analyze a steady steam turbine with one inlet and one exit. For specific examples, click on the help icon at the bottom margin of the daemon.

Pure Solid and Pure Liquid: Constant density and constant specific heats ($c_p = c_v = c$) characterize the solid/liquid (*SL*) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.

Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.

Examples: Liquid water is pumped steadily from a given *inlet-state* to a given *exit-state* with no possibility of a phase change. For specific examples, click on the help icon at the bottom margin of the daemon.

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



Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English | < Case-0 > | ☑ Help Messages On

< ©State-0 > | No-Plots | Superheated Vapor | R-134a

| | | | | |
|---|---|---|---|---|
| ☑ p0 | ☑ T0 | ☐ x0 | ☐ y0 | ☐ v0 |
| 100.0 kPa | 25.0 deg-C | fraction | fraction | 0.2382 m^3/kg |
| ☐ u0 | ☐ h0 | ☐ s0 | ☑ Vel0 | ☑ z0 |
| 251.49637 kJ/kg | 275.31653 kJ/kg | 1.10207 kJ/kg.K | 0.0 m/s | 0.0 m |
| ☐ e0 | ☐ j0 | phi0 | psi0 | ☐ mdot0 |
| 251.49637 kJ/kg | 275.31653 kJ/kg | 0.0 kJ/kg | 0.0 kJ/kg | kg/s |
| ☐ Voldot0 | ☐ A0 | MM0 | | |
| m^3/s | m^2 | 102.03 kg/kmol | | |

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

Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English
Case-0
☑ Help Messages On
State-1
No-Plots
Saturated Liquid
R-134a

☑ p1 = 1200.0 kPa
☐ T1 = 46.29141 deg-C
☑ x1 = 0.0 fraction
☐ y1 = 0.0 fraction
☐ v1 = 8.9E-4 m^3/kg
☐ u1 = 116.05018 kJ/kg
☐ h1 = 117.12393 kJ/kg
☐ s1 = 0.4215 kJ/kg.K
☑ Vel1 = 0.0 m/s
☑ z1 = 0.0 m
☐ e1 = 116.05018 kJ/kg
☐ j1 = 117.12393 kJ/kg
phi1 kJ/kg
psi1 kJ/kg
☐ mdot1 kg/s
☐ Voldot1 m^3/s
☐ A1 m^2
MM1 = 102.03 kg/kmol

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.*

Move mouse over a variable to display its value with more precision.

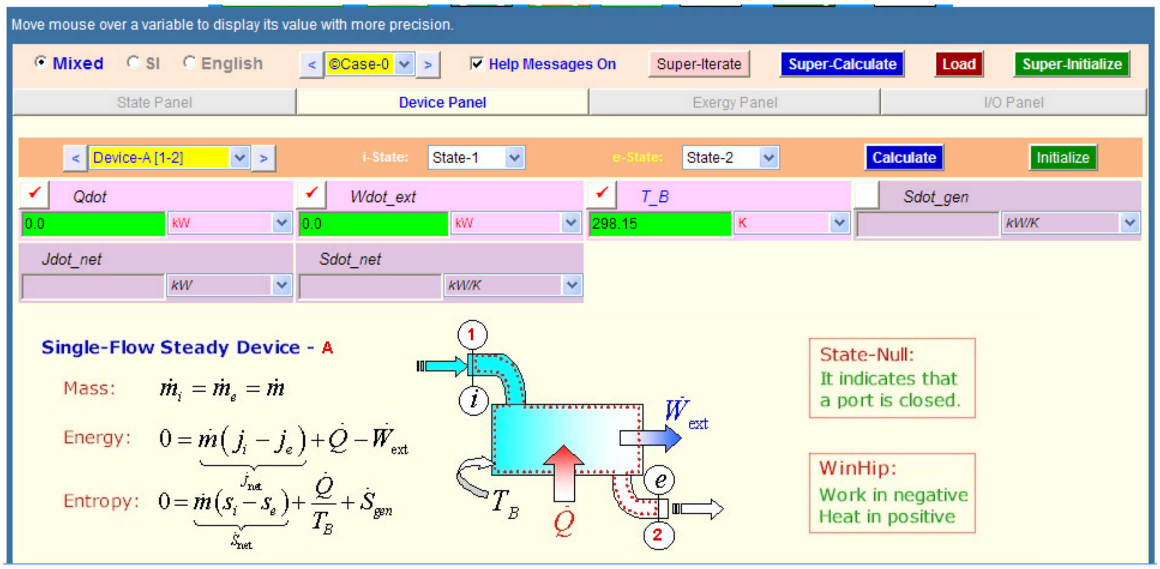
● Mixed ○ SI ○ English
Case-0
☑ Help Messages On
State-2
No-Plots
Sat.Mixture: Liq.+Vap.
R-134a

☑ p2 = 200.0 kPa
☐ T2 = -10.22257 deg-C
☐ x2 = 0.38731 fraction
☐ y2 = 0.98821 fraction
☐ v2 = 0.03923 m^3/kg
☐ u2 = 109.28457 kJ/kg
☑ h2 = =h1 kJ/kg
☐ s2 = 0.45355 kJ/kg.K
☑ Vel2 = 0.0 m/s
☑ z2 = 0.0 m
☐ e2 = 109.28457 kJ/kg
☐ j2 = 117.12393 kJ/kg
phi2 kJ/kg
psi2 kJ/kg
☐ mdot2 kg/s
☐ Voldot2 m^3/s
☐ A2 m^2
MM2 = 102.03 kg/kmol

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:


Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

Device-A [1-2] | i-State: State-1 | e-State: State-2

☑ Qdot: 0.0 kW
☑ Wdot_ext: 0.0 kW
☑ T_B: 298.15 K
☐ Sdot_gen: kW/K
Jdot_net: kW
Sdot_net: kW/K

Single-Flow Steady Device - A

Mass: $\dot{m}_i = \dot{m}_e = \dot{m}$

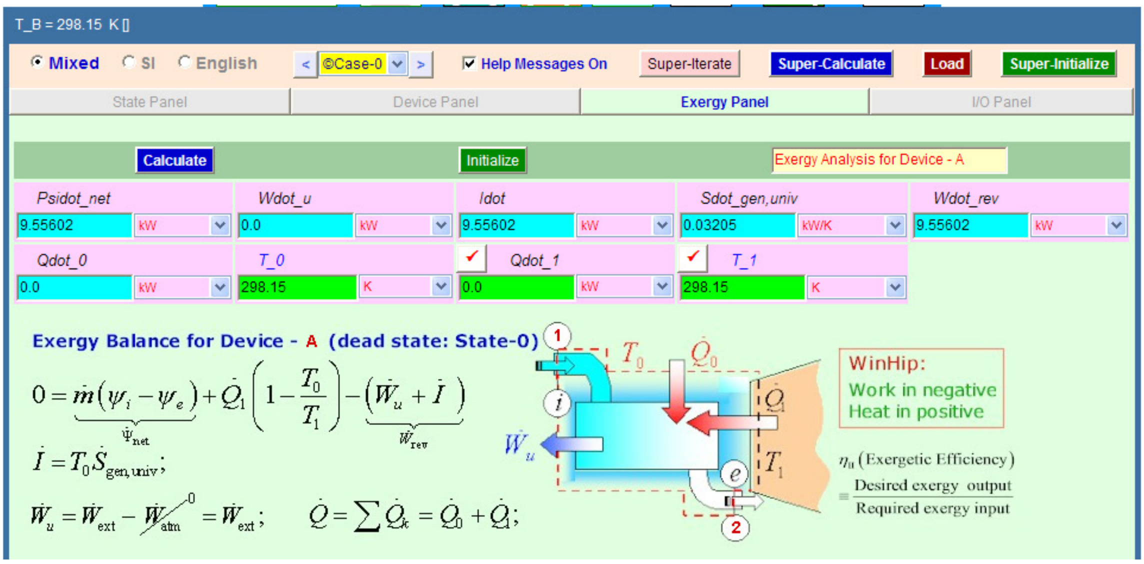
Energy: $0 = \underbrace{\dot{m}(j_i - j_e)}_{\dot{J}_{net}} + \dot{Q} - \dot{W}_{ext}$

Entropy: $0 = \underbrace{\dot{m}(s_i - s_e)}_{\dot{S}_{net}} + \frac{\dot{Q}}{T_B} + \dot{S}_{gen}$

State-Null: It indicates that a port is closed.

WinHip: Work in negative Heat in positive

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


T_B = 298.15 K

● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

Exergy Analysis for Device - A

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
T_0: 298.15 K
☑ Qdot_1: 0.0 kW
☑ T_1: 298.15 K

Exergy Balance for Device - A (dead state: State-0)

$0 = \underbrace{\dot{m}(\psi_i - \psi_e)}_{\dot{\Psi}_{net}} + \dot{Q}_1\left(1 - \frac{T_0}{T_1}\right) - \underbrace{(\dot{W}_u + \dot{I})}_{\dot{W}_{rev}}$

$\dot{I} = T_0 \dot{S}_{gen,univ}$;

$\dot{W}_u = \dot{W}_{ext} - \cancel{\dot{W}_{atm}}^{0} = \dot{W}_{ext}$; $\dot{Q} = \sum \dot{Q}_k = \dot{Q}_0 + \dot{Q}_1$;

WinHip: Work in negative Heat in positive

$\eta_{II}$ (Exergetic Efficiency) $= \frac{\text{Desired exergy output}}{\text{Required exergy input}}$

**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;
#
```

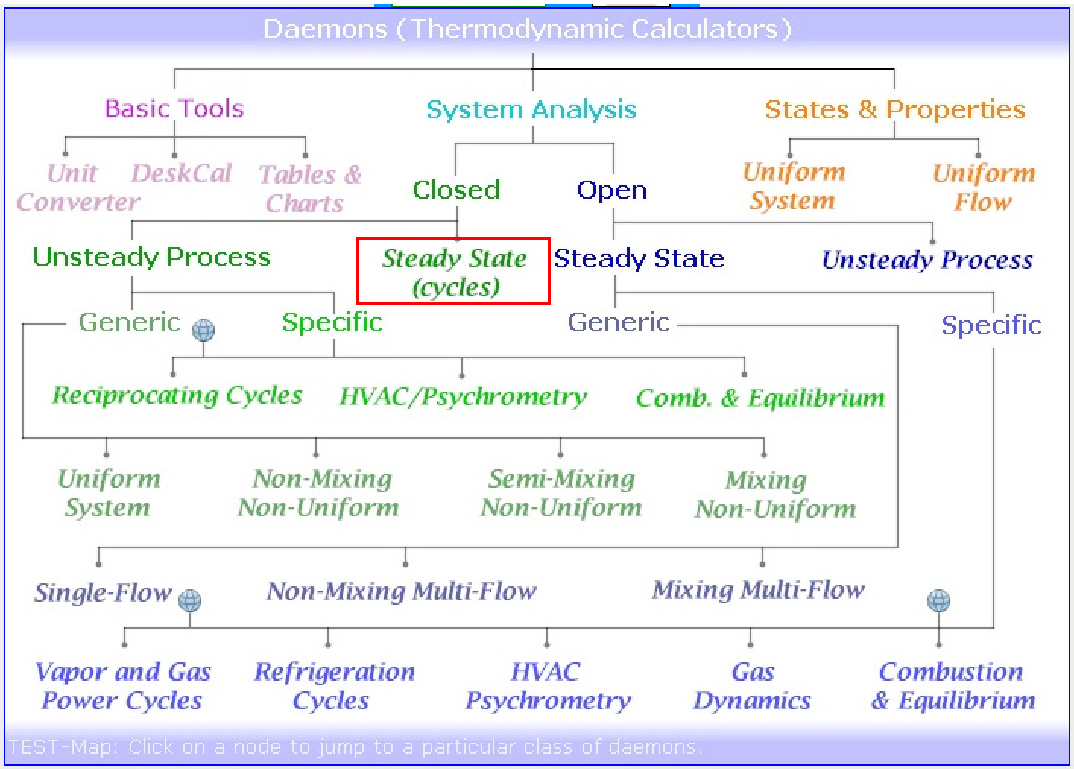
```
#--------Property spreadsheet starts:
#
# State  p(kPa)     T(K)    x      v(m3/kg)    u(kJ/kg)    h(kJ/kg)    s(kJ/kg)
# 00     100.0      298.2          0.2382      251.5       275.32      1.102
# 01     1200.0     319.4   0.0    9.0E-4      116.05      117.12      0.421
# 02     200.0      262.9   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]

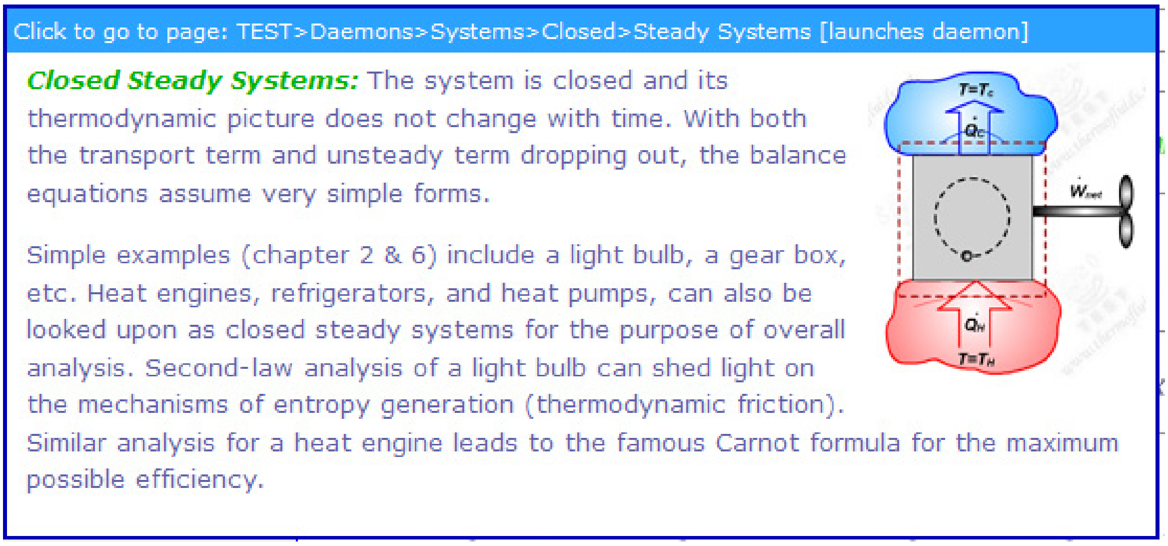
**TEST Solution:**

**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:



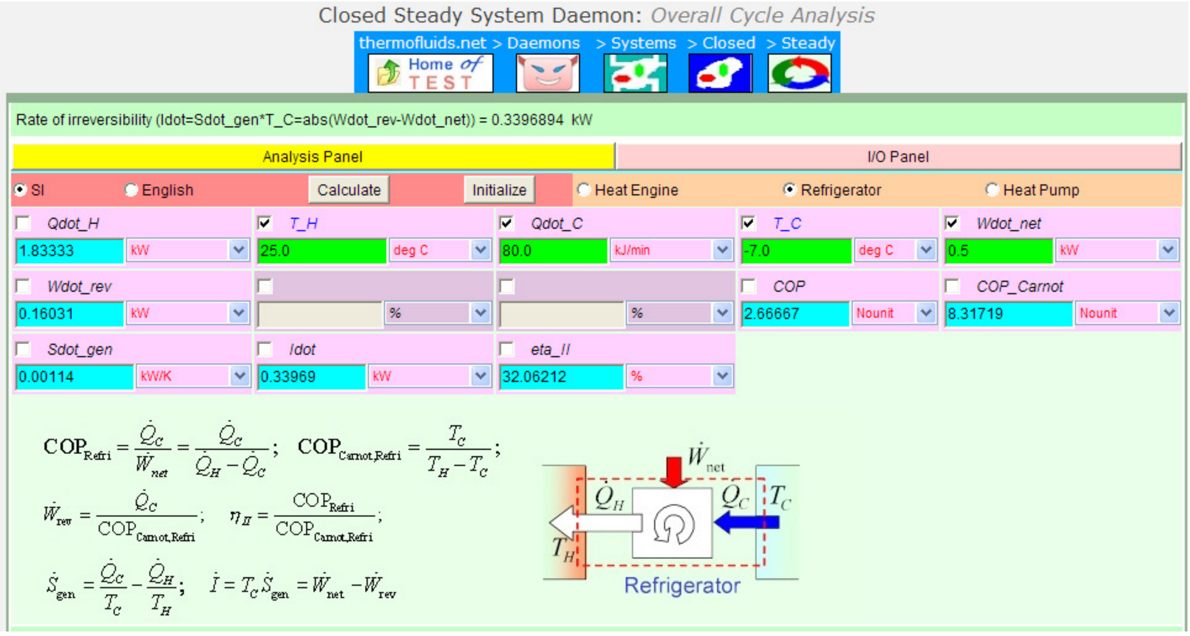
Hovering the mouse pointer over 'Steady State (cycles)' brings up the following pop up:


Click to go to page: TEST>Daemons>Systems>Closed>Steady Systems [launches daemon]

**Closed Steady Systems:** The system is closed and its thermodynamic picture does not change with time. With both the transport term and unsteady term dropping out, the balance equations assume very simple forms.

Simple examples (chapter 2 & 6) include a light bulb, a gear box, etc. Heat engines, refrigerators, and heat pumps, can also be looked upon as closed steady systems for the purpose of overall analysis. Second-law analysis of a light bulb can shed light on the mechanisms of entropy generation (thermodynamic friction). Similar analysis for a heat engine leads to the famous Carnot formula for the maximum possible efficiency.

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:



Closed Steady System Daemon: *Overall Cycle Analysis*

Rate of irreversibility (Idot=Sdot_gen*T_C=abs(Wdot_rev-Wdot_net)) = 0.3396894 kW

● SI ○ English ○ Heat Engine ● Refrigerator ○ Heat Pump

☐ Qdot_H: 1.83333 kW
☑ T_H: 25.0 deg C
☑ Qdot_C: 80.0 kJ/min
☑ T_C: -7.0 deg C
☑ Wdot_net: 0.5 kW
☐ Wdot_rev: 0.16031 kW
☐ COP: 2.66667 Nounit
☐ COP_Carnot: 8.31719 Nounit
☐ Sdot_gen: 0.00114 kW/K
☐ Idot: 0.33969 kW
☐ eta_II: 32.06212 %

$$\mathrm{COP}_{\mathrm{Refri}} = \frac{\dot{Q}_C}{\dot{W}_{net}} = \frac{\dot{Q}_C}{\dot{Q}_H - \dot{Q}_C}; \quad \mathrm{COP}_{\mathrm{Carnot,Refri}} = \frac{T_C}{T_H - T_C};$$

$$\dot{W}_{\mathrm{rev}} = \frac{\dot{Q}_C}{\mathrm{COP}_{\mathrm{Carnot,Refri}}}; \quad \eta_{II} = \frac{\mathrm{COP}_{\mathrm{Refri}}}{\mathrm{COP}_{\mathrm{Carnot,Refri}}};$$

$$\dot{S}_{\mathrm{gen}} = \frac{\dot{Q}_C}{T_C} - \frac{\dot{Q}_H}{T_H}; \quad \dot{I} = T_C \dot{S}_{\mathrm{gen}} = \dot{W}_{\mathrm{net}} - \dot{W}_{\mathrm{rev}}$$

**Thus:**

**Reversible power = Wdot_rev =0.16031 kW …. Ans.**

**Irreversibility = Idot = 0.33969 kW… Ans.**

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

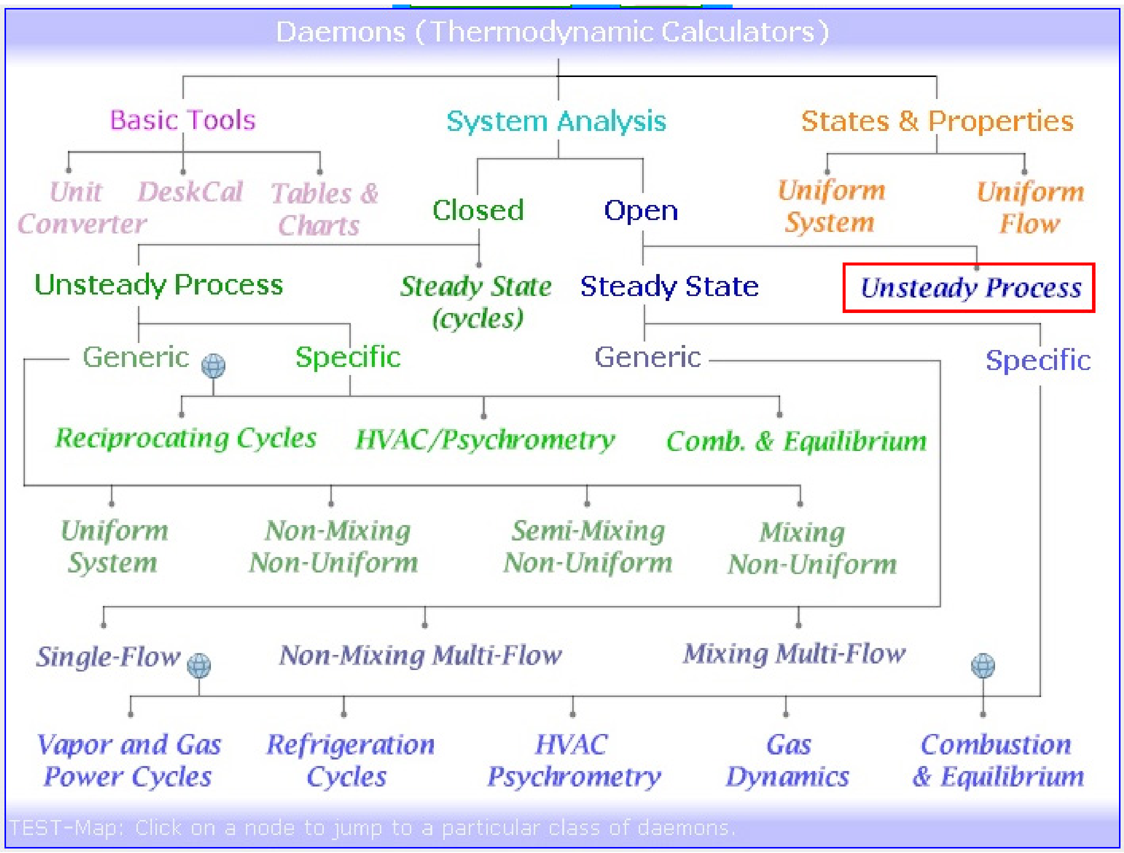
======================================================================

**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:**

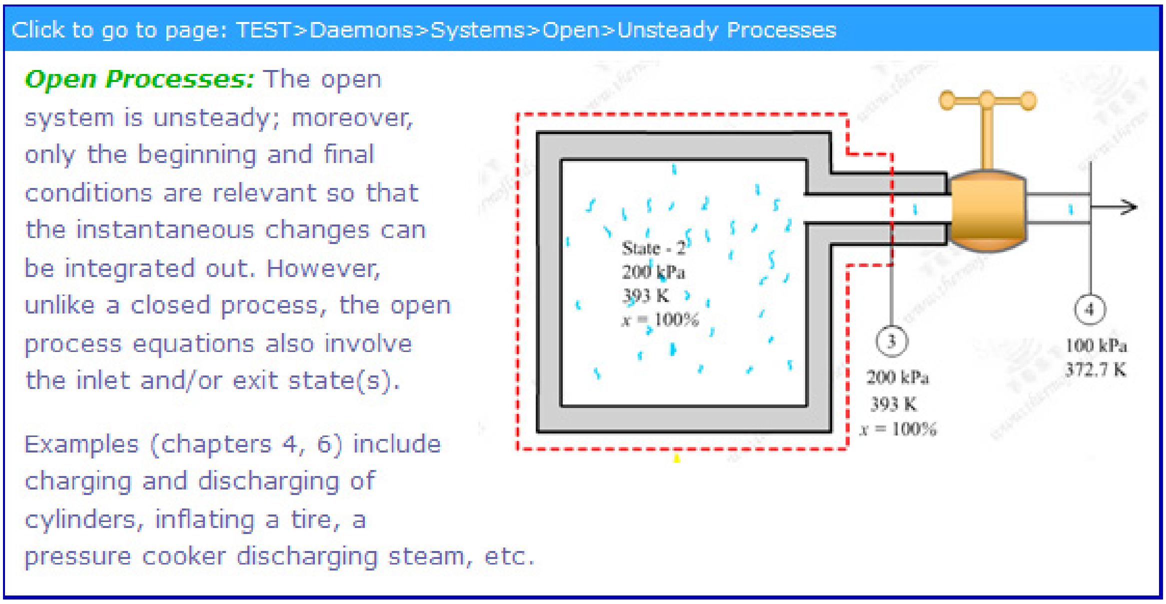
**Following are the steps:**

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



TEST-Map: Click on a node to jump to a particular class of daemons.

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

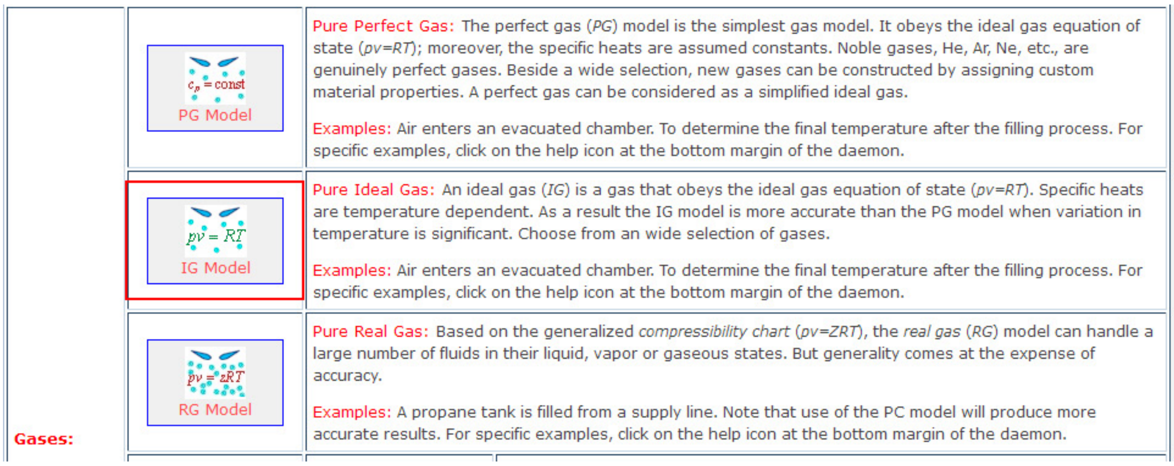


Click to go to page: TEST>Daemons>Systems>Open>Unsteady Processes

**Open Processes:** The open system is unsteady; moreover, only the beginning and final conditions are relevant so that the instantaneous changes can be integrated out. However, unlike a closed process, the open process equations also involve the inlet and/or exit state(s).

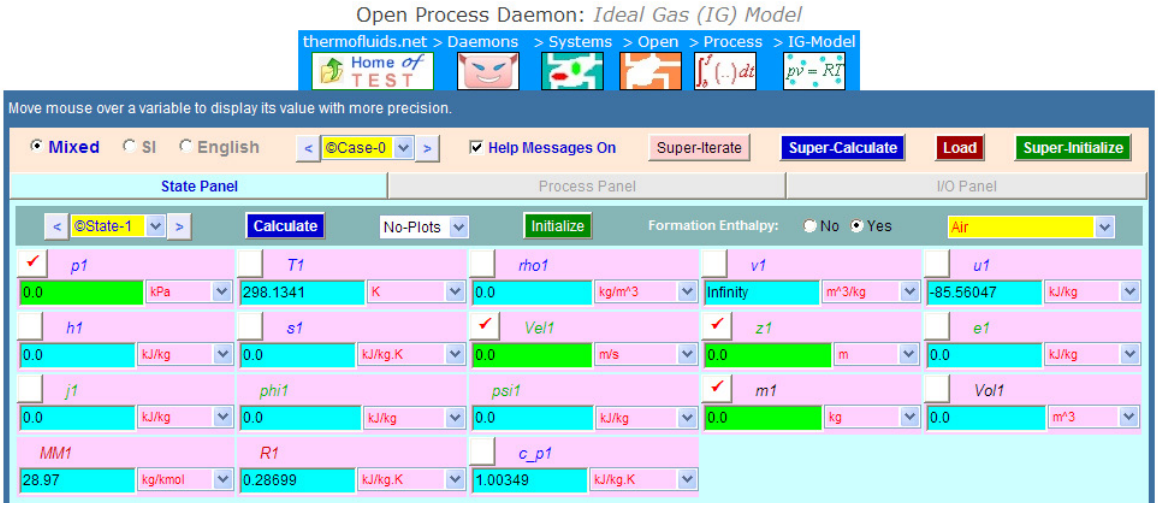
Examples (chapters 4, 6) include charging and discharging of cylinders, inflating a tire, a pressure cooker discharging steam, etc.

2. For material model, choose IG model:



| | | |
|---|---|---|
| | PG Model | Pure Perfect Gas: The perfect gas (PG) model is the simplest gas model. It obeys the ideal gas equation of state (pv=RT); moreover, the specific heats are assumed constants. Noble gases, He, Ar, Ne, etc., are genuinely perfect gases. Beside a wide selection, new gases can be constructed by assigning custom material properties. A perfect gas can be considered as a simplified ideal gas.<br>Examples: Air enters an evacuated chamber. To determine the final temperature after the filling process. For specific examples, click on the help icon at the bottom margin of the daemon. |
| | IG Model | Pure Ideal Gas: An ideal gas (IG) is a gas that obeys the ideal gas equation of state (pv=RT). Specific heats are temperature dependent. As a result the IG model is more accurate than the PG model when variation in temperature is significant. Choose from an wide selection of gases.<br>Examples: Air enters an evacuated chamber. To determine the final temperature after the filling process. For specific examples, click on the help icon at the bottom margin of the daemon. |
| Gases: | RG Model | Pure Real Gas: Based on the generalized compressibility chart (pv=ZRT), the real gas (RG) model can handle a large number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy.<br>Examples: A propane tank is filled from a supply line. Note that use of the PC model will produce more accurate results. For specific examples, click on the help icon at the bottom margin of the daemon. |

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:



Open Process Daemon: *Ideal Gas (IG) Model*

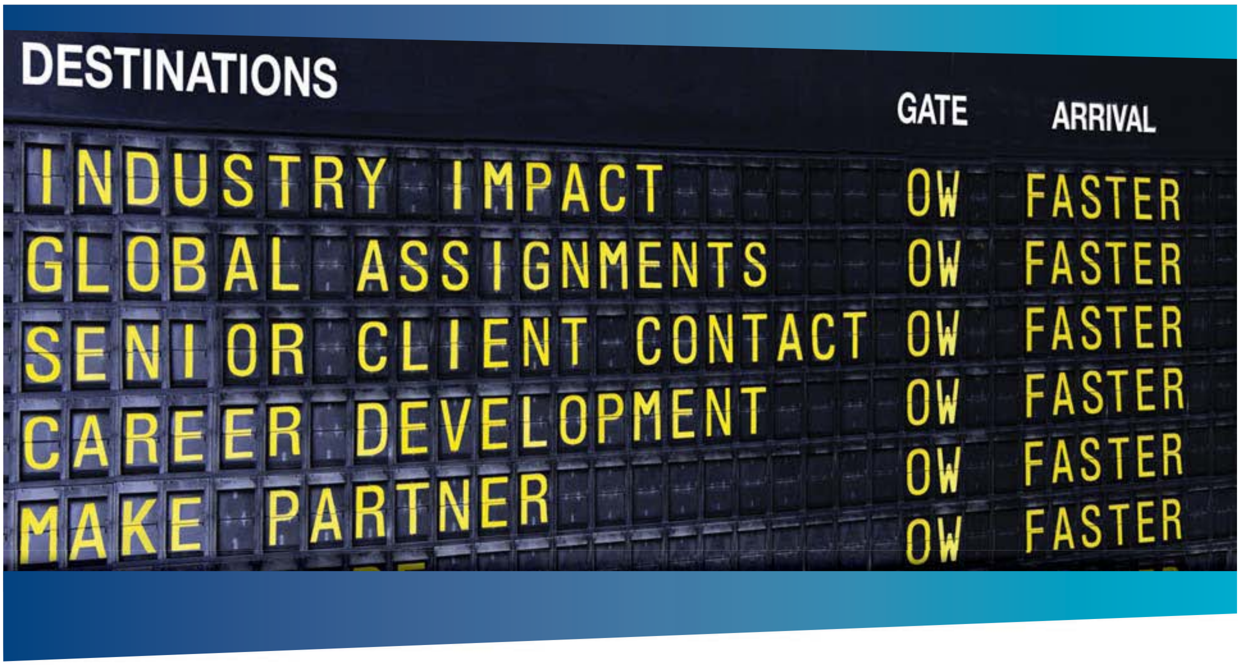
thermofluids.net > Daemons > Systems > Open > Process > IG-Model

Move mouse over a variable to display its value with more precision.

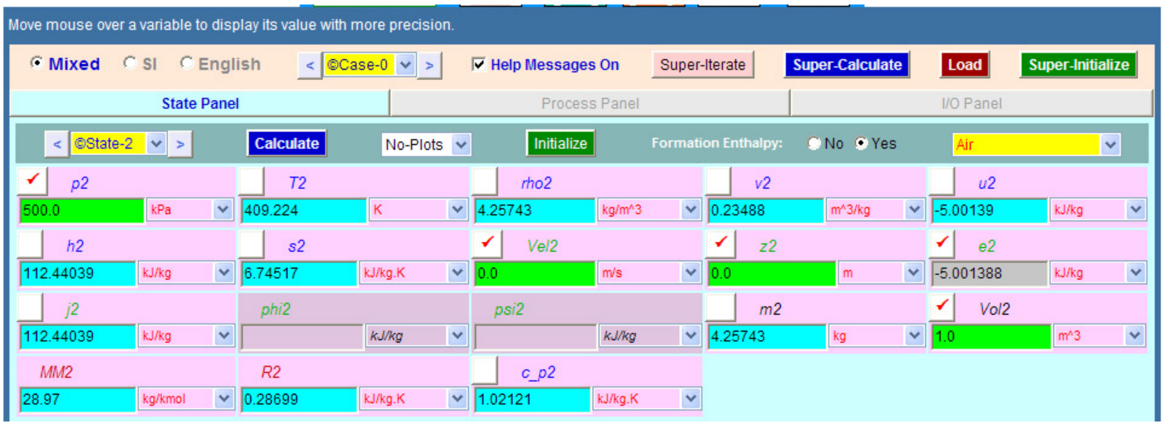
● Mixed ○ SI ○ English | ©Case-0 | ☑ Help Messages On

State Panel | ©State-1 | No-Plots | Formation Enthalpy: ○ No ● Yes | Air

| | | |
|---|---|---|
| ☑ p1 | 0.0 | kPa |
| ☐ T1 | 298.1341 | K |
| ☐ rho1 | 0.0 | kg/m^3 |
| ☐ v1 | Infinity | m^3/kg |
| ☐ u1 | -85.56047 | kJ/kg |
| ☐ h1 | 0.0 | kJ/kg |
| ☐ s1 | 0.0 | kJ/kg.K |
| ☑ Vel1 | 0.0 | m/s |
| ☑ z1 | 0.0 | m |
| ☐ e1 | 0.0 | kJ/kg |
| ☐ j1 | 0.0 | kJ/kg |
| phi1 | 0.0 | kJ/kg |
| psi1 | 0.0 | kJ/kg |
| ☑ m1 | 0.0 | kg |
| ☐ Vol1 | 0.0 | m^3 |
| MM1 | 28.97 | kg/kmol |
| R1 | 0.28699 | kJ/kg.K |
| ☐ c_p1 | 1.00349 | kJ/kg.K |

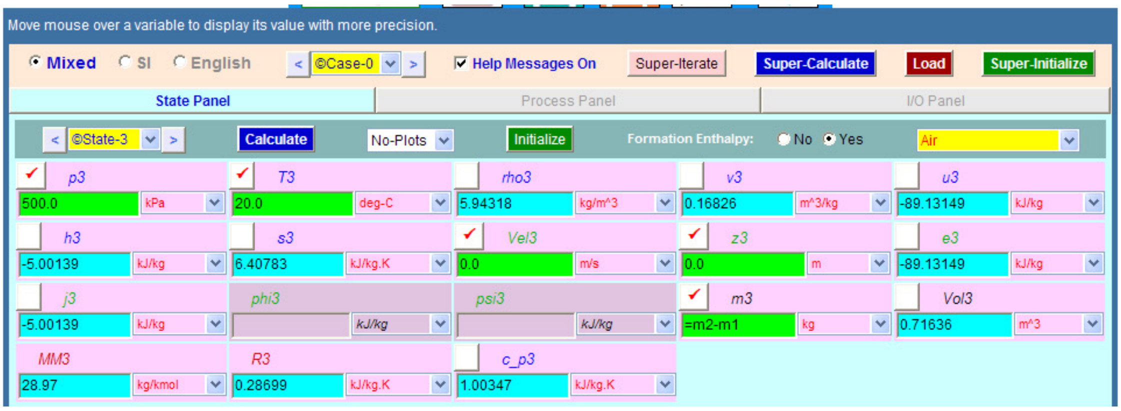


4. Now, enter for State 2. This is the condition of gas in the volume, after it is filled up. Enter p2 = 500 kPa, Vol2 = 1 m^3. Hit Enter. All properties are not calculated since data is not enough. However, they are calculated at the end when SuperCalculate is clicked.



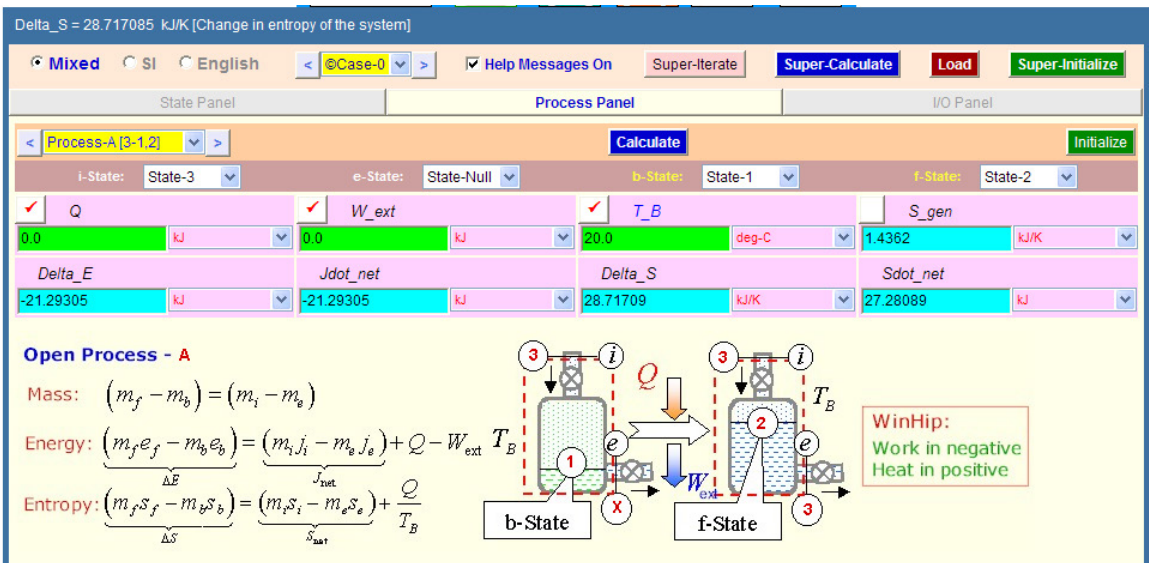
☑ p2: 500.0 kPa
☐ T2: 409.224 K
☐ rho2: 4.25743 kg/m^3
☐ v2: 0.23488 m^3/kg
☐ u2: -5.00139 kJ/kg
☐ h2: 112.44039 kJ/kg
☐ s2: 6.74517 kJ/kg.K
☑ Vel2: 0.0 m/s
☑ z2: 0.0 m
☑ e2: -5.001388 kJ/kg
☐ j2: 112.44039 kJ/kg
phi2: kJ/kg
psi2: kJ/kg
☐ m2: 4.25743 kg
☑ Vol2: 1.0 m^3
MM2: 28.97 kg/kmol
R2: 0.28699 kJ/kg.K
☐ c_p2: 1.02121 kJ/kg.K

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:



☑ p3: 500.0 kPa
☑ T3: 20.0 deg-C
☐ rho3: 5.94318 kg/m^3
☐ v3: 0.16826 m^3/kg
☐ u3: -89.13149 kJ/kg
☐ h3: -5.00139 kJ/kg
☐ s3: 6.40783 kJ/kg.K
☑ Vel3: 0.0 m/s
☑ z3: 0.0 m
☐ e3: -89.13149 kJ/kg
☐ j3: -5.00139 kJ/kg
phi3: kJ/kg
psi3: kJ/kg
☑ m3: =m2-m1 kg
☐ Vol3: 0.71636 m^3
MM3: 28.97 kg/kmol
R3: 0.28699 kJ/kg.K
☐ c_p3: 1.00347 kJ/kg.K

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:


Delta_S = 28.717085 kJ/K [Change in entropy of the system]

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Process Panel — Process-A [3-1,2]

i-State: State-3 e-State: State-Null b-State: State-1 f-State: State-2

☑ Q: 0.0 kJ
☑ W_ext: 0.0 kJ
☑ T_B: 20.0 deg-C
☐ S_gen: 1.4362 kJ/K

Delta_E: -21.29305 kJ
Jdot_net: -21.29305 kJ
Delta_S: 28.71709 kJ/K
Sdot_net: 27.28089 kJ

Open Process - A

Mass: $(m_f - m_b) = (m_i - m_e)$

Energy: $\underbrace{(m_f e_f - m_b e_b)}_{\Delta E} = \underbrace{(m_i j_i - m_e j_e)}_{J_{net}} + Q - W_{ext}$

Entropy: $\underbrace{(m_f s_f - m_b s_b)}_{\Delta S} = \underbrace{(m_i s_i - m_e s_e)}_{S_{net}} + \frac{Q}{T_B}$

WinHip:
Work in negative
Heat in positive

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

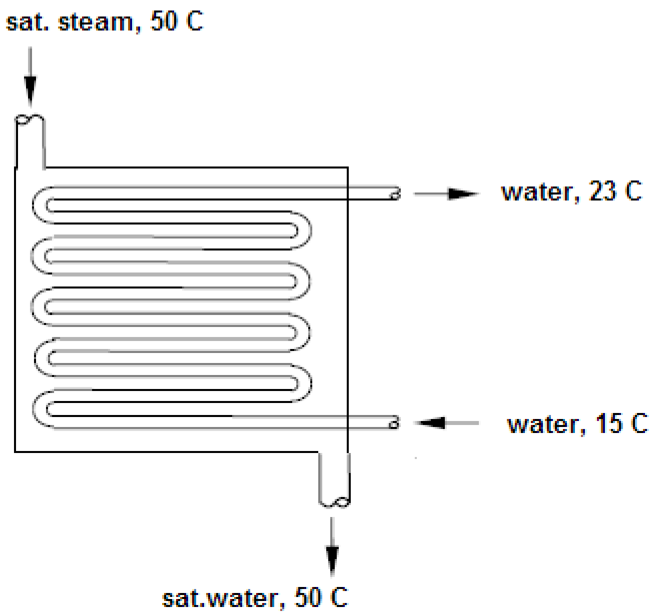
Therefore, change in Availability:

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

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

=================================================================

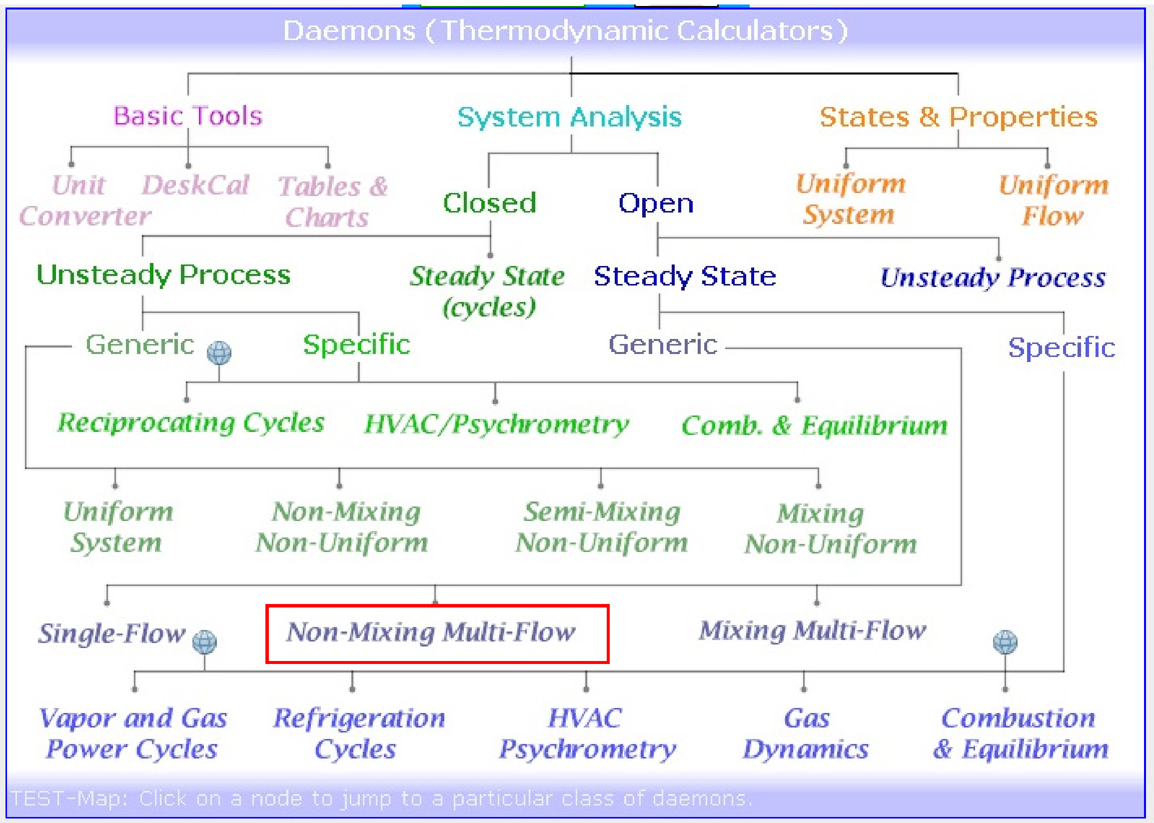
**Prob.8.26.** Steam is to be condensed on the shell side of a heat exchanger at 50 C. Cooling water enters the tubes at 15 C at a rate of 55 kg/s and leaves at 23 C. Assuming the heat exchanger to be well insulated, determine: (a) rate of heat transfer in the heat exchanger, and (b) rate of exergy destruction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



**TEST Solution:**

**Following are the steps:**

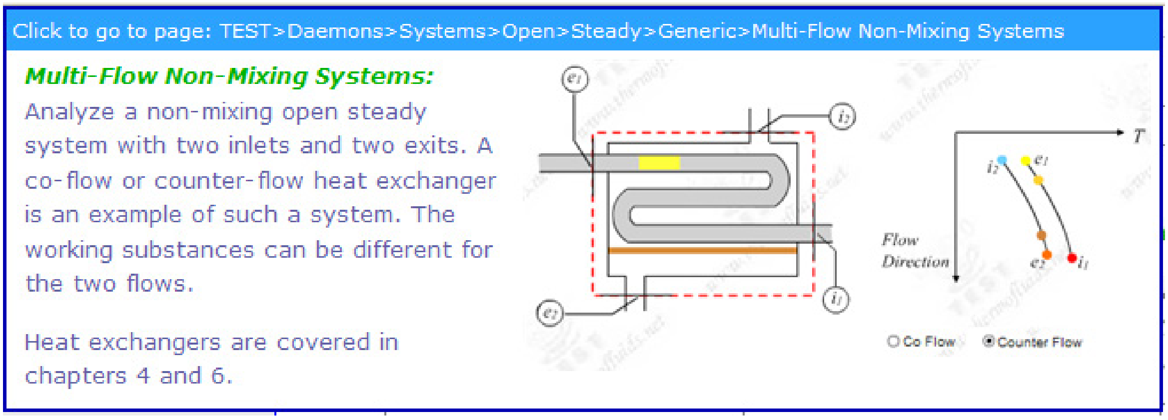
1. Choose System Analysis-Open-Non-Mixing Multi-flow daemon from the daemon tree.



Daemons (Thermodynamic Calculators)

TEST-Map: Click on a node to jump to a particular class of daemons.

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



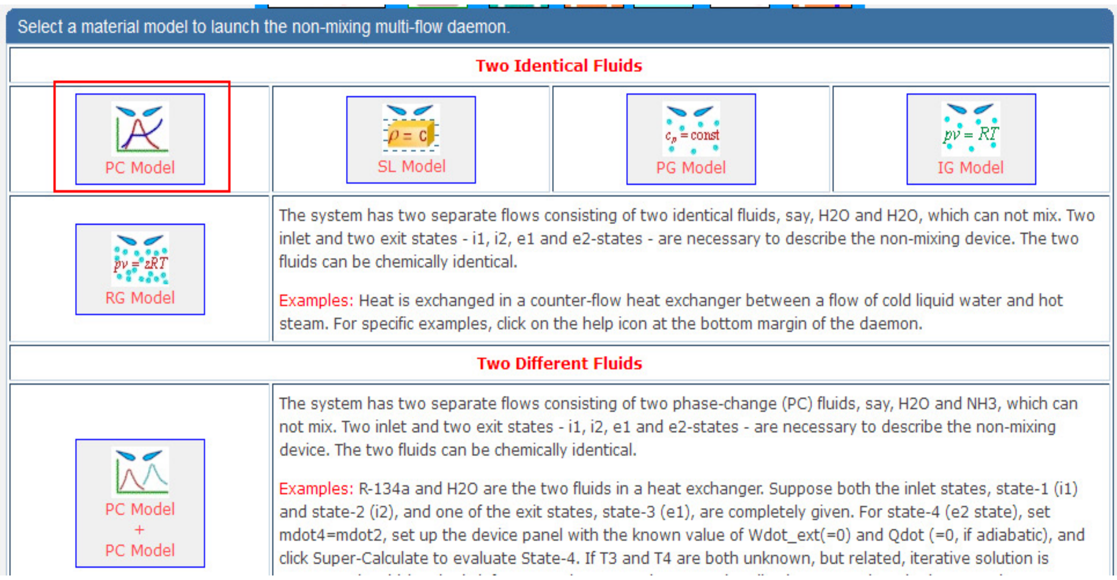
Click to go to page: TEST>Daemons>Systems>Open>Steady>Generic>Multi-Flow Non-Mixing Systems

***Multi-Flow Non-Mixing Systems:***

Analyze a non-mixing open steady system with two inlets and two exits. A co-flow or counter-flow heat exchanger is an example of such a system. The working substances can be different for the two flows.

Heat exchangers are covered in chapters 4 and 6.

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



Select a material model to launch the non-mixing multi-flow daemon.

Two Identical Fluids

The system has two separate flows consisting of two identical fluids, say, H2O and H2O, which can not mix. Two inlet and two exit states - i1, i2, e1 and e2-states - are necessary to describe the non-mixing device. The two fluids can be chemically identical.

Examples: Heat is exchanged in a counter-flow heat exchanger between a flow of cold liquid water and hot steam. For specific examples, click on the help icon at the bottom margin of the daemon.

Two Different Fluids

The system has two separate flows consisting of two phase-change (PC) fluids, say, H2O and NH3, which can not mix. Two inlet and two exit states - i1, i2, e1 and e2-states - are necessary to describe the non-mixing device. The two fluids can be chemically identical.

Examples: R-134a and H2O are the two fluids in a heat exchanger. Suppose both the inlet states, state-1 (i1) and state-2 (i2), and one of the exit states, state-3 (e1), are completely given. For state-4 (e2 state), set mdot4=mdot2, set up the device panel with the known value of Wdot_ext(=0) and Qdot (=0, if adiabatic), and click Super-Calculate to evaluate State-4. If T3 and T4 are both unknown, but related, iterative solution is

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:

Move mouse over a variable to display its value with more precision.

Saturated Mixture

H2O

☐ p1: 12.35001 kPa
☑ T1: 50.0 deg-C
☑ x1: 0.0 fraction
☐ y1: 0.0 fraction
☐ v1: 0.00101 m^3/kg
☐ u1: 209.3175 kJ/kg
☐ h1: 209.33 kJ/kg
☐ s1: 0.7038 kJ/kg.K
☑ Vel1: 0.0 m/s
☑ z1: 0.0 m
☐ e1: 209.3175 kJ/kg
☐ j1: 209.33 kJ/kg
phi1: kJ/kg
psi1: kJ/kg
☑ mdot1: =mdot3*(h4-h3)/(I kg/s
☐ Voldot1: 7.8E-4 m^3/s
☐ A1: 78.2984 m^2
MM1: 18.0 kg/kmol

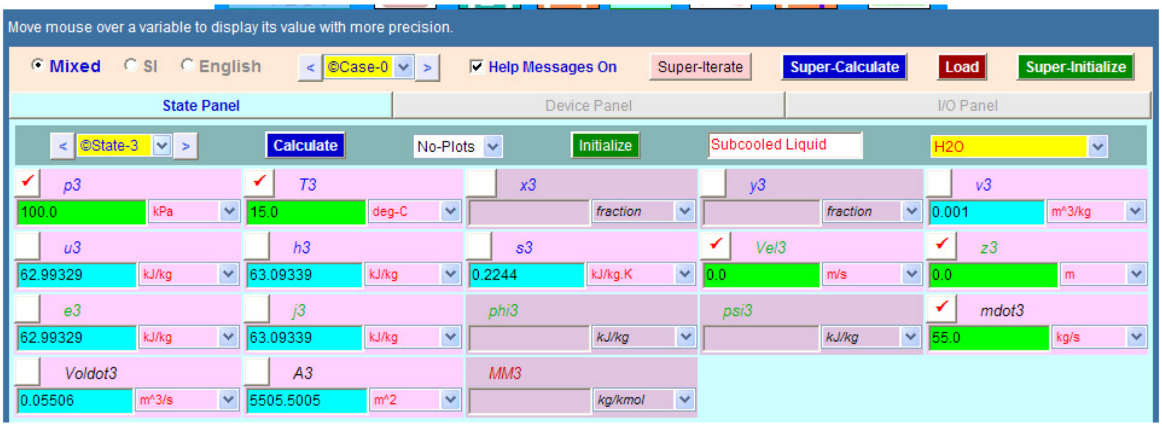
4. For State 2, i.e. sat.vapour state, inlet of steam to condenser: enter T2, x2 = 1 for sat. vap. Also, mdot2 = mdot1, unknown as of now, but will be posted back later. Hit Enter. We get:

Move mouse over a variable to display its value with more precision.

©State-2 | Saturated Mixture | H2O

p2: 12.35001 kPa
✓ T2: 50.0 deg-C
✓ x2: 1.0 fraction
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
✓ Vel2: 0.0 m/s
✓ z2: 0.0 m
e2: 2443.5295 kJ/kg
j2: 2592.1 kJ/kg
phi2: kJ/kg
psi2: kJ/kg
✓ mdot2: 0.7736996 kg/s
Voldot2: 9.30761 m^3/s
A2: 930760.56 m^2
MM2: 18.0 kg/kmol

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

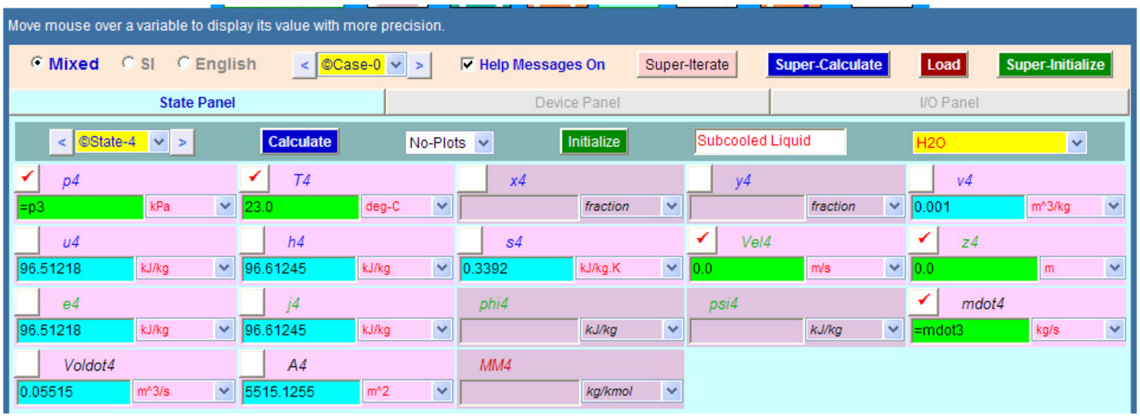


Move mouse over a variable to display its value with more precision.

©State-3 | Subcooled Liquid | H2O

✓ p3: 100.0 kPa
✓ T3: 15.0 deg-C
x3: fraction
y3: fraction
v3: 0.001 m^3/kg
u3: 62.99329 kJ/kg
h3: 63.09339 kJ/kg
s3: 0.2244 kJ/kg.K
✓ Vel3: 0.0 m/s
✓ z3: 0.0 m
e3: 62.99329 kJ/kg
j3: 63.09339 kJ/kg
phi3: kJ/kg
psi3: kJ/kg
✓ mdot3: 55.0 kg/s
Voldot3: 0.05506 m^3/s
A3: 5505.5005 m^2
MM3: kg/kmol

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

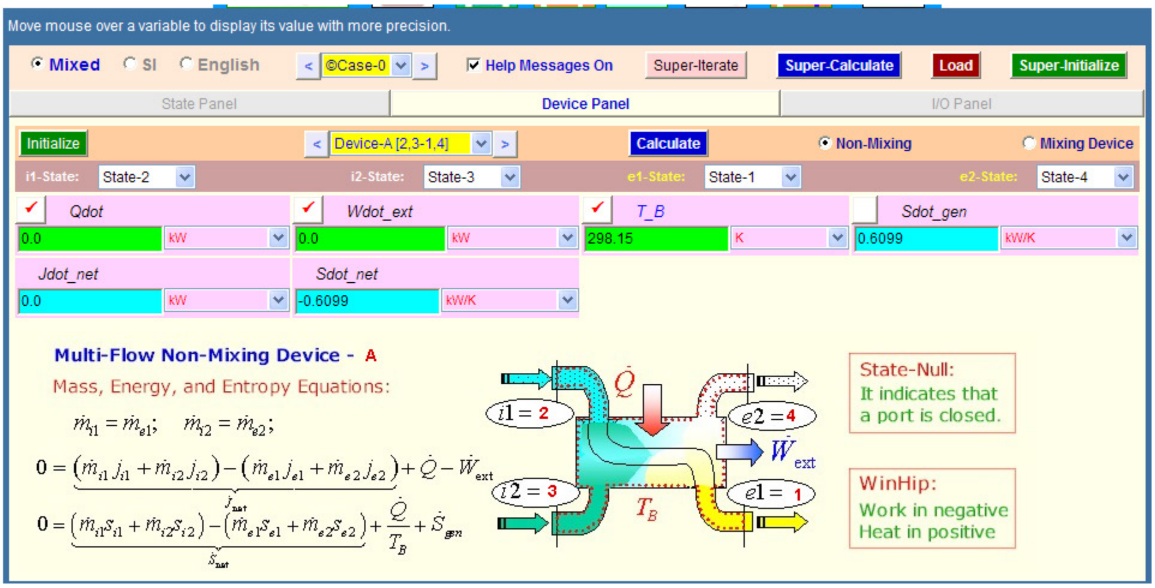


Move mouse over a variable to display its value with more precision.

©State-4 | Subcooled Liquid | H2O

✓ p4: =p3 kPa
✓ T4: 23.0 deg-C
x4: fraction
y4: fraction
v4: 0.001 m^3/kg
u4: 96.51218 kJ/kg
h4: 96.61245 kJ/kg
s4: 0.3392 kJ/kg.K
✓ Vel4: 0.0 m/s
✓ z4: 0.0 m
e4: 96.51218 kJ/kg
j4: 96.61245 kJ/kg
phi4: kJ/kg
psi4: kJ/kg
✓ mdot4: =mdot3 kg/s
Voldot4: 0.05515 m^3/s
A4: 5515.1255 m^2
MM4: kg/kmol

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:


Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English

©Case-0

☑ Help Messages On

Device-A [2,3-1,4]

● Non-Mixing ○ Mixing Device

i1-State: State-2
i2-State: State-3
e1-State: State-1
e2-State: State-4

✓ Qdot: 0.0 kW
✓ Wdot_ext: 0.0 kW
✓ T_B: 298.15 K
☐ Sdot_gen: 0.6099 kW/K
Jdot_net: 0.0 kW
Sdot_net: -0.6099 kW/K

State-Null: It indicates that a port is closed.

WinHip: Work in negative Heat in positive

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:**

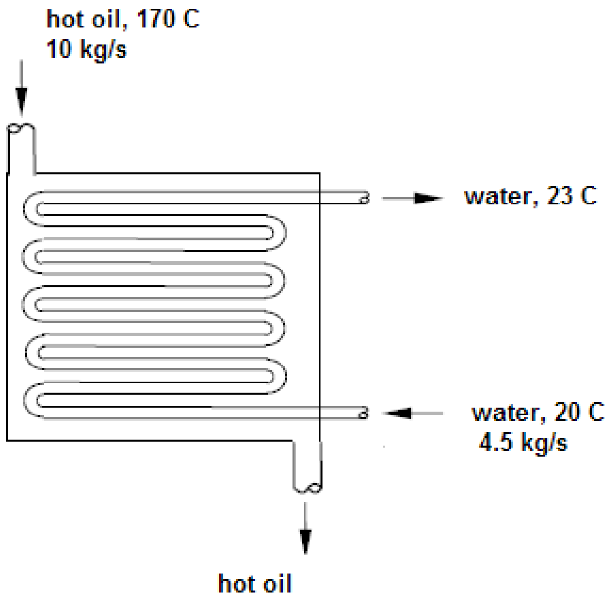
```
#    Device-A: i-State = State-2, State-3; e-State = State-1, State-4; Mixing: false;

#    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;

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

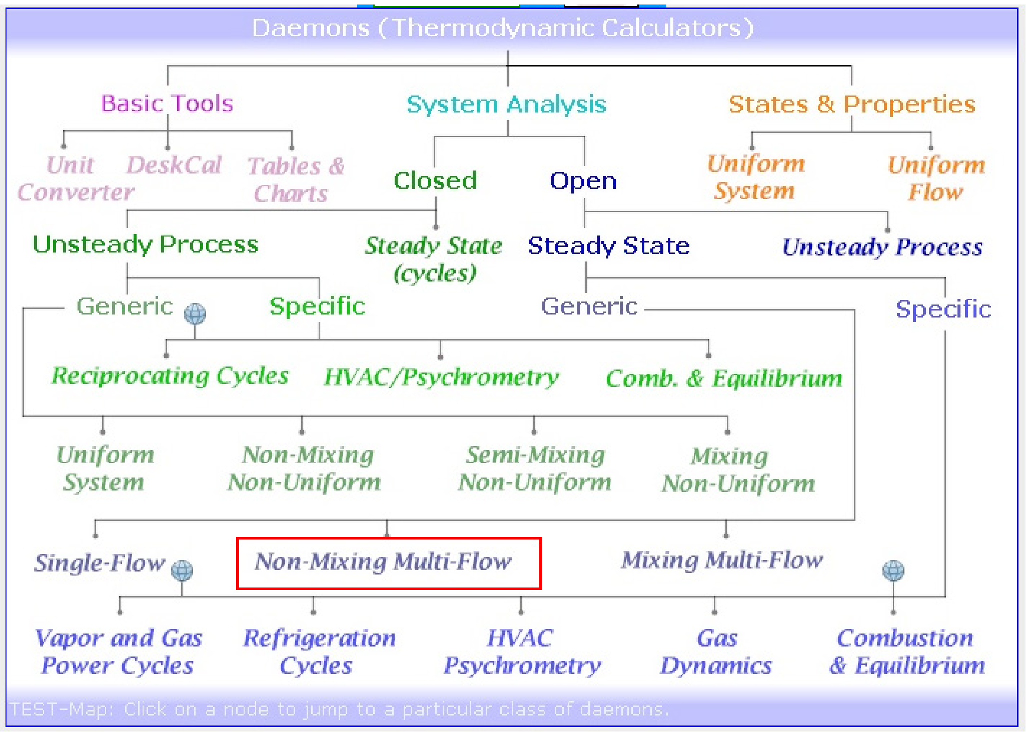
**Prob.8.27.** A well insulated shell & tube heat exchanger is used to heat water (cp = 4.184 kJ/kg.C) in the tubes from 20 to 70 C at a rate of 4.5 kg/s. Heat is supplied by hot oil (cp = 1.8 kJ/kg.C) that enters the shell side at 170 C at a rate of 10 kg/s. Neglecting the heat loss from the heat exchanger,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



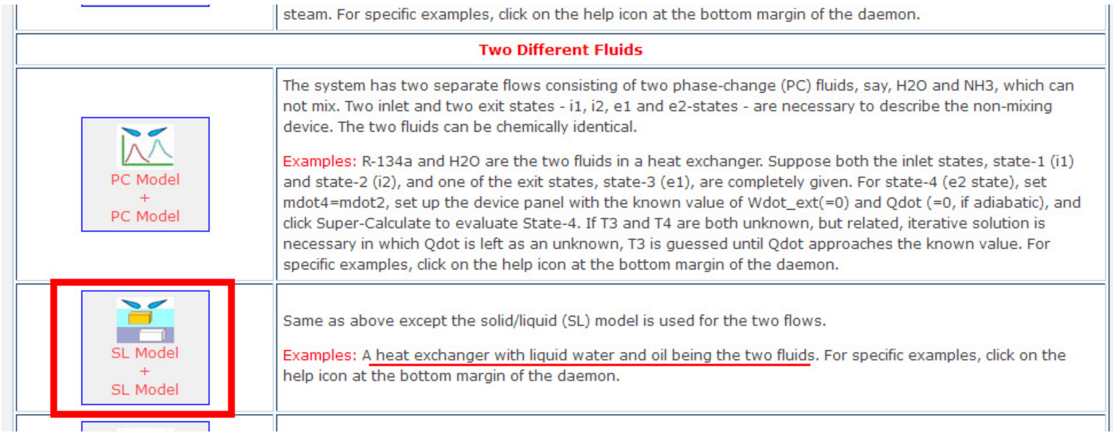
**TEST Solution:**

**Following are the steps:**

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

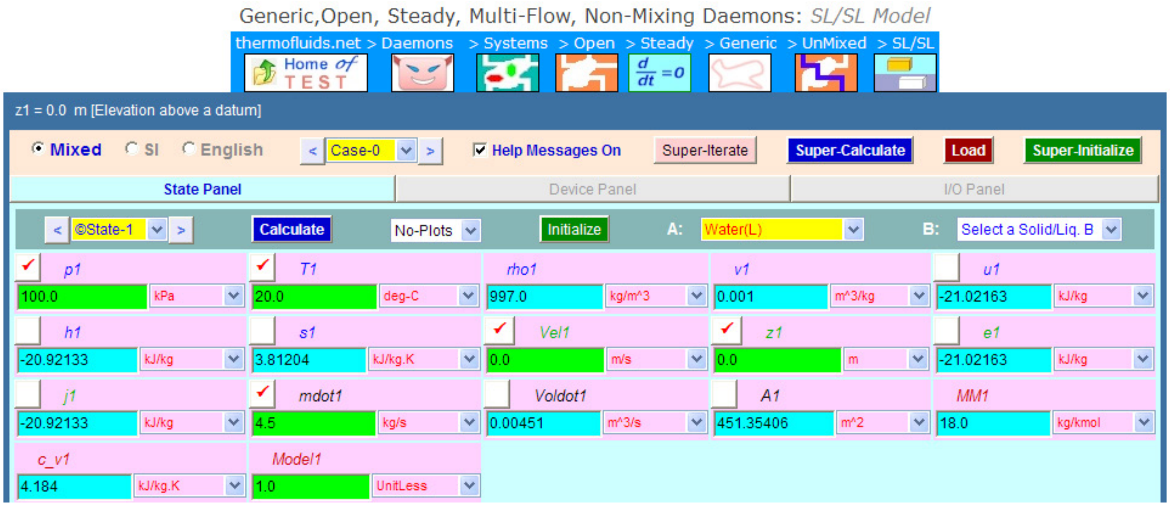


2. For material model, select SL/SL model since we are dealing with water / oil.



| | |
|---|---|
| | steam. For specific examples, click on the help icon at the bottom margin of the daemon. |
| **Two Different Fluids** | |
| PC Model + PC Model | The system has two separate flows consisting of two phase-change (PC) fluids, say, H2O and NH3, which can not mix. Two inlet and two exit states - i1, i2, e1 and e2-states - are necessary to describe the non-mixing device. The two fluids can be chemically identical.<br>Examples: R-134a and H2O are the two fluids in a heat exchanger. Suppose both the inlet states, state-1 (i1) and state-2 (i2), and one of the exit states, state-3 (e1), are completely given. For state-4 (e2 state), set mdot4=mdot2, set up the device panel with the known value of Wdot_ext(=0) and Qdot (=0, if adiabatic), and click Super-Calculate to evaluate State-4. If T3 and T4 are both unknown, but related, iterative solution is necessary in which Qdot is left as an unknown, T3 is guessed until Qdot approaches the known value. For specific examples, click on the help icon at the bottom margin of the daemon. |
| SL Model + SL Model | Same as above except the solid/liquid (SL) model is used for the two flows.<br>Examples: A heat exchanger with liquid water and oil being the two fluids. For specific examples, click on the help icon at the bottom margin of the daemon. |

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:



Generic,Open, Steady, Multi-Flow, Non-Mixing Daemons: *SL/SL Model*

thermofluids.net > Daemons > Systems > Open > Steady > Generic > UnMixed > SL/SL

z1 = 0.0 m [Elevation above a datum]

● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On | Super-Iterate | Super-Calculate | Load | Super-Initialize

State Panel | Device Panel | I/O Panel

State-1 | Calculate | No-Plots | Initialize | A: Water(L) | B: Select a Solid/Liq. B

| | | | | |
|---|---|---|---|---|
| ☑ p1<br>100.0 kPa | ☑ T1<br>20.0 deg-C | rho1<br>997.0 kg/m^3 | v1<br>0.001 m^3/kg | ☐ u1<br>-21.02163 kJ/kg |
| ☐ h1<br>-20.92133 kJ/kg | ☐ s1<br>3.81204 kJ/kg.K | ☑ Vel1<br>0.0 m/s | ☑ z1<br>0.0 m | ☐ e1<br>-21.02163 kJ/kg |
| ☐ j1<br>-20.92133 kJ/kg | ☑ mdot1<br>4.5 kg/s | ☐ Voldot1<br>0.00451 m^3/s | ☐ A1<br>451.35406 m^2 | MM1<br>18.0 kg/kmol |
| c_v1<br>4.184 kJ/kg.K | Model1<br>1.0 UnitLess | | | |

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

Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English | Case-0 | ☑ Help Messages On | Super-Iterate | Super-Calculate | Load | Super-Initialize

State Panel | Device Panel | I/O Panel

State-2 | Calculate | No-Plots | Initialize | A: Water(L) | B: Water(L)

| | | | | |
|---|---|---|---|---|
| ☑ p2<br>100.0 kPa | ☑ T2<br>70.0 deg-C | rho2<br>997.0 kg/m^3 | v2<br>0.001 m^3/kg | ☐ u2<br>188.17838 kJ/kg |
| ☐ h2<br>188.27867 kJ/kg | ☐ s2<br>4.47095 kJ/kg.K | ☑ Vel2<br>0.0 m/s | ☑ z2<br>0.0 m | ☐ e2<br>188.17838 kJ/kg |
| ☐ j2<br>188.27867 kJ/kg | ☑ mdot2<br>=mdot1 kg/s | ☐ Voldot2<br>0.00451 m^3/s | ☐ A2<br>451.35406 m^2 | MM2<br>18.0 kg/kmol |
| c_v2<br>4.184 kJ/kg.K | Model2<br>2.0 UnitLess | | | |

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

p3 = 100.0 kPa [Absolute pressure]

A: Oil(L)
B: Oil(L)

| | Property | Value | Unit |
|---|---|---|---|
| ✓ | p3 | 100.0 | kPa |
| ✓ | T3 | 170.0 | deg-C |
| | rho3 | 910.0 | kg/m^3 |
| | v3 | 0.0011 | m^3/kg |
| ☐ | u3 | 260.88864 | kJ/kg |
| ☐ | h3 | 260.99854 | kJ/kg |
| ☐ | s3 | 0.71336 | kJ/kg.K |
| ✓ | Vel3 | 0.0 | m/s |
| ✓ | z3 | 0.0 | m |
| ☐ | e3 | 260.88864 | kJ/kg |
| ☐ | j3 | 260.99854 | kJ/kg |
| ✓ | mdot3 | 10.0 | kg/s |
| ☐ | Voldot3 | 0.01099 | m^3/s |
| ☐ | A3 | 1098.9011 | m^2 |
| | MM3 | 114.0 | kg/kmol |
| | c_v3 | 1.8 | kJ/kg.K |
| | Model3 | 2.0 | UnitLess |

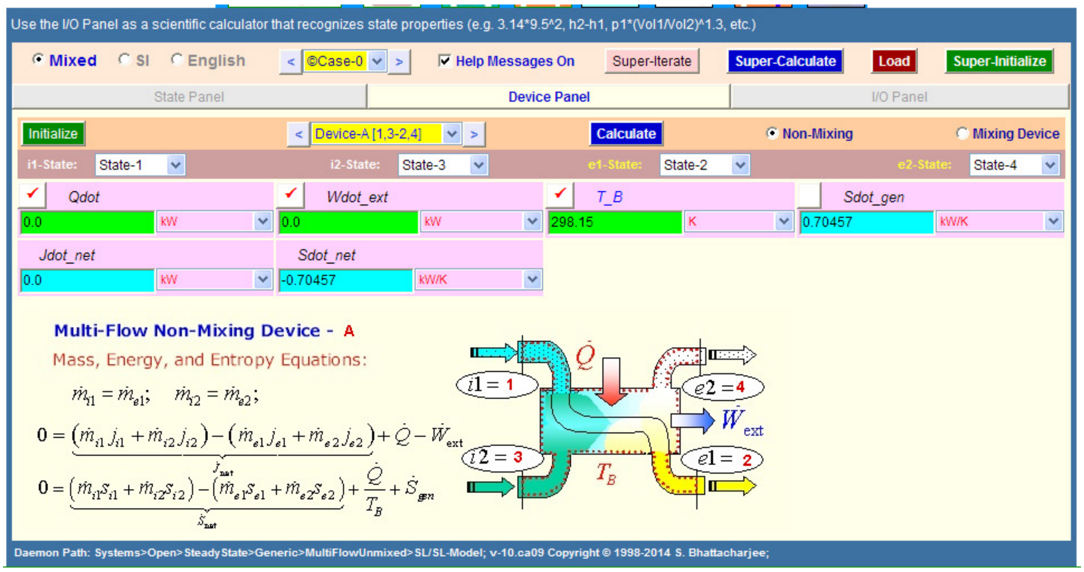
6. For State 4: Enter p4, mdot4, and T4 = T3 – (mdot1 * c_v1) * (T2 – T1) / (mdot3* c_v3). Hit Enter. We get:

A: Oil(L)
B: Oil(L)

☑ p4: 100.0 kPa
☑ T4: =T3-(mdot1*c_v1) deg-C
rho4: 910.0 kg/m^3
v4: 0.0011 m^3/kg
☐ u4: 166.74866 kJ/kg
☐ h4: 166.85854 kJ/kg
☐ s4: 0.48731 kJ/kg.K
☑ Vel4: 0.0 m/s
☑ z4: 0.0 m
☐ e4: 166.74866 kJ/kg
☐ j4: 166.85854 kJ/kg
☑ mdot4: =mdot3 kg/s
☐ Voldot4: 0.01099 m^3/s
☐ A4: 1098.9011 m^2
MM4: 114.0 kg/kmol
c_v4: 1.8 kJ/kg.K
Model4: 2.0 UnitLess

**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:



i1-State: State-1
i2-State: State-3
e1-State: State-2
e2-State: State-4

☑ Qdot: 0.0 kW
☑ Wdot_ext: 0.0 kW
☑ T_B: 298.15 K
☐ Sdot_gen: 0.70457 kW/K
Jdot_net: 0.0 kW
Sdot_net: -0.70457 kW/K

**Multi-Flow Non-Mixing Device - A**

Mass, Energy, and Entropy Equations:

$$\dot{m}_{i1} = \dot{m}_{e1}; \quad \dot{m}_{i2} = \dot{m}_{e2};$$

$$0 = \underbrace{\left(\dot{m}_{i1} j_{i1} + \dot{m}_{i2} j_{i2}\right) - \left(\dot{m}_{e1} j_{e1} + \dot{m}_{e2} j_{e2}\right)}_{\dot{J}_{net}} + \dot{Q} - \dot{W}_{ext}$$

$$0 = \underbrace{\left(\dot{m}_{i1} s_{i1} + \dot{m}_{i2} s_{i2}\right) - \left(\dot{m}_{e1} s_{e1} + \dot{m}_{e2} s_{e2}\right)}_{\dot{S}_{net}} + \frac{\dot{Q}}{T_B} + \dot{S}_{gen}$$

Daemon Path: Systems>Open>SteadyState>Generic>MultiFlowUnmixed>SL/SL-Model; v-10.ca09 Copyright © 1998-2014 S. Bhattacharjee;

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.**

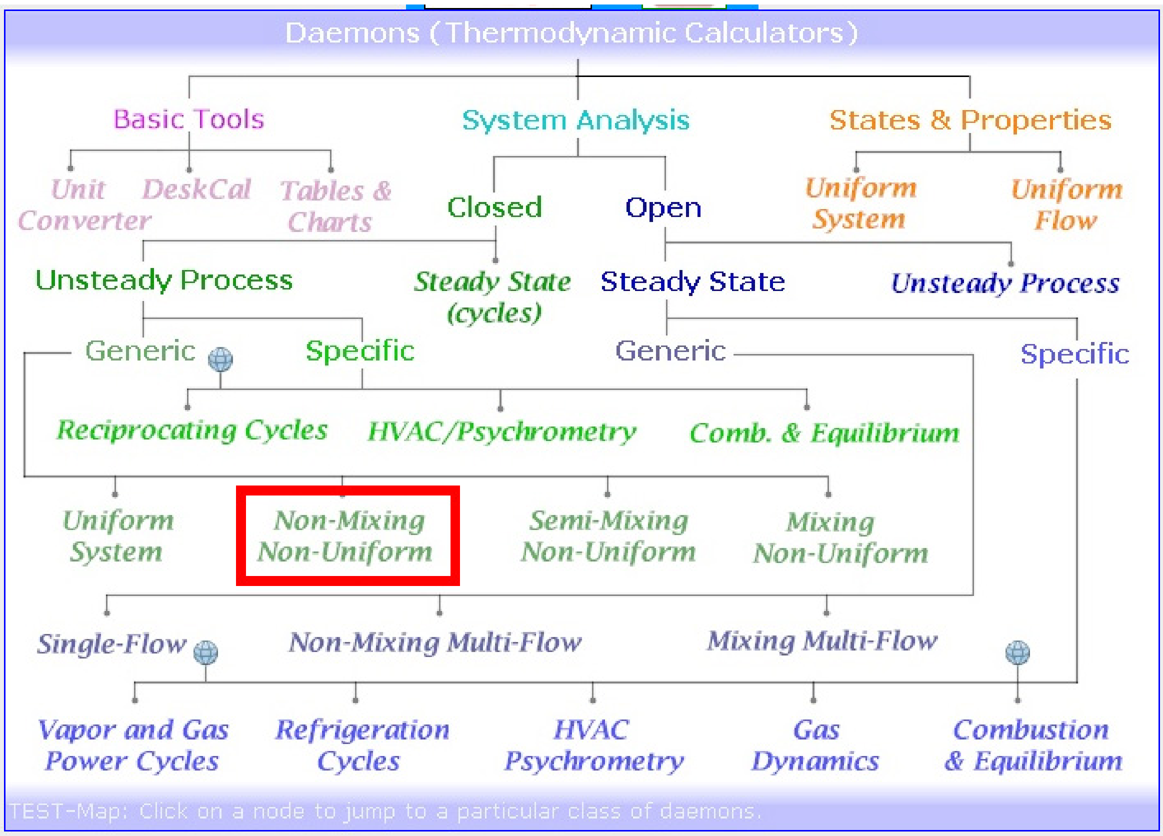
=====================================================================

**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.

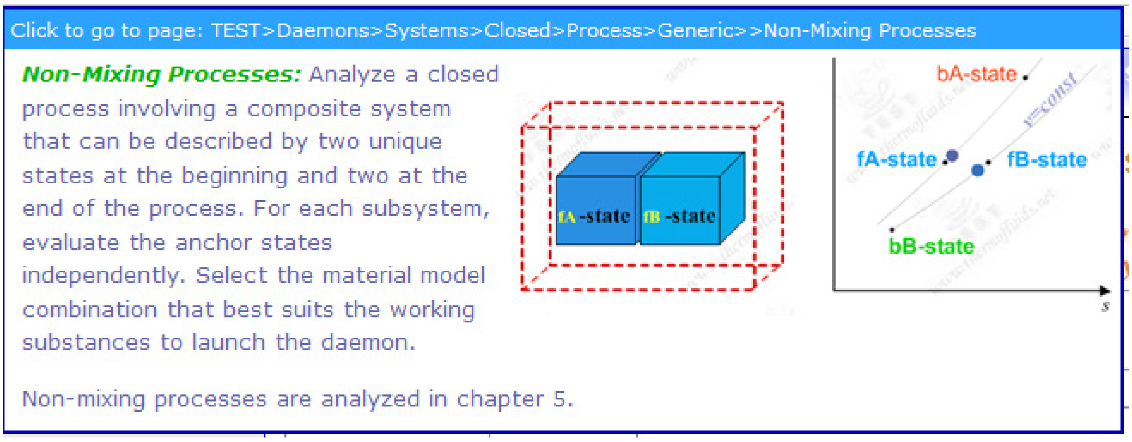
**TEST Solution:**

**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:

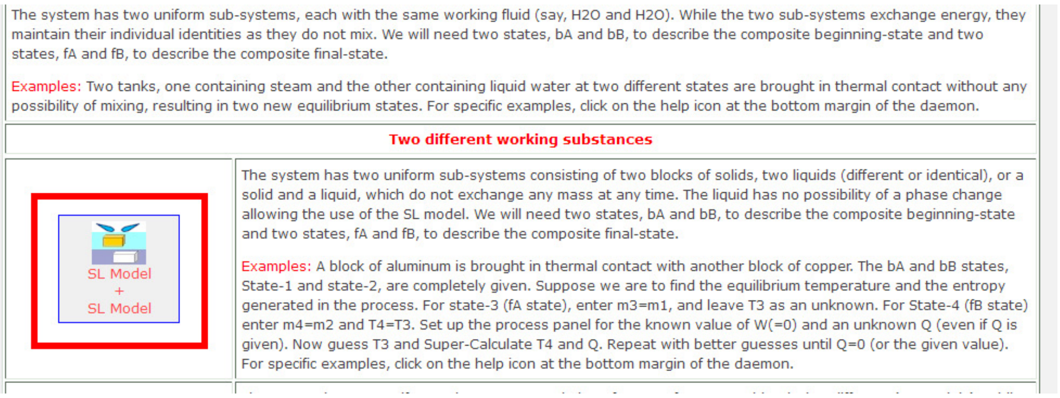


Click to go to page: TEST>Daemons>Systems>Closed>Process>Generic>>Non-Mixing Processes

***Non-Mixing Processes:*** Analyze a closed process involving a composite system that can be described by two unique states at the beginning and two at the end of the process. For each subsystem, evaluate the anchor states independently. Select the material model combination that best suits the working substances to launch the daemon.

Non-mixing processes are analyzed in chapter 5.

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



The system has two uniform sub-systems, each with the same working fluid (say, H2O and H2O). While the two sub-systems exchange energy, they maintain their individual identities as they do not mix. We will need two states, bA and bB, to describe the composite beginning-state and two states, fA and fB, to describe the composite final-state.

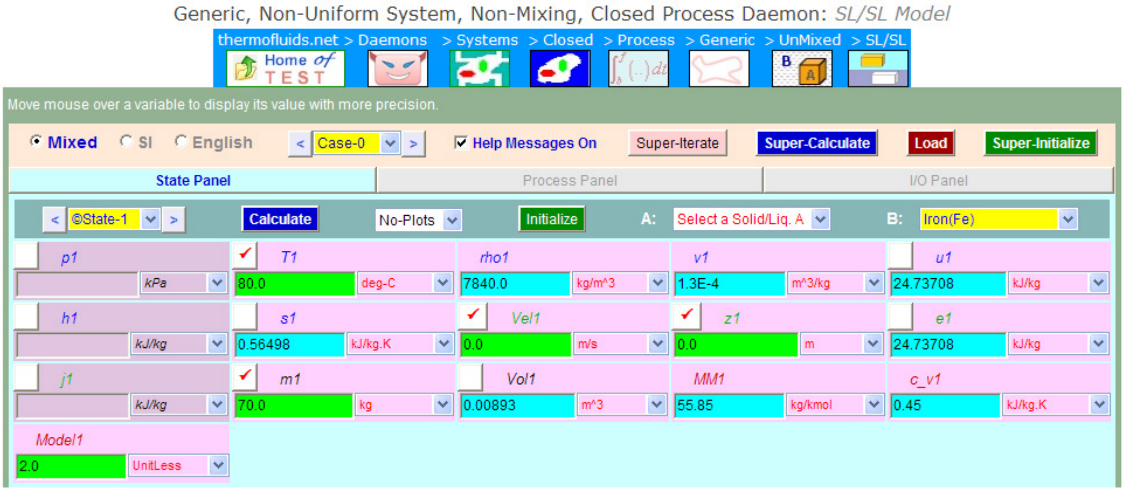
Examples: Two tanks, one containing steam and the other containing liquid water at two different states are brought in thermal contact without any possibility of mixing, resulting in two new equilibrium states. For specific examples, click on the help icon at the bottom margin of the daemon.

**Two different working substances**

The system has two uniform sub-systems consisting of two blocks of solids, two liquids (different or identical), or a solid and a liquid, which do not exchange any mass at any time. The liquid has no possibility of a phase change allowing the use of the SL model. We will need two states, bA and bB, to describe the composite beginning-state and two states, fA and fB, to describe the composite final-state.

Examples: A block of aluminum is brought in thermal contact with another block of copper. The bA and bB states, State-1 and state-2, are completely given. Suppose we are to find the equilibrium temperature and the entropy generated in the process. For state-3 (fA state), enter m3=m1, and leave T3 as an unknown. For State-4 (fB state) enter m4=m2 and T4=T3. Set up the process panel for the known value of W(=0) and an unknown Q (even if Q is given). Now guess T3 and Super-Calculate T4 and Q. Repeat with better guesses until Q=0 (or the given value). For specific examples, click on the help icon at the bottom margin of the daemon.

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:

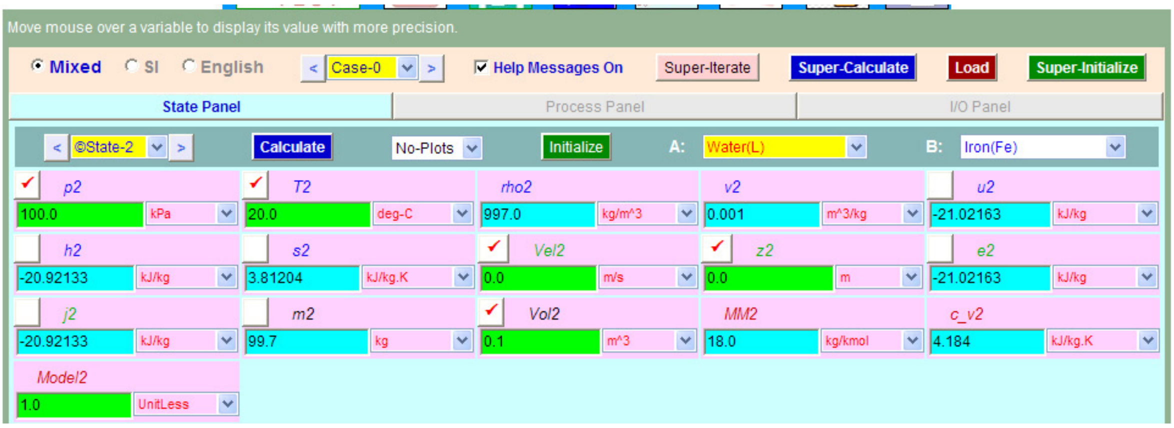


Generic, Non-Uniform System, Non-Mixing, Closed Process Daemon: *SL/SL Model*

A: Select a Solid/Liq. A    B: Iron(Fe)

☐ p1: kPa
☑ T1: 80.0 deg-C
rho1: 7840.0 kg/m^3
v1: 1.3E-4 m^3/kg
☐ u1: 24.73708 kJ/kg
☐ h1: kJ/kg
☐ s1: 0.56498 kJ/kg.K
☑ Vel1: 0.0 m/s
☑ z1: 0.0 m
☐ e1: 24.73708 kJ/kg
☐ j1: kJ/kg
☑ m1: 70.0 kg
☐ Vol1: 0.00893 m^3
MM1: 55.85 kg/kmol
c_v1: 0.45 kJ/kg.K
Model1: 2.0 UnitLess

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:



Move mouse over a variable to display its value with more precision.

● Mixed ○ SI ○ English

Case-0

☑ Help Messages On

©State-2

No-Plots

A: Water(L)

B: Iron(Fe)

☑ p2 = 100.0 kPa
☑ T2 = 20.0 deg-C
rho2 = 997.0 kg/m^3
v2 = 0.001 m^3/kg
☐ u2 = -21.02163 kJ/kg
☐ h2 = -20.92133 kJ/kg
☐ s2 = 3.81204 kJ/kg.K
☑ Vel2 = 0.0 m/s
☑ z2 = 0.0 m
☐ e2 = -21.02163 kJ/kg
☐ j2 = -20.92133 kJ/kg
☐ m2 = 99.7 kg
☑ Vol2 = 0.1 m^3
MM2 = 18.0 kg/kmol
c_v2 = 4.184 kJ/kg.K
Model2 = 1.0 UnitLess

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:

T3 =(m1*c_v1*T1 + m2*c_v2*T2)/ (m1*c_v1+m2*c_v2) = 24.212687 deg-C [Absolute temperature]

● Mixed ○ SI ○ English; Case-0; ☑ Help Messages On

State-3; No-Plots; A: Water(L); B: Iron(Fe)

☐ p3: kPa
☑ T3: =(m1*c_v1*T1 + m deg-C
rho3: 7840.0 kg/m^3
v3: 1.3E-4 m^3/kg
☐ u3: -0.36722 kJ/kg
☐ h3: kJ/kg
☐ s3: 0.48761 kJ/kg.K
☑ Vel3: 0.0 m/s
☑ z3: 0.0 m
☐ e3: -0.36722 kJ/kg
☐ j3: kJ/kg
☑ m3: =m1 kg
☐ Vol3: 0.00893 m^3
MM3: 55.85 kg/kmol
c_v3: 0.45 kJ/kg.K
Model3: 2.0 UnitLess

**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:

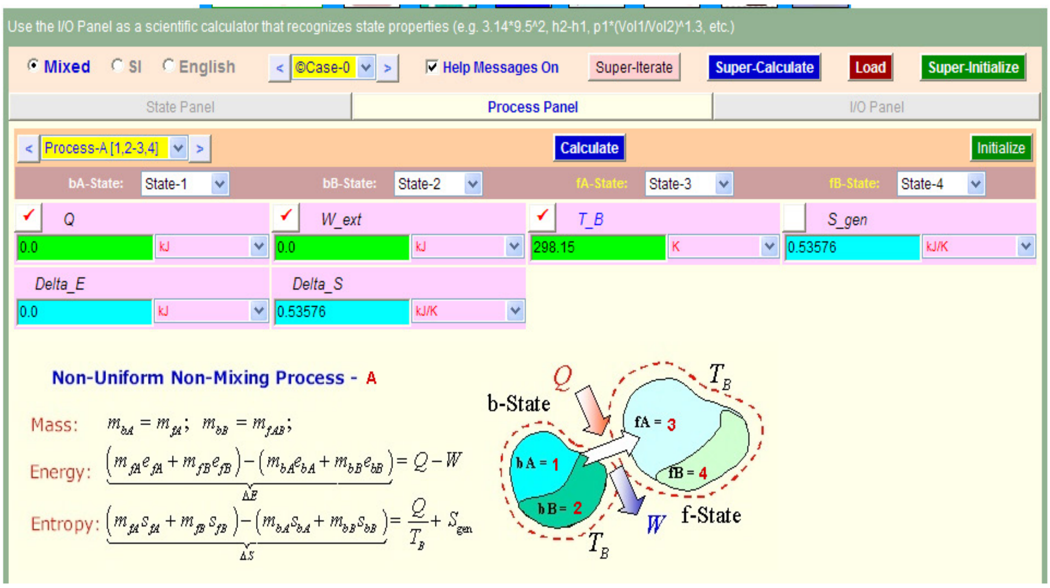
T4 =T3 = 24.212687 deg-C [Absolute temperature]

● Mixed ○ SI ○ English; Case-0; ☑ Help Messages On

State-4; No-Plots; A: Water(L); B: Water(L)

☑ p4: 100.0 kPa
☑ T4: =T3 deg-C
rho4: 997.0 kg/m^3
v4: 0.001 m^3/kg
☐ u4: -3.39575 kJ/kg
☐ h4: -3.29545 kJ/kg
☐ s4: 3.87174 kJ/kg.K
☑ Vel4: 0.0 m/s
☑ z4: 0.0 m
☐ e4: -3.39575 kJ/kg
☐ j4: -3.29545 kJ/kg
☑ m4: =m2 kg
☐ Vol4: 0.1 m^3
MM4: 18.0 kg/kmol
c_v4: 4.184 kJ/kg.K
Model4: 2.0 UnitLess

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:



Use the I/O Panel as a scientific calculator that recognizes state properties (e.g. 3.14*9.5^2, h2-h1, p1*(Vol1/Vol2)^1.3, etc.)

● Mixed ○ SI ○ English

©Case-0

☑ Help Messages On

Process-A [1,2-3,4]

bA-State: State-1

bB-State: State-2

fA-State: State-3

fB-State: State-4

☑ Q: 0.0 kJ

☑ W_ext: 0.0 kJ

☑ T_B: 298.15 K

☐ S_gen: 0.53576 kJ/K

Delta_E: 0.0 kJ

Delta_S: 0.53576 kJ/K

**Non-Uniform Non-Mixing Process - A**

Mass: $m_{bA} = m_{fA};\ m_{bB} = m_{fAB};$

Energy: $\underbrace{\left(m_{fA}e_{fA} + m_{fB}e_{fB}\right) - \left(m_{bA}e_{bA} + m_{bB}e_{bB}\right)}_{\Delta E} = Q - W$

Entropy: $\underbrace{\left(m_{fA}s_{fA} + m_{fB}s_{fB}\right) - \left(m_{bA}s_{bA} + m_{bB}s_{bB}\right)}_{\Delta S} = \dfrac{Q}{T_B} + S_{gen}$

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:

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