

# Basic Thermodynamics: Software Solutions – Part IV

Dr. M. Thirumaleshwar




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# **Basic Thermodynamics: Software Solutions – Part IV**

Availability (or 'Exergy') and Second Law analysis



Basic Thermodynamics: Software Solutions – Part IV

1<sup>st</sup> edition

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# 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:

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

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

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

Also, the unavailable energy (or 'anergy') =  $T_0 \cdot \Delta s$

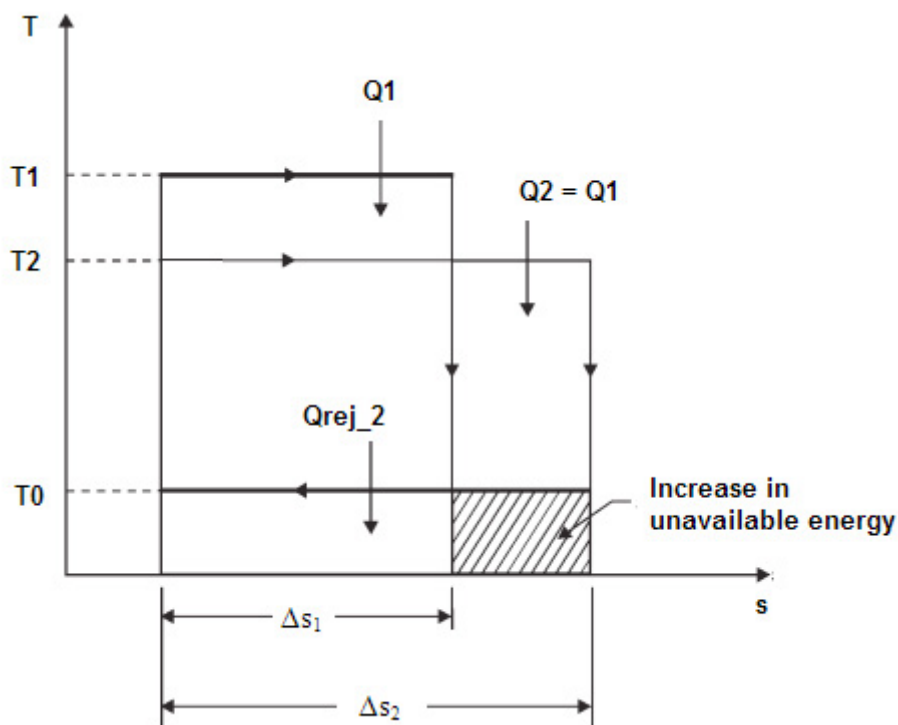
**Exergy of Work:** Exergy of work is work itself, since there is no Thermodynamic restriction on its availability.

**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,  $Q_1$ , supplied at temp  $T_1$ , the surrounding being at  $T_0$ . Then the availability of this heat  $Q_1$  supplied at  $T_1$  is:  $A = W_{\max} = (T_1 - T_0) \cdot \Delta s_1$



Now, if the *same amount* of heat is supplied from the source at  $T_1$  to the engine through a finite temp difference, absorbing heat at a lower temp  $T_2$ , availability of heat as received by the engine at  $T_2$  is calculated as follows:

We have heat supplied:  $Q_1 = T_1 \cdot \Delta s_1 = Q_2 = T_2 \cdot \Delta s_2$

Since  $T_2 < T_1$ , we have:  $\Delta s_1 < \Delta s_2$



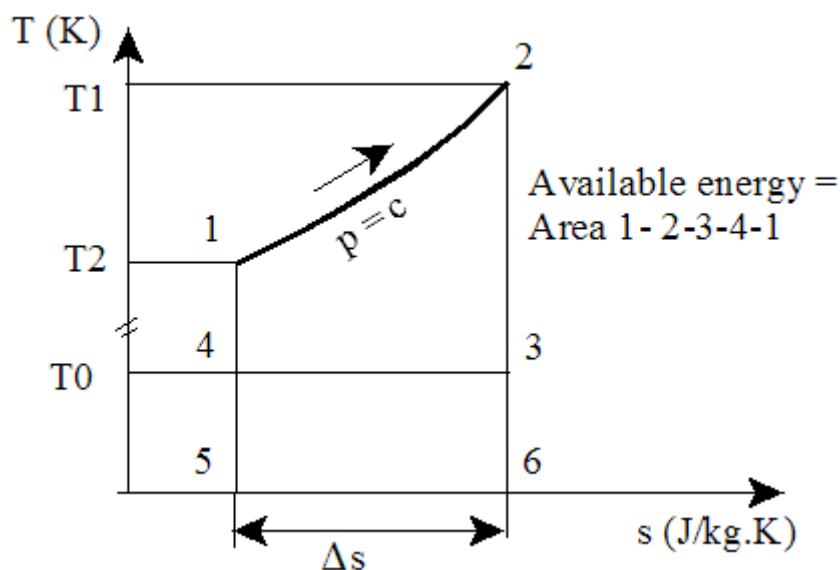
And the heat rejected in the second case:  $Q_{rej\_2} = T_0 \cdot \Delta s_2$  which is more than the heat rejected in the first case, i.e.  $Q_{rej\_1} = T_0 \cdot \Delta s_1$

Therefore, available energy lost =  $W_1 - W_2 = T_0 \cdot (\Delta s_2 - \Delta s_1)$  .... Eqn. (8.3)

Note that greater the temp difference ( $T_1 - T_2$ ), greater is the heat rejection  $Q_{rej\_2}$  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:

$$\text{Heat supplied} = c_p \cdot (T_2 - T_1) \text{ ....J/kg} = \text{Area } 1-2-6-5-1$$

$$\text{Unavailable\_energy} = \text{Area } 4-3-6-5-4 = T_0 \cdot \Delta s = T_0 \cdot c_p \cdot \ln\left(\frac{T_2}{T_1}\right) \text{ J/kg}$$

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

$$\text{i.e. Available energy} = \text{Area } 12651 - \text{Area } 43654$$

$$\text{i.e. Available\_energy} = c_p \cdot (T_2 - T_1) - T_0 \cdot c_p \cdot \ln\left(\frac{T_2}{T_1}\right) \text{ J/kg}$$

**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:  $p_1, T_1$ .

Now, let the state change from State 1 to the ambient or 'dead state' (denoted by  $p_0, T_0$ ).

Then, we have:

$$\text{Max. work available} = (u_1 - u_0) - T_0 \cdot (s_1 - s_0) - p_0 \cdot (v_0 - v_1) \dots \text{eqn. (8.4)},$$

where  $u$  = int. energy,  $s$  = entropy. And  $p_0 \cdot (v_0 - v_1)$  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:

$$W_{\max} = a_1 - a_0 \dots \text{eqn. (8.5)}$$

where,  $a = u + p_0 \cdot v - T_0 \cdot s$  (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  $p_1, T_1, Z_1$ . Let this state be reduced to atmospheric or 'dead state' denoted by  $p_0, T_0, Z_0 (= 0)$ , through an ideal process. Then,

$$W_{\max} = \left( h_1 + \frac{C_1^2}{2} + Z_1 g \right) - h_0 - T_0 \cdot (s_1 - s_0) \dots \text{eqn. (8.7)}$$

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

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

where the property,  $b = h - T_0 \cdot s$  (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:

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

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

The term  $(u - T \cdot s)$  is known as **Helmholtz function**.

If the work against atmosphere is  $p_0 \cdot (v_0 - v_1)$ , then:

Max. *available* work =

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

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

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

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

where

$g = (h - T \cdot s)$  is known as '**Gibbs function**' or '**free energy function**'

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

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

Similarly, for steady flow system:

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

Note that Gibbs function,  $g = (h - T \cdot s)$  is a property of the system whereas availability function, i.e.  $a = (u + p_0 \cdot v - T_0 \cdot s)$  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:**

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

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



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

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

$$\text{i.e.} \quad I \geq 0$$

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

$$I = (W_{\text{max}} - W) = \left[ \left( b_1 + \frac{C_1^2}{2} + g \cdot Z_1 \right) - \left( b_2 + \frac{C_2^2}{2} + g \cdot Z_2 \right) \right] - \left[ \left( h_1 + \frac{C_1^2}{2} + g \cdot Z_1 \right) - \left( h_1 + \frac{C_1^2}{2} + g \cdot Z_1 \right) + Q \right]$$

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

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

#### 8.1.7 Effectiveness [5]:

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

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

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

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

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

#### 8.1.8 Second Law efficiency, $\eta_{II}$ [4]:

Second Law efficiency is defined as:

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

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

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  $A = W_{\max}$ .

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

Now, I Law efficiency is given by:

$$\eta_I = \frac{W}{Q_1} = \frac{W}{W_{\max}} \cdot \frac{W_{\max}}{Q_1} = \eta_{II} \cdot \eta_{\text{carnot}} \quad \dots \text{eqn. (8.19)}$$

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

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

if heat is involved,  $A_{\min} = Q \cdot (1 - T_0/T)$

### 8.1.9 Exergy balance [1]:

For closed systems:

*For unit mass:*

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

where  $x$  = exergy

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

Also,

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

**For Steady flow systems:**

*For unit mass:*

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



where

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

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

$\psi$  is flow exergy per unit mass and is given by:

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

**Remember, on unit mass basis:**

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

$$x_{\text{work}} = w_{\text{useful}} \quad \dots \text{exergy of work}$$

$$x_{\text{mass}} = m \cdot \psi \quad \dots \text{exergy of mass flow}$$

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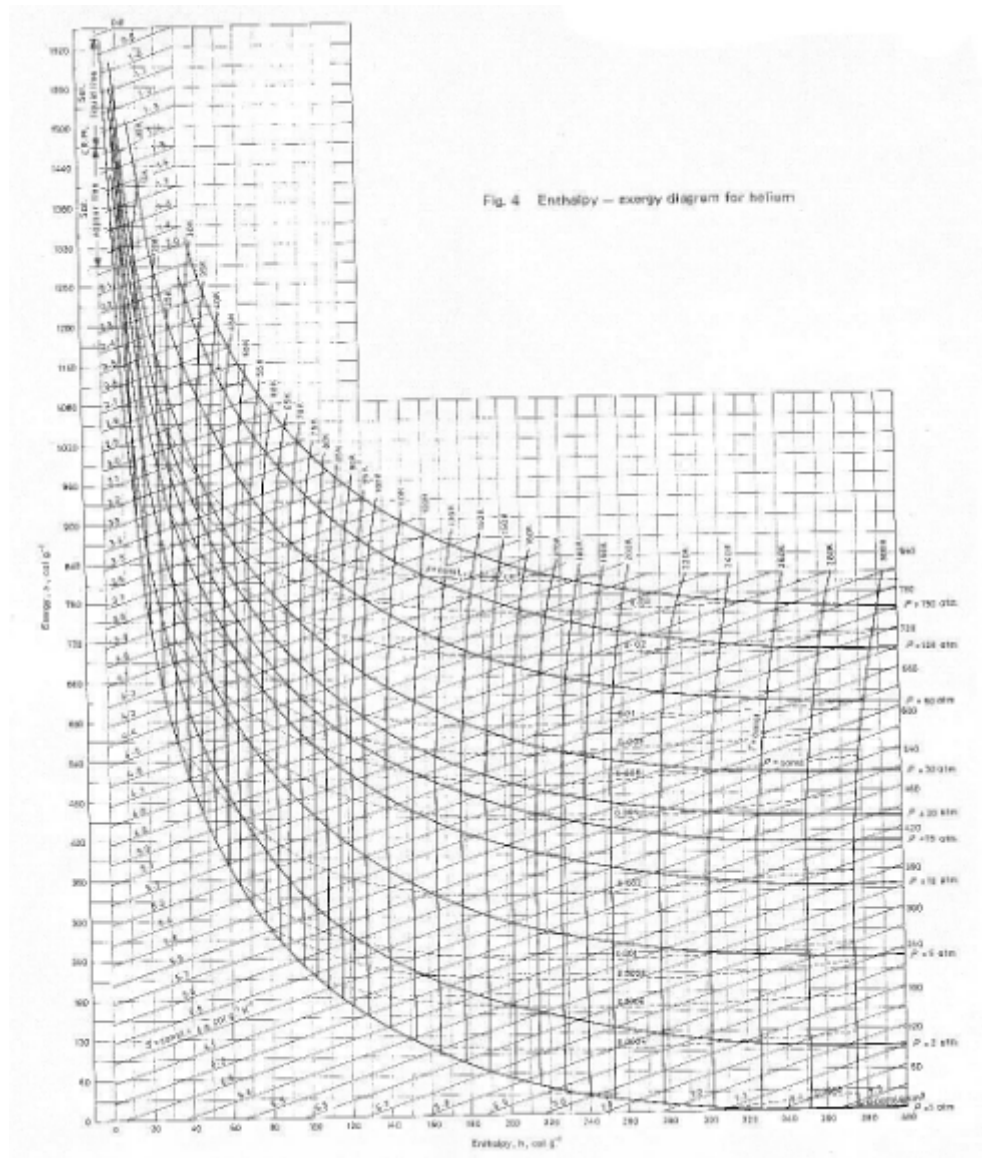
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### 8.1.10 Enthalpy-exergy diagram [6]:

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.



**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:**

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

**Exergy balance is written as:**

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

where, 1 represents inlets and 2 represents exits, and  $\Delta e$  is the exergy loss.



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

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

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

Therefore:

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

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

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

For an **isothermal compression** at ambient temp  $T_0$ , we can write:

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

since though an amount of heat  $q$  is evolved during compression, its exergy  $e_q = 0$ , compression being at  $T_0$ .

Similarly:

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

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

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

And, if expansion is **isentropic**:

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

=====

## 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.

}



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$g := 9.81 \text{ "m/s}^2\text{"}$

$h := \text{Enthalpy}(\text{RealFluid}\$, T=T, P=P)$

$s := \text{Entropy}(\text{RealFluid}\$, T=T, P=P)$

$h0 := \text{Enthalpy}(\text{RealFluid}\$, T=T0, P=P0)$

$s0 := \text{Entropy}(\text{RealFluid}\$, T=T0, P=P0)$

$\text{Exergy\_massflow\_RealFluid} := (h - h0) - (T0+273) * (s - s0) + V^2 / 2 + g * Z$

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

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

}

$\text{Entropy\_change\_Idealgas} = cp * \ln((T2 + 273) / (T1 + 273)) - R * \ln(p2 / p1)$

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

“-----”

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**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.

}

$u := \text{IntEnergy}(\text{IdealGas}, T=T) \text{ "J/kg"}$

$u0 := \text{IntEnergy}(\text{IdealGas}, T=T0) \text{ "J/kg"}$

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

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

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

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

$\text{Exergy\_ClosedSystem\_IdealGas} := (u - u0) - (T0+273) * (s - s0) + p0 * (v - v0) \text{ "J/kg"}$

$\{W\_useful\_ClosedSystem\_IdealGas := (u - u0) - (T0 + 273) * (s - s0) \text{ "J/kg"}\}$

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?”

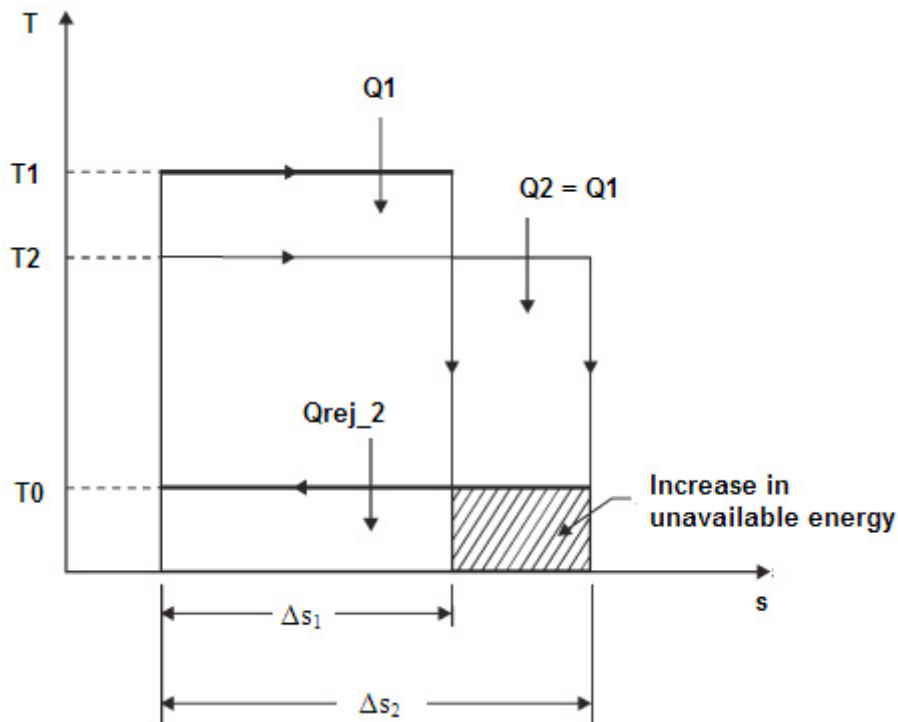


Fig.Prob.8.1

**"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:"**

$$Q = 100 \text{ "J"}$$

$$T1 = 400 \text{ "C"}$$

$$T2 = 250 \text{ "C"}$$

$$T0 = 30 \text{ "C"}$$

$$e\_q1 = \text{ExergyofHeat\_ConstTemp}(Q,T1,T0) \text{ "J ... exergy of heat supplied at T1"}$$

$$e\_q2 = \text{ExergyofHeat\_ConstTemp}(Q,T2,T0) \text{ "J ... exergy of heat supplied at T2"}$$

$$\text{Difference} = e\_q1 - e\_q2 \text{ "J.... difference in exergies of heat supplied at T1 and T2"}$$

$$\text{Fraction} = \text{Difference} / e\_q1 \text{ "Fraction of difference as compared to exergy of heat supplied at T1"}$$

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**Results:**

Main	ExergyofHeat_ConstTemp	
<b>Unit Settings: SI C Pa J mass deg</b>		
Difference = 12.91 [J]	e <sub>q1</sub> = 54.98 [J]	e <sub>q2</sub> = 42.07 [J]
<b>Fraction = 0.2349</b>	Q = 100 [J]	T <sub>0</sub> = 30 [C]
T <sub>1</sub> = 400 [C]	T <sub>2</sub> = 250 [C]	

Main	ExergyofHeat_ConstTemp
<b>Local variables in Function ExergyofHeat_ConstTemp (2 calls, 0.00 sec)</b>	
ExergyofHeatConstTemp = 42.07 [J]	Q = 100 [J]
T = 250 [C]	T <sub>0</sub> = 30 [C]

Thus,

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

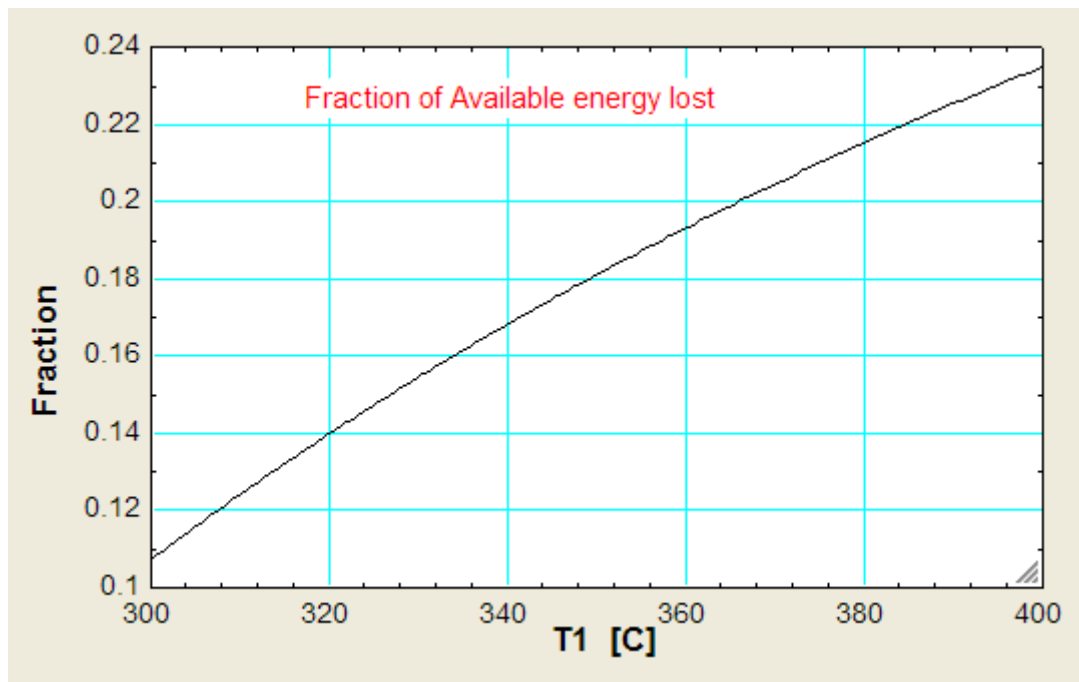
In addition:

Plot the variation of Fraction as a function of the temp of heat supplied , T<sub>1</sub> varies from 300 C to 400 C:

First, compute the Parametric Table:

Table 1		
	1	2
	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 ( $c_p = 3 \text{ kJ/kg.K}$ ) 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?”

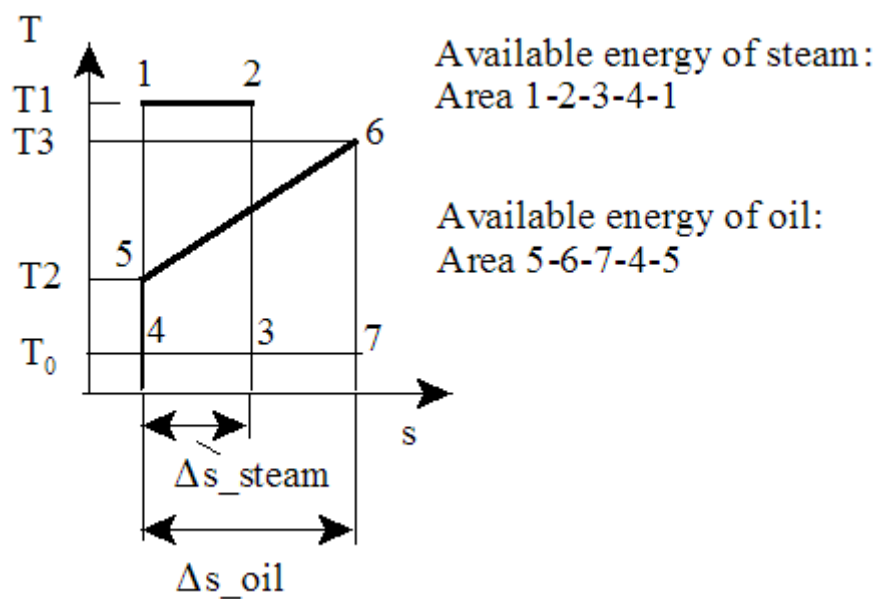


Fig.Prob.8.2

**“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:”**

$$m_{\text{oil}} = 400 \text{ “kg/min”}$$

$$T1 = 106 \text{ “C”}$$

$$h_g = \text{Enthalpy}(\text{Steam\_NBS}, T=T1, x=1)$$

$$h_f = \text{Enthalpy}(\text{Steam\_NBS}, T=T1, x=0)$$

$$h_{fg} = (h_g - h_f) \text{ “J/kg.... latent heat of steam at 106 C”}$$

$$cp_{\text{oil}} = 3000 \text{ “J/kg.C ... sp. heat of oil”}$$

$$T2 = 30 \text{ “C”}$$

$$T3 = 80 \text{ “C”}$$

$$T0 = 7 \text{ “C”}$$

**“Calculations:”**

$$Q = m_{\text{oil}} * cp_{\text{oil}} * (T3 - T2) \text{ “ J/min...heat gained by oil”}$$

$$m_{\text{steam}} = Q / h_{fg} \text{ “kg/min ... amount of steam required”}$$

**“Method 1: Using the EES Functions written earlier”**

$$e_{q\_steam} = \text{ExergyofHeat\_ConstTemp}(Q, T1, T0) \text{ “J/min ... exergy of heat supplied at T1”}$$

$$e_{q2} = \text{ExergyofHeat\_ConstPressure}(cp_{\text{oil}}, T2, T0) \text{ “J/kg ... exergy of heat supplied at T2”}$$

$$e_{q3} = \text{ExergyofHeat\_ConstPressure}(cp_{\text{oil}}, T3, T0) \text{ “J/kg ... exergy of heat supplied at T3”}$$

“Therefore: exergy change of oil:”

$$e_{q\_oil} = m_{oil} * (e_{q3} - e_{q2}) \text{ “J/min”}$$

“Therefore: Loss in available energy:”

$$\text{ExergyLoss} = e_{q\_steam} - e_{q\_oil} \text{ “J/min”}$$

**Results:**

Main	ExergyofHeat_ConstTemp	ExergyofHeat_ConstPressure
<b>Unit Settings: SI C Pa J mass deg</b>		
$cp_{oil} = 3000 \text{ [J/kg-K]}$		<b>ExergyLoss = 6.992E+06 [J/min]</b>
$e_{q2} = 2688 \text{ [J/kg]}$		$e_{q3} = 24390 \text{ [J/kg]}$
$e_{q,oil} = 8.681E+06$		$e_{q,steam} = 1.567E+07 \text{ [J/min]}$
$h_f = 444409 \text{ [J/kg]}$		$h_{fg} = 2.241E+06 \text{ [J/kg]}$
$h_g = 2.685E+06 \text{ [J/kg]}$		$m_{oil} = 400 \text{ [kg/min]}$
$m_{steam} = 26.78 \text{ [kg/min]}$		$Q = 6.000E+07 \text{ [J/min]}$
$T0 = 7 \text{ [C]}$		$T1 = 106 \text{ [C]}$
$T2 = 30 \text{ [C]}$		$T3 = 80 \text{ [C]}$

Main	ExergyofHeat_ConstTemp	ExergyofHeat_ConstPressure
<b>Local variables in Function ExergyofHeat_ConstTemp (1 call, 0.00 sec)</b>		
$\text{ExergyofHeatConstTemp} = 1.567E+07 \text{ [J/min]}$		
$Q = 6.000E+07 \text{ [J/min]}$		
$T = 106 \text{ [C]}$		
$T0 = 7 \text{ [C]}$		

Main	ExergyofHeat_ConstTemp	ExergyofHeat_ConstPressure
<b>Local variables in Function ExergyofHeat_ConstPressure (2 calls, 0.00 sec)</b>		
$cp = 3000 \text{ [J/kg-K]}$		
$\text{ExergyofHeatConstPressure} = 24390 \text{ [J/kg]}$		
$T = 80 \text{ [C]}$		
$T0 = 7 \text{ [C]}$		

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 =  $T_0 \times \text{DELTA\_S\_tot}$

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)



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$$h_f = \text{Enthalpy}(\text{Steam\_NBS}, T=T1, x=0)$$

$$h_{fg} = (h_g - h_f) \text{ "J/kg.... latent heat of steam at 106 C"}$$

$$cp_{oil} = 3000 \text{ "J/kg.C ... sp. heat of oil"}$$

$$T2 = 30 \text{ "C"}$$

$$T3 = 80 \text{ "C"}$$

$$T0 = 7 \text{ "C"}$$

**"Calculations:"**

$$Q = m_{oil} * cp_{oil} * (T3 - T2) \text{ " J/min...heat gained by oil"}$$

$$m_{steam} = Q / h_{fg} \text{ "kg/min ... amount of steam required"}$$

**"Method 2:"**

**"Entropy change of steam:"**

$$\Delta S_{steam} = - Q / (T1 + 273) \text{ "J/K ... entropy decrease of steam"}$$

**"Entropy change of oil:"**

$$\Delta S_{oil} = m_{oil} * cp_{oil} * \ln ((T3 + 273) / (T2 + 273)) \text{ "J/K.. entropy increase of oil"}$$

**"Therefore:"**

$$\Delta S_{tot} = \Delta S_{steam} + \Delta S_{oil} \text{ "J/K ... entropy change of (oil + steam)"}$$

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

$$ExergyLoss = (T0 + 273) * \Delta S_{tot} \text{ "J ...Loss in Available energy"}$$

## Results:

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

$$c_{p_{oil}} = 3000 \text{ [J/kg-K]}$$

$$\Delta S_{steam} = -158311 \text{ [J/K]}$$

$$\text{ExergyLoss} = 6.992\text{E}+06 \text{ [J/min]}$$

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

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

$$Q = 6.000\text{E}+07 \text{ [J/min]}$$

$$T_1 = 106 \text{ [C]}$$

$$T_3 = 80 \text{ [C]}$$

$$\Delta S_{oil} = 183282 \text{ [J/K]}$$

$$\Delta S_{tot} = 24971 \text{ [J/K]}$$

$$h_f = 444409 \text{ [J/kg]}$$

$$h_g = 2.685\text{E}+06 \text{ [J/kg]}$$

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

$$T_0 = 7 \text{ [C]}$$

$$T_2 = 30 \text{ [C]}$$

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.  $c_v = 0.86 \text{ kJ/kg.K}$  for the gas. Find the loss in available energy of the system. Surrounding temp = 300 K.”

**“EES Solution:”**

**“Data:”**

$$Q = 450\text{E}03 \text{ "J"}$$

$$T_{source} = 900 \text{ "K"}$$

$$m_{gas} = 2 \text{ "kg"}$$

$$P_1 = 2\text{E}05 \text{ "Pa"}$$

$$T_1 = 350 \text{ "K"}$$

$$c_v = 860 \text{ "J/kg.K"}$$

$$T_0 = 300 \text{ "K"}$$

“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:”

$$Q = m_{\text{gas}} * cv * (T2 - T1) \text{ “...finds } T2, \text{ in Kelvin”}$$

“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:  $\text{Loss} = T0 * dS_{\text{net}}$ ”

“Entropy decrease for Source:”

$$dS_{\text{source}} = - Q / T_{\text{source}} \text{ “J/K .... negative, since heat is leaving the source”}$$

The advertisement features a light blue background. At the top left, the text "SMS from your computer" is in a large, bold, blue font, followed by "...Sync'd with your Android phone & number" in a smaller blue font. In the top right corner, a blue diagonal banner contains the text "FREE 30 days trial!!" in white. Below the main text, there is a screenshot of a MacBook Pro screen on the left showing a web browser with a list of contacts and a chat window. To the right of the laptop is an HTC smartphone displaying a text message conversation. A blue double-headed arrow connects the laptop screen to the phone. To the right of the phone, the text "Go to" is above a green rounded rectangle containing "BrowserTexting.com". Below this, the text "and start texting from your computer!" is displayed. At the bottom right, there is a speech bubble icon followed by "BrowserTexting".



**“Entropy increase for gas:”**

$$dS_{\text{gas}} = m_{\text{gas}} * c_v * \ln (T_2/T_1) \text{ “J.K ... entropy increase of gas”}$$

**“Therefore, dS\_net:”**

$$dS_{\text{net}} = dS_{\text{source}} + dS_{\text{gas}} \text{ “J/K... net entropy change of (source + gas)”}$$

**“Therefore: Loss in availability:”**

$$\text{Loss} = T_0 * dS_{\text{net}} \text{ “J ....Loss in Availability”}$$

**Results:**

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

$$c_v = 860 \text{ [J/kg.K]}$$

$$dS_{\text{source}} = -500 \text{ [J/K]}$$

$$P_1 = 200000 \text{ [Pa]}$$

$$T_1 = 350 \text{ [K]}$$

$$dS_{\text{gas}} = 960.1 \text{ [J/K]}$$

$$\text{Loss} = 138027 \text{ [J]}$$

$$Q = 450000 \text{ [J]}$$

$$T_2 = 611.6 \text{ [K]}$$

$$dS_{\text{net}} = 460.1 \text{ [J/K]}$$

$$m_{\text{gas}} = 2 \text{ [kg]}$$

$$T_0 = 300 \text{ [K]}$$

$$T_{\text{source}} = 900 \text{ [K]}$$

**Thus:**

$$\text{Loss in Availability} = 138.027 \text{ kJ .... Ans.}$$

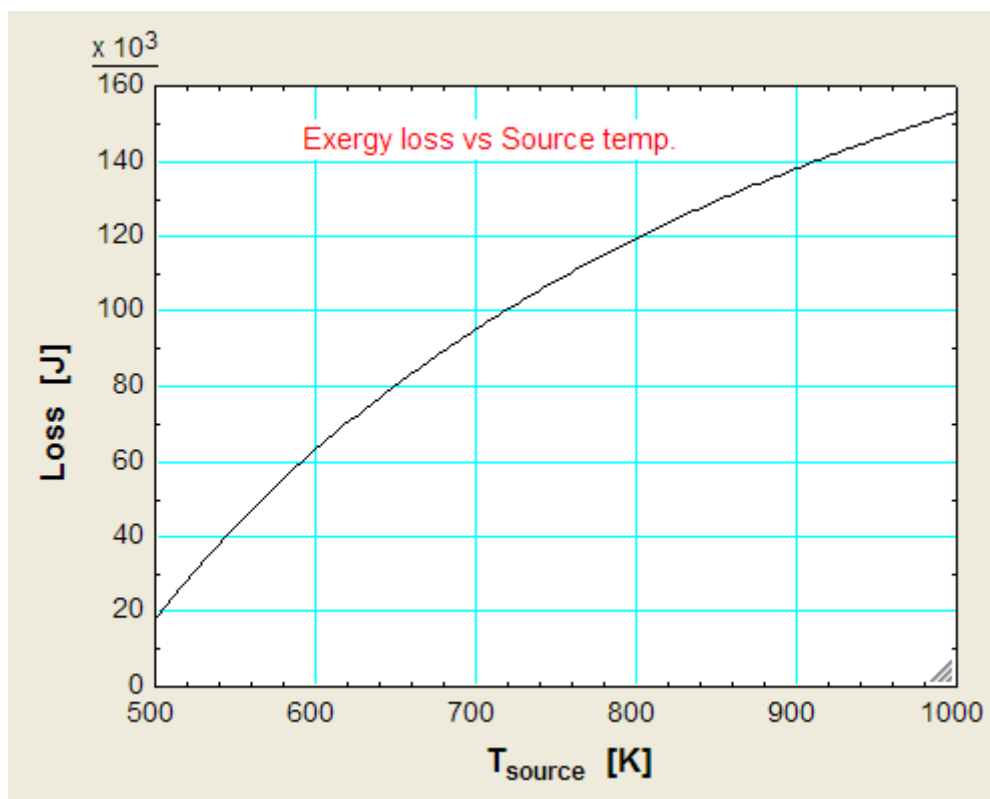
**In addition:**

**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 $T_{\text{source}}$ [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:”**

$Q = 7200 \text{E}03 \text{ "J/min"}$

$T_{\text{source}} = 1000 \text{ "K"}$

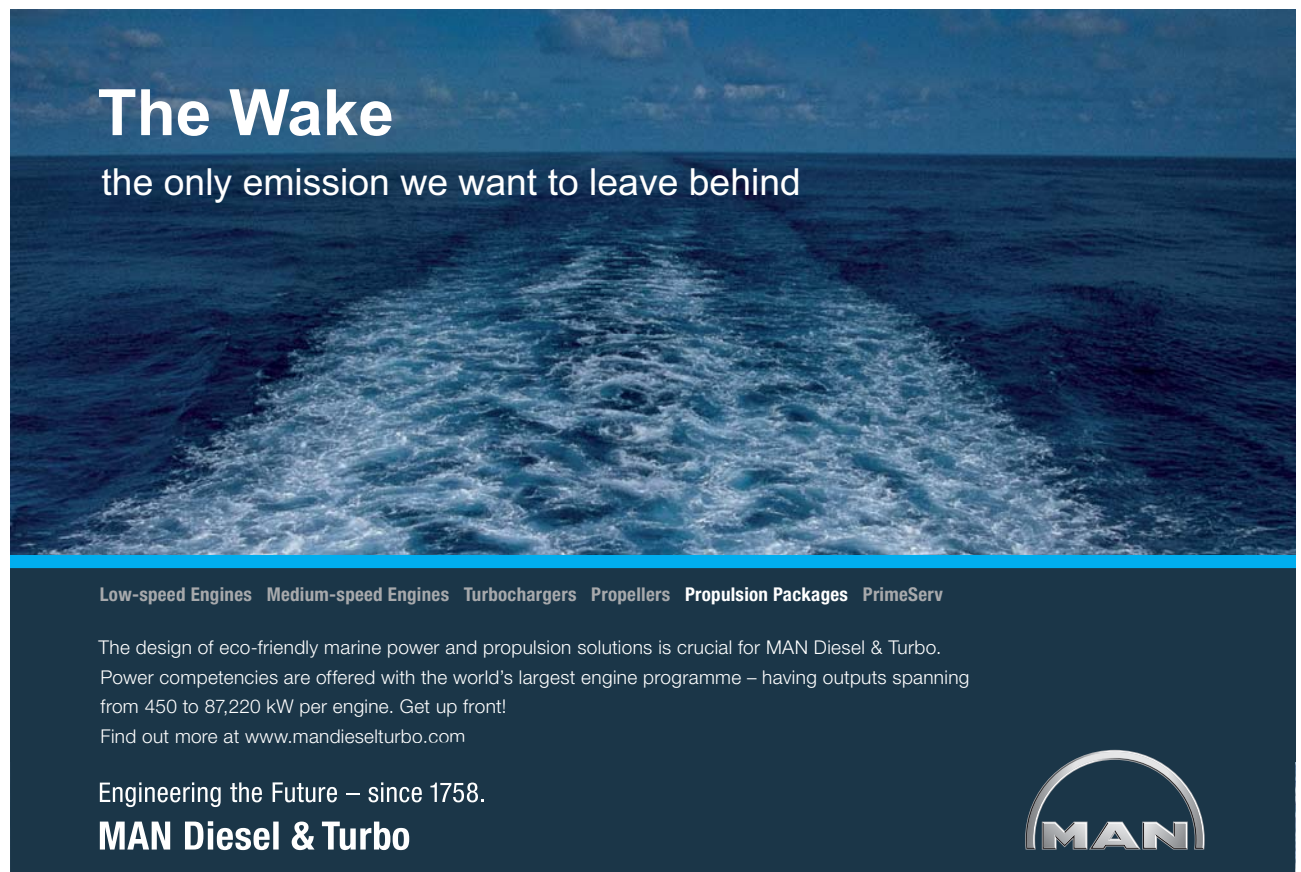
$T_{\text{system}} = 500 \text{ "K"}$

$T_0 = 300 \text{ "K"}$

**“Calculations:”**

**“Entropy decrease of Source:”**

$dS_{\text{source}} = - Q / T_{\text{source}} \text{ "J/K per min"}$




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**“Entropy increase of system:”**

$$dS_{\text{system}} = Q / T_{\text{system}} \text{ “J/K per min”}$$

**“Net increase of entropy:”**

$$dS_{\text{net}} = dS_{\text{source}} + dS_{\text{system}} \text{ “J/K per min”}$$

**“Loss in Availability:”**

$$\text{Loss} = T_0 * dS_{\text{net}} \text{ “J/min”}$$

**Results:**

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

$$dS_{\text{net}} = 7200 \text{ [J/K-min]}$$

$$dS_{\text{system}} = 14400 \text{ [J/K-min]}$$

$$Q = 7.200\text{E}+06 \text{ [J/min]}$$

$$T_{\text{source}} = 1000 \text{ [K]}$$

$$dS_{\text{source}} = -7200 \text{ [J/K-min]}$$

$$\text{Loss} = 2.160\text{E}+06 \text{ [J/min]}$$

$$T_0 = 300 \text{ [K]}$$

$$T_{\text{system}} = 500 \text{ [K]}$$

**Thus:**

**Net change of entropy =  $dS_{\text{net}} = 7200 \text{ J/K per min} \dots \text{ Ans.}$**

**Loss in availability =  $2.16\text{E}06 \text{ J/min} \dots \text{ Ans.}$**

=====

**“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:”**

$$m_{\text{air}} = 2 \text{ “kg”}$$

$$T_1 = 80 + 273 \text{ “K”}$$

$$P1 = 5E05 \text{ "Pa"}$$

$$P2 = 1E05 \text{ "Pa"}$$

$$T2 = T0 \text{ "...by data"}$$

$$P0 = 1E05 \text{ "Pa .... atm. pressure"}$$

$$V2 = 2 * V1$$

$$T0 = 5 + 273 \text{ "K"}$$

$$R_{\text{air}} = 287 \text{ "J/kg.K .... Gas constant for Air"}$$

$$\gamma = 1.4 \text{ " = (cp/cv) for air"}$$

**"Calculations:"**

**"Initial Volume, V1:"**

$$P1 * V1 = m_{\text{air}} * R_{\text{air}} * T1 \text{ "...finds Volume V1"}$$

**"Applying I Law to Closed system:**

$$Q = dU + W$$

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

Therefore:"

$$cv = R_{\text{air}} / (\gamma - 1) \text{ "...finds cv, sp. heat at const. vol.....since } R = (cp - cv)\text{"}$$

$$dU = m_{\text{air}} * cv * (T2 - T1) \text{ "...finds change in Int. energy"}$$

**"To find change in entropy of air:"**

$$dS_{\text{air}} = m_{\text{air}} * (cv * \ln (T2/T1) + R_{\text{air}} * \ln (V2/V1)) \text{ "J/K"}$$

**"Change in entropy of surroundings:"**

$$dS_{\text{surr}} = 0 \text{ "...since adiabatic"}$$

**“Net increase in entropy:”**

$$dS_{\text{net}} = dS_{\text{air}} + dS_{\text{surr}} \text{ “J.K...net increase in entropy”}$$

**“Therefore: W\_max:”**

$$W_{\text{max}} = (U_1 - U_2) - T_0 * (S_1 - S_2) \text{...from definition of max. work or availability”}$$

$$W_{\text{max}} = -dU - (-T_0 * dS_{\text{air}}) \text{ “J ..Max. work”}$$

**“Change in Availability:”**

$$\text{“Change\_in\_availability} = (U_1 - U_2) - T_0 * (S_1 - S_2) + P_0 * (V_1 - V_2)\text{”}$$

$$\text{Change\_availability} = -dU - T_0 * (-dS_{\text{air}}) + P_0 * (V_1 - V_2) \text{ “J”}$$

**“Irreversibility:”**

$$\text{Irreversibility} = T_0 * dS_{\text{net}} \text{ “J ... Irreversibility for the process”}$$

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**Results:**

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

$$\text{Change}_{\text{availability}} = 82424 \text{ [J]}$$

$$dS_{\text{air}} = 55.12 \text{ [J/K]}$$

$$dS_{\text{surr}} = 0 \text{ [J/K]}$$

$$\gamma = 1.4$$

$$m_{\text{air}} = 2 \text{ [kg]}$$

$$P_1 = 500000 \text{ [Pa]}$$

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

$$T_1 = 353 \text{ [K]}$$

$$V_1 = 0.4052 \text{ [m}^3\text{]}$$

$$W_{\text{max}} = 122949 \text{ [J]}$$

$$cv = 717.5 \text{ [J/kg-K]}$$

$$dS_{\text{net}} = 55.12 \text{ [J/K]}$$

$$dU = -107625 \text{ [J]}$$

$$\text{Irreversibility} = 15324 \text{ [J]}$$

$$P_0 = 100000 \text{ [Pa]}$$

$$P_2 = 100000 \text{ [Pa]}$$

$$T_0 = 278 \text{ [K]}$$

$$T_2 = 278 \text{ [K]}$$

$$V_2 = 0.8105 \text{ [m}^3\text{]}$$

**Thus:**

**Max. work =  $W_{\text{max}} = 122.949 \text{ kJ}$  ... Ans.**

**Change in Availability =  $82.424 \text{ kJ}$  ... Ans.**

**Irreversibility =  $15.324 \text{ kJ}$  ... 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:”**

$T = 85 \text{ }^{\circ}\text{C}$

$T_0 = 15 \text{ }^{\circ}\text{C}$

$c_p = 4180 \text{ J/kg}\cdot\text{K}$

$m_{\text{water}} = 30 \text{ kg}$

$\text{Exergy} = m_{\text{water}} * \text{ExergyofHeat\_ConstPressure}(c_p, T, T_0) \text{ J}$

**Results:**

Main	ExergyofHeat_ConstPressure
<b>Unit Settings: SI C Pa J mass deg</b>	
$c_p = 4180 \text{ J/kg}\cdot\text{K}$	<b>Exergy = 920325 [J]</b>
$T = 85 \text{ }^{\circ}\text{C}$	$m_{\text{water}} = 30 \text{ kg}$
	$T_0 = 15 \text{ }^{\circ}\text{C}$

Main	ExergyofHeat_ConstPressure
<b>Local variables in Function ExergyofHeat_ConstPressure (1 call, 0.00 sec)</b>	
$c_p = 4180 \text{ J/kg}\cdot\text{K}$	
$\text{ExergyofHeatConstPressure} = 30678 \text{ J/kg}$	
$T = 85 \text{ }^{\circ}\text{C}$	
$T_0 = 15 \text{ }^{\circ}\text{C}$	

**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.  $c_p$  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:”

$m_{\text{iron}} = 4 \text{ "kg"}$

$T1_{\text{iron}} = 900 \text{ "C"}$

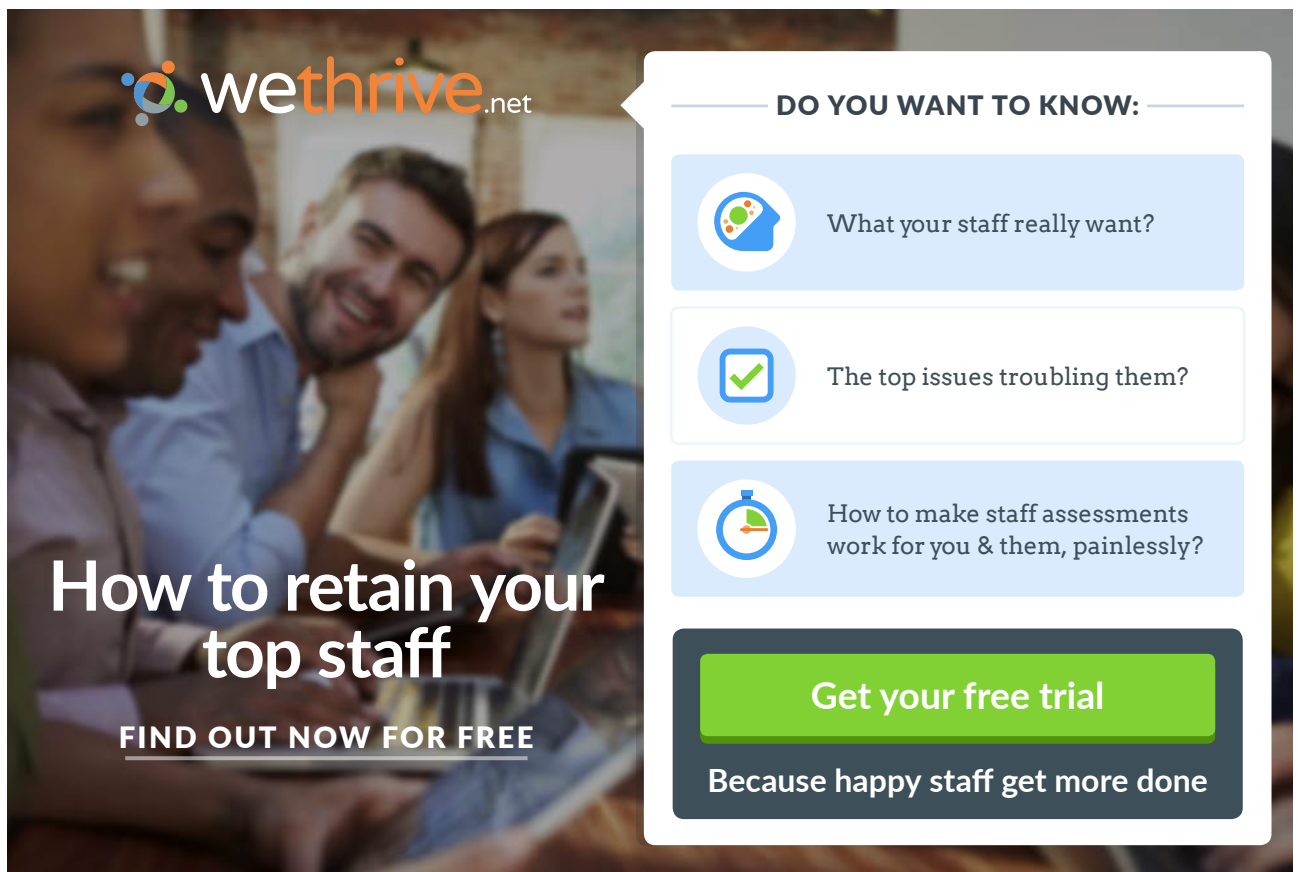
$m_{\text{oil}} = 20 \text{ "kg"}$

$T1_{\text{oil}} = 65 \text{ "C"}$

$T_0 = 27 \text{ "C .... temp of ambient"}$

$cp_{\text{iron}} = 400 \text{ "J/kg.K"}$

$cp_{\text{oil}} = 2000 \text{ "J/kg.K"}$



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**“Calculations:”**

**“Find the final temp,  $T_f$  after equilibrium is reached:”**

$$(m_{\text{iron}} * cp_{\text{iron}} * T1_{\text{iron}}) + (m_{\text{oil}} * cp_{\text{oil}} * T1_{\text{oil}}) = (m_{\text{iron}} * cp_{\text{iron}} + m_{\text{oil}} * cp_{\text{oil}}) * T_f$$

“..determines final temp,  $T_f$ ”

**“Entropy decrease of iron:”**

$$dS_{\text{iron}} = m_{\text{iron}} * cp_{\text{iron}} * \ln((T_f + 273) / (T1_{\text{iron}} + 273)) \text{ “J/K”}$$

**“Entropy increase of oil:”**

$$dS_{\text{oil}} = m_{\text{oil}} * cp_{\text{oil}} * \ln((T_f + 273) / (T1_{\text{oil}} + 273)) \text{ “J/K”}$$

**“Net increase of entropy:”**

$$dS_{\text{net}} = dS_{\text{iron}} + dS_{\text{oil}} \text{ “J/K”}$$

**“Loss in availability:”**

$$\text{Loss} = (T_0 + 273) * dS_{\text{net}} \text{ “J”}$$

**Results:**

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

$$cp_{\text{iron}} = 400 \text{ [J/kg-C]}$$

$$dS_{\text{net}} = 1785 \text{ [J/K]}$$

$$m_{\text{iron}} = 4 \text{ [kg]}$$

$$T1_{\text{oil}} = 65 \text{ [C]}$$

$$cp_{\text{oil}} = 2000 \text{ [J/kg-C]}$$

$$dS_{\text{oil}} = 3631 \text{ [J/K]}$$

$$m_{\text{oil}} = 20 \text{ [kg]}$$

$$T_0 = 27 \text{ [C]}$$

$$dS_{\text{iron}} = -1846 \text{ [J/K]}$$

$$\text{Loss} = 535545 \text{ [J]}$$

$$T1_{\text{iron}} = 900$$

$$T_f = 97.12 \text{ [C]}$$

**Thus:**

$$\text{Final temp} = T_f = 97.12 \text{ C ... Ans.}$$

$$\text{Exergy loss} = 535.545 \text{ kJ .... Ans.}$$

**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:”**

$(m_{\text{iron}} * cp_{\text{iron}} * T1_{\text{iron}}) + (m_{\text{oil}} * cp_{\text{oil}} * T1_{\text{oil}}) = (m_{\text{iron}} * cp_{\text{iron}} + m_{\text{oil}} * cp_{\text{oil}}) * T_f$   
“..determines final temp, T\_f”

**“Initial exergy of iron:”**

$e_{1\_iron} = m_{\text{iron}} * \text{ExergyofHeat\_ConstPressure}(cp_{\text{iron}}, T1_{\text{iron}}, T_0)$  “J .... Using the EES Function already written”

**“Initial exergy of oil:”**

$e_{1\_oil} = m_{\text{oil}} * \text{ExergyofHeat\_ConstPressure}(cp_{\text{oil}}, T1_{\text{oil}}, T_0)$  “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:”**

$$e_{2\_iron} = m_{iron} * \text{ExergyofHeat\_ConstPressure}(cp_{iron}, T_f, T_0) \text{ “J”}$$

**“Final exergy of oil:”**

$$e_{2\_oil} = m_{oil} * \text{ExergyofHeat\_ConstPressure}(cp_{oil}, T_f, T_0) \text{ “J”}$$

**“Therefore, Total final exergy:”**

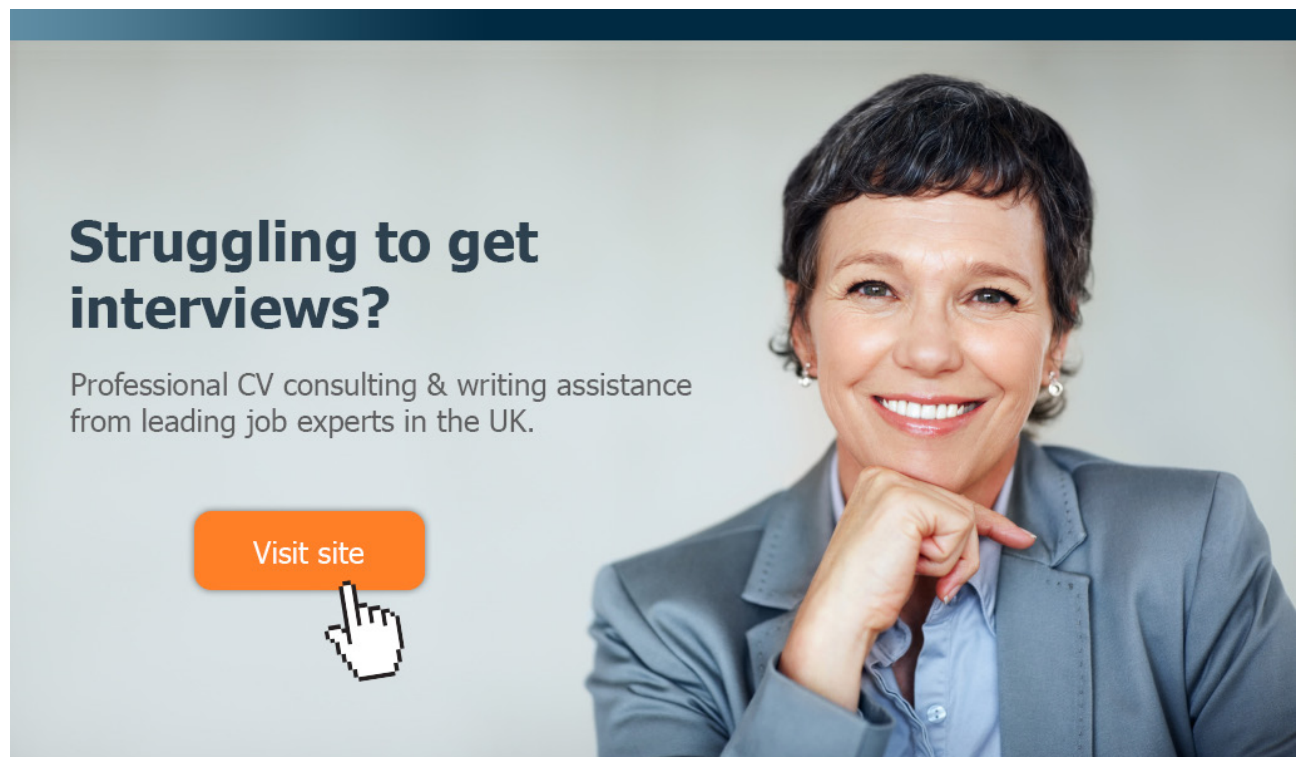
$$e_{2\_total} = e_{2\_iron} + e_{2\_oil} \text{ “J”}$$

**“Now, from an exergy balance:**

$$\text{Total initial exergy} = \text{Total final exergy} + \text{Losses”}$$

**“Therefore:”**

$$e_{1\_total} = e_{2\_total} + e_{losses} \text{ “...by an exergy balance..finds exergy losses”}$$



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$$T_{1\_H2} = 450 \text{ "K"}$$

$$T_0 = 300 \text{ "K .... temp of ambient"}$$

$$R_{O2} = 270 \text{ "J/kg.K"}$$

$$R_{H2} = 4160 \text{ "J/kg.K"}$$

$$p = 1E05 \text{ "Pa"}$$

**"Calculations:"**

**"Initial volume of O2:"**

$$v_{O2} = R_{O2} * T_{1\_O2} / p \text{ "m^3 ....initial vol. of O2"}$$

**"Initial volume of H2:"**

$$v_{H2} = R_{H2} * T_{1\_H2} / p \text{ "m^3 ....initial vol. of H2"}$$

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

$$v_{final} = v_{O2} + v_{H2} \text{ "m^3 ... final volume"}$$

**"Entropy changes:"**

**"Entropy change for O2:"**

$$dS_{O2} = m_{O2} * R_{O2} * \ln (v_{final} / v_{O2}) \text{ "J/K"}$$

**"Entropy change for H2:"**

$$dS_{H2} = m_{H2} * R_{H2} * \ln (v_{final} / v_{H2}) \text{ "J/K"}$$

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

$$dS_{net} = dS_{O2} + dS_{H2} \text{ "J/K .... net entropy change"}$$

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

$$Losses = T_0 * dS_{net} \text{ "J .... exergy losses"}$$

**Results:**

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

$$dS_{H_2} = 261.6 \text{ [J/K]}$$

$$\text{Losses} = 305096 \text{ [J]}$$

$$p = 100000 \text{ [Pa]}$$

$$T_{1H_2} = 450 \text{ [K]}$$

$$v_{\text{final}} = 19.94 \text{ [m}^3\text{]}$$

$$dS_{\text{net}} = 1017 \text{ [J/K]}$$

$$m_{H_2} = 1 \text{ [kg]}$$

$$R_{H_2} = 4160 \text{ [J/kg-K]}$$

$$T_{1O_2} = 450 \text{ [K]}$$

$$v_{H_2} = 18.72 \text{ [m}^3\text{]}$$

$$dS_{O_2} = 755.4 \text{ [J/K]}$$

$$m_{O_2} = 1 \text{ [kg]}$$

$$R_{O_2} = 270$$

$$T_0 = 300 \text{ [K]}$$

$$v_{O_2} = 1.215 \text{ [m}^3\text{]}$$

**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.”



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**“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<sub>air</sub> = 10 “kg”

P = 1E06 “Pa”

T = 60 “C”

P0 = 1E05 “Pa”

T0 = 27 “C”

Exergy = m<sub>air</sub> \* Exergy\_ClosedSystem\_IdealGas(IdealGas\$,T, P, T0, P0)

**Results:**

Main	Exergy_ClosedSystem_IdealGas
<b>Unit Settings: SI C Pa J mass deg</b>	
Exergy = 1.139E+06 [J]	IdealGas\$ = 'Air'
P = 1000000 [Pa]	m <sub>air</sub> = 10 [kg]
T0 = 27 [C]	p0 = 100000 [Pa]
	T = 60 [C]

Main	Exergy_ClosedSystem_IdealGas
<b>Local variables in Function Exergy_ClosedSystem_IdealGas (1 call, 0.00 sec)</b>	
ExergyClosedSystem,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 <sup>3</sup> /kg]	v0=0.8615 [m <sup>3</sup> /kg]



Thus:

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

=====

**“Prob.8.10.** In a parallel flow heat exchanger, 1 kg/s of oil ( $c_p = 2.5 \text{ kJ/kg.C}$ ) 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.”

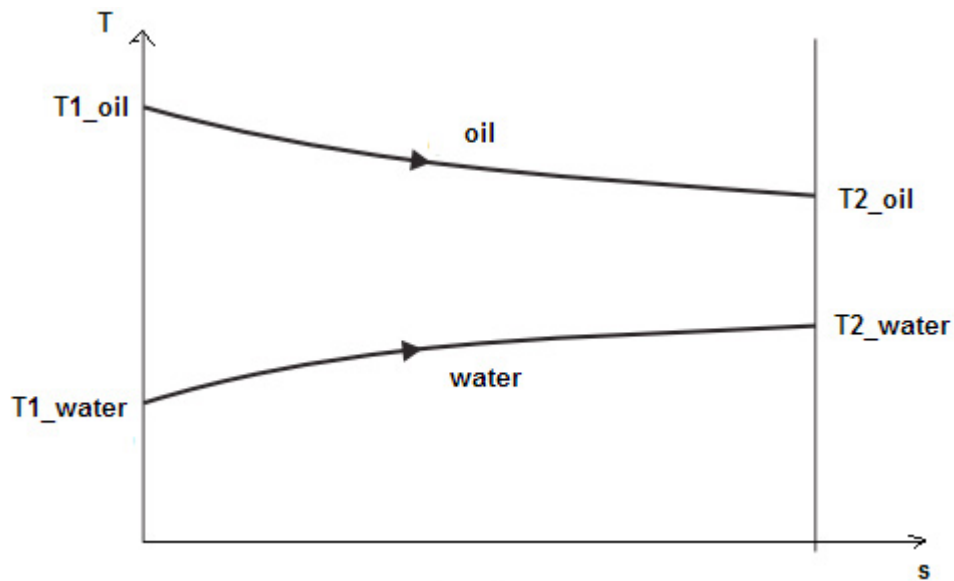


Fig.Prob.8.10

“EES Solution:”

“Data:”

$$m_{\text{oil}} = 1 \text{ "kg/s"}$$

$$T1_{\text{oil}} = 260 \text{ "C"}$$

$$T2_{\text{oil}} = 90 \text{ "C"}$$

$$T1_{\text{water}} = 60 \text{ "C"}$$

$$T2_{\text{water}} = 85 \text{ "C"}$$

$$T_0 = 27 \text{ "C"}$$

$$c_{p_{\text{oil}}} = 2500 \text{ "J/kg.C"}$$

$$c_{p_{\text{water}}} = 4180 \text{ "J/kg.C"}$$

“Calculations:”

“Find the flow rate of water by heat balance:”

$m_{\text{oil}} * c_{p_{\text{oil}}} * (T1_{\text{oil}} - T2_{\text{oil}}) = m_{\text{water}} * c_{p_{\text{water}}} * (T2_{\text{water}} - T1_{\text{water}})$  “...finds the mass flow rate of water”

“Decrease in entropy of oil:”

$dS_{\text{oil}} = c_{p_{\text{oil}}} * \ln ((T2_{\text{oil}}+273)/(T1_{\text{oil}}+273))$  “J/kg.K”

“Increase in entropy of water:”

$dS_{\text{water}} = c_{p_{\text{water}}} * \ln ((T2_{\text{water}}+273)/(T1_{\text{water}}+273))$  “J/kg.K”

“Change in availability of oil:”

$e_{\text{oil}} = m_{\text{oil}} * (c_{p_{\text{oil}}} * (T2_{\text{oil}} - T1_{\text{oil}}) - (T_0 + 273) * dS_{\text{oil}})$  “J/s”

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**“Change in availability of water:”**

$$e_{\text{water}} = m_{\text{water}} * (c_{p_{\text{water}}} * (T_{2_{\text{water}}} - T_{1_{\text{water}}}) - (T_0 + 273) * dS_{\text{water}}) \text{ J/s}$$

**“Therefore: Loss in availability:”**

$$\text{Loss} = e_{\text{oil}} + e_{\text{water}} \text{ J/s}$$

**Results:**

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

$c_{p_{\text{oil}}} = 2500 \text{ [J/kg-K]}$	$c_{p_{\text{water}}} = 4180 \text{ [J/kg-K]}$	$dS_{\text{oil}} = -960.3 \text{ [J/kg-K]}$
$dS_{\text{water}} = 302.6 \text{ [J/kg-K]}$	$e_{\text{oil}} = -136911 \text{ [J/s]}$	$e_{\text{water}} = 55808 \text{ [J/s]}$
<b>Loss = -81103 [J/s]</b>	$m_{\text{oil}} = 1 \text{ [kg/s]}$	$m_{\text{water}} = 4.067 \text{ [kg/s]}$
$T_{1_{\text{oil}}} = 260 \text{ [C]}$	$T_{1_{\text{water}}} = 60 \text{ [C]}$	$T_{2_{\text{oil}}} = 90 \text{ [C]}$
$T_{2_{\text{water}}} = 85 \text{ [C]}$	$T_0 = 27 \text{ [C]}$	

**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:  $Exergy\_massflow\_RealFluid := (h - h_0) - (T_0 + 273) * (s - s_0) + V^2 / 2 + g * Z$ }

"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**

$cp_{oil} = 2500 \text{ [J/kg-K]}$	$cp_{water} = 4180 \text{ [J/kg-K]}$	$e_{1,oil} = 151446 \text{ [J]}$
$e_{1,water} = 29030 \text{ [J/s]}$	$e_{2,oil} = 14535 \text{ [J/s]}$	$e_{2,water} = 85130 \text{ [J/s]}$
<b>Losses = 80811 [J/s]</b>	$m_{oil} = 1 \text{ [kg/s]}$	$m_{water} = 4.067 \text{ [kg/s]}$
$P1_{oil} = 100000 \text{ [Pa]}$	$P1_{water} = 100000 \text{ [Pa]}$	$P2_{oil} = 100000 \text{ [Pa]}$
$P2_{water} = 100000$	$P_0 = 100000 \text{ [Pa]}$	$RealFluid\$ = 'Steam\_NBS'$
$T1_{oil} = 260 \text{ [C]}$	$T1_{water} = 60 \text{ [C]}$	$T2_{oil} = 90 \text{ [C]}$
$T2_{water} = 85 \text{ [C]}$	$T_0 = 27 \text{ [C]}$	$V = 0 \text{ [m/s]}$
$Z = 0 \text{ [m]}$		

**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.

=====



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**“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]”

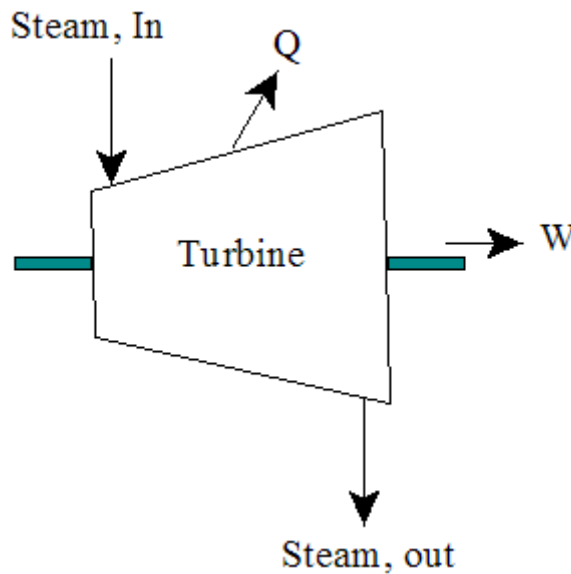


Fig.Prob.8.11

**“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:”**

$$P1 = 3E06 \text{ "Pa"}$$

$$T1 = 450 \text{ "C"}$$

$$m\_steam = 8 \text{ "kg/s"}$$

$$P2 = 0.2E06 \text{ "Pa"}$$

$$T2 = 150 \text{ "C"}$$

$$Q\_loss = 300E03 \text{ "W"}$$

$$P0 = 100E03 \text{ "Pa"}$$

$$T0 = 25 \text{ "C"}$$

$$V = 0 \text{ "m/s"}$$

$$Z = 0 \text{ "m"}$$

**“Calculations:”**

**“For exergy of mass flow:**

**we shall use the EES Function already written:**

viz.  $\text{Exergy\_massflow\_RealFluid}(\text{RealFluid}\$, T1\_water, P1\_water, V, Z, T_0, P_0) \dots \text{J/kg}$

$\text{RealFluid}\$ = \text{'Steam\_NBS'}$

**“Exergy at Inlet:”**

$e_{f1} = \text{Exergy\_massflow\_RealFluid}(\text{RealFluid}\$, T1, P1, V, Z, T_0, P_0) \dots \text{J/kg}$

**“Exergy at exit:”**

$e_{f2} = \text{Exergy\_massflow\_RealFluid}(\text{RealFluid}\$, T2, P2, V, Z, T_0, P_0) \dots \text{J/kg}$

**“Reversible work, or Max. possible work:”**

$W_{\text{rev}} = m_{\text{steam}} * (e_{f1} - e_{f2}) \text{ “J/s”}$

**“Actual work output:**

**By I Law applied to turbine:**

$m_{\text{steam}} * (h_1 - h_2) = W_{\text{actual}} + Q$

$h_1 = \text{Enthalpy}(\text{Steam\_NBS}, T=T_1, P=P_1) \text{ “J/kg .... enthalpy of steam at inlet”}$

$h_2 = \text{Enthalpy}(\text{Steam\_NBS}, T=T_2, P=P_2) \text{ “J/kg .... enthalpy of steam at exit”}$

**“Therefore: actual work output is found from”**

$m_{\text{steam}} * (h_1 - h_2) = W_{\text{actual}} + Q_{\text{loss}}$  “ $W$  .... actual work output”

**“Then, Second Law efficiency:”**

$\eta_{\text{II}} = W_{\text{actual}} / W_{\text{rev}}$  “...Second Law effcy.”

**“Exergy destroyed:”**

$e_{\text{destroyed}} = W_{\text{rev}} - W_{\text{actual}}$  “ $W$  .... exergy destroyed”

“ ..... ”

“Alternatively:

**Exergy destroyed =  $T_0 \cdot \Delta S_{\text{gen}}$ ”**

$s_1 = \text{Entropy}(\text{Steam\_NBS}, T=T_1, P=P_1)$  "J/kg.K ... entropy of steam at inlet"

$s_2 = \text{Entropy}(\text{Steam\_NBS}, T=T_2, P=P_2)$  "J/kg.K .... entropy of steam at exit"

$dS_{\text{steam}} = m_{\text{steam}} \cdot (s_2 - s_1)$  "W/K ... entropy change of steam"

$dS_{\text{surr}} = Q_{\text{loss}} / (T_0 + 273)$  "W/K ... entropy change of surroundings"

$dS_{\text{gen}} = dS_{\text{steam}} + dS_{\text{surr}}$  "W/K ... entropy generated"

$e_{\text{destr2}} = (T_0 + 273) \cdot dS_{\text{gen}}$  "W ... Irreversibility or exergy destroyed"

“=====”



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**Results:**

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

$$dS_{\text{gen}} = 2573 \text{ [W/K]}$$

$$\eta_{II} = 0.8488$$

$$e_{f1} = 1.238E+06 \text{ [J/kg]}$$

$$h_2 = 2.769E+06 \text{ [J/kg]}$$

$$P_1 = 3.000E+06 \text{ [Pa]}$$

$$\text{RealFluid\$} = \text{'Steam\_NBS'}$$

$$T_0 = 25 \text{ [C]}$$

$$V = 0 \text{ [m/s]}$$

$$Z = 0 \text{ [m]}$$

$$dS_{\text{steam}} = 1567 \text{ [W/K]}$$

$$e_{\text{destr2}} = 766889 \text{ [W]}$$

$$e_{f2} = 603877 \text{ [J/kg]}$$

$$m_{\text{steam}} = 8 \text{ [kg/s]}$$

$$P_2 = 200000 \text{ [Pa]}$$

$$s_1 = 7083 \text{ [J/kg-K]}$$

$$T_1 = 450 \text{ [C]}$$

$$W_{\text{actual}} = 4.304E+06 \text{ [W]}$$

$$dS_{\text{surr}} = 1007 \text{ [W/K]}$$

$$e_{\text{destroyed}} = 766889 \text{ [W]}$$

$$h_1 = 3.344E+06 \text{ [J/kg]}$$

$$P_0 = 100000 \text{ [Pa]}$$

$$Q_{\text{loss}} = 300000 \text{ [W]}$$

$$s_2 = 7279 \text{ [J/kg-K]}$$

$$T_2 = 150 \text{ [C]}$$

$$W_{\text{rev}} = 5.071E+06 \text{ [W]}$$

**Thus:**

**Actual power output:  $W_{\text{actual}} = 4304 \text{ kW} \dots \text{Ans.}$**

**Max. power output:  $W_{\text{rev}} = 5071 \text{ kW} \dots \text{Ans.}$**

**Second Law efficiency:  $\eta_{II} = 0.8488 \dots \text{Ans.}$**

**Exergy destroyed:  $e_{\text{destroyed}} = 766.889 \text{ kW} \dots \text{Ans.}$**

**Note that by the alternative method too,**

**we get: exergy destroyed =  $e_{\text{destr2}} = 766.889 \text{ kW} \dots \text{same as earlier} \dots \text{Ans.}$**

=====

**“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”

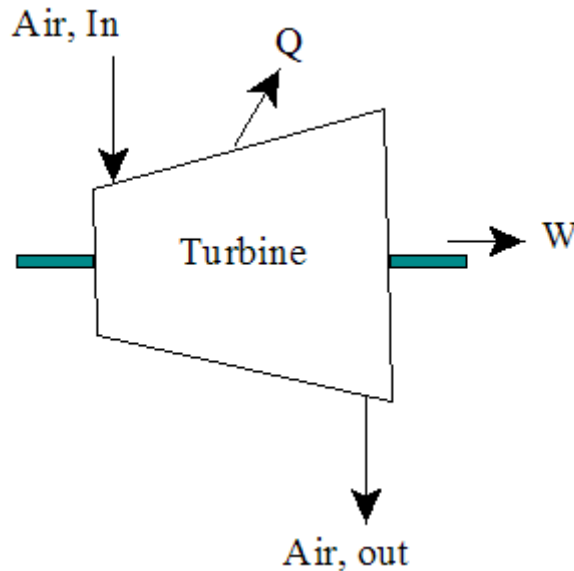


Fig.Prob.8.12

**“EES Solution:”**

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

**“Data:”**

$$P1 = 8E05 \text{ "Pa"}$$

$$T1 = 650 \text{ "C"}$$

$$m\_air = 1 \text{ "kg/s"}$$

$$P2 = 1E05 \text{ "Pa"}$$

$$T2 = 250 \text{ "C"}$$

$$Q\_loss = 9E03 \text{ "W"}$$

$$P0 = 1E05 \text{ "Pa"}$$

$$T0 = 20 \text{ "C"}$$

$$V = 0 \text{ "m/s"}$$

$$Z = 0 \text{ "m"}$$

**“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:**

$$m_{\text{air}} * (h_1 - h_2) = W_{\text{actual}} + Q$$

$$h_1 = \text{Enthalpy}(\text{Air}, T=T_1) \text{ [J/kg]}$$

$$h_2 = \text{Enthalpy}(\text{Air}, T=T_2) \text{ [J/kg]}$$

**“Therefore: actual work output is found from”**

$$m_{\text{air}} * (h_1 - h_2) = W_{\text{actual}} + Q_{\text{loss}} \text{ “} W_{\text{actual}} \text{ .... actual work output”}$$

**“Then, Second Law efficiency:”**

$$\eta_{\text{II}} = W_{\text{actual}} / W_{\text{rev}} \text{ “...Second Law effcy.”}$$

**“Exergy destroyed, or Irreversibility:”**

$$e_{\text{destroyed}} = W_{\text{rev}} - W_{\text{actual}} \text{ “} W_{\text{rev}} \text{ .... exergy destroyed”}$$

“ ..... ”

**Results:**

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

$\eta_{\text{II}} = 0.9885$	$e_{\text{destroyed}} = 4901 \text{ [W]}$	$e_{f1} = 489527 \text{ [J/kg]}$	$e_{f2} = 61628 \text{ [J/kg]}$
$h_1 = 959215 \text{ [J/kg]}$	$h_2 = 527217 \text{ [J/kg]}$	$\text{IdealGas\$} = \text{'Air'}$	$m_{\text{air}} = 1 \text{ [kg/s]}$
$P_0 = 100000 \text{ [Pa]}$	$P_1 = 800000 \text{ [Pa]}$	$P_2 = 100000 \text{ [Pa]}$	$Q_{\text{loss}} = 9000 \text{ [W]}$
$T_0 = 20 \text{ [C]}$	$T_1 = 650 \text{ [C]}$	$T_2 = 250 \text{ [C]}$	$V = 0 \text{ [m/s]}$
$W_{\text{actual}} = 422998 \text{ [W]}$	$W_{\text{rev}} = 427899 \text{ [W]}$	$Z = 0 \text{ [m]}$	

**Thus:**

$$\text{Decrease in availability} = (e_{f1} - e_{f2}) = 427.8891 \text{ kW .... Ans.}$$

$$\text{Max. power output: } W_{\text{rev}} = (e_{f1} - e_{f2}) = 427.8891 \text{ kW ... Ans.}$$

$$\text{Actual power output: } W_{\text{actual}} = 422.998 \text{ kW ... Ans.}$$

$$\text{Second Law efficiency: } \eta_{\text{II}} = 0.9885 \text{ ... Ans.}$$

$$\text{Irreversibility} = \text{Exergy destroyed: } e_{\text{destroyed}} = 4.901 \text{ kW .... Ans.}$$

=====

**“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:”**

$$P1 = 150 \times 10^3 \text{ "Pa"}$$

$$T1 = -10 \text{ "C"}$$

$$m_{R134a} = 1 \text{ "kg/s"}$$

$$P2 = 1 \times 10^6 \text{ "Pa"}$$

$$P0 = 1 \times 10^5 \text{ "Pa"}$$

$$T0 = 20 \text{ "C"}$$

$$V = 0 \text{ "m/s"}$$

$$Z = 0 \text{ "m"}$$

$$\eta_{II} = 0.75$$

**“Calculatons:”**

**“For isentropic compression:”**

$$s1 = \text{Entropy}(R134a, T=T1, P=P1) \text{ "J/kg.K"}$$

$$s2 = s1 \text{ "...for isentropic compression"}$$

**“Therefore, find T2:”**

$$s2 = \text{Entropy}(R134a, T=T2, P=P2) \text{ "J/kg.K ..... finds T2 (C)"}$$

**“ Now, Exergy at Inlet and exit .... using the Exergy Function already written:”**

$$\text{RealFluid\$} = \text{'R134a'}$$

$$e_{f1} = \text{Exergy\_massflow\_RealFluid}(\text{RealFluid\$}, T1, P1, V, Z, T0, P0) \text{ " ... J/kg"}$$

“ And, Exergy at exit:”

$e_{f2} = \text{Exergy\_massflow\_RealFluid}(\text{RealFluid}\$, T2, P2, V, Z, T0, P0)$  “ ... J/kg”

“Therefore: Reversible work = minimum required work:”

$W_{\text{rev}} = e_{f2} - e_{f1}$  “J/kg ... rev. work”

“Actual work is determined, knowing Second Law efficiency, as:”

$\eta_{\text{II}} = W_{\text{rev}} / W_{\text{act}}$  “... detrmnes  $W_{\text{act}}$ , the actual work required”

“Then: Exergy destroyed or Loss:”

$e_{\text{loss}} = W_{\text{act}} - W_{\text{rev}}$  “W”

“Isentropic efficiency:”

$h_{2s} = \text{Enthalpy}(\text{R134a}, T=T2, s=s2)$  “J/kg ... enthalpy at exit if compression were isentropic”

“ $h_2$  is determined from:  $W_{\text{act}} = h_2 - h_1$ ”

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“Then:”

$h_1 = \text{Enthalpy}(\text{R134a}, T=T_1, s=s_1)$  “J/kg .... enthalpy at inlet to compressor”

$W_{\text{act}} = h_2 - h_1$  “...determines  $h_2$ , enthalpy at exit for actual compression process”

$\eta_{\text{isentropic}} = (h_{2s} - h_1) / (h_2 - h_1)$  “... by definition of Isentropic efficiency”

**Results:**

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

$\eta_{II} = 0.75$	$\eta_{\text{isentropic}} = 0.75$	$e_{f1} = 10780 \text{ [J/kg]}$	$e_{f2} = 51798 \text{ [J/kg]}$
$e_{\text{loss}} = 13673 \text{ [W]}$	$h_1 = 246081 \text{ [J/kg]}$	$h_2 = 300771 \text{ [J/kg]}$	$h_{2s} = 287099 \text{ [J/kg]}$
$m_{\text{R134a}} = 1 \text{ [kg/s]}$	$P_0 = 100000 \text{ [Pa]}$	$P_1 = 150000 \text{ [Pa]}$	$P_2 = 1000000 \text{ [Pa]}$
$\text{RealFluid\$} = \text{'R134a'}$	$s_1 = 966 \text{ [J/kg-K]}$	$s_2 = 966 \text{ [J/kg-K]}$	$T_0 = 20 \text{ [C]}$
$T_1 = -10 \text{ [C]}$	$T_2 = 54.05 \text{ [C]}$	$V = 0 \text{ [m/s]}$	$W_{\text{act}} = 54691 \text{ [W]}$
$W_{\text{rev}} = 41018 \text{ [W]}$	$Z = 0 \text{ [m]}$		

**Thus:**

**Actual work required =  $W_{\text{act}} = 54.691 \text{ kW}$  ... Ans.**

**Isentropic efficiency =  $\eta_{\text{isentropic}} = 0.75$  ... Ans.**

**Exergy destroyed =  $e_{\text{loss}} = 13.673 \text{ kW}$  ... 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:**”

$P_1 = 900\text{E}03 \text{ “Pa”}$

$T_1 = 70 \text{ “C”}$

$P_2 = 200\text{E}03 \text{ “Pa”}$

$P_0 = 1\text{E}05 \text{ “Pa”}$

$T_0 = 25 \text{ “C”}$

$m_{\text{air}} = 0.5 \text{ “kg/s”}$

**“Calculations:”**

**“Exergy loss is easily calculated as:  $T_0 * S_{\text{gen}}$ , (remember:  $T_0$  in Kelvin)”**

$h_1 = \text{Enthalpy}(\text{Air}, T=T_1)$  “J/kg ... enthalpy at inlet to the throttle valve”

$h_2 = h_1$  “...since enthalpy remains constant during throttling”

$s_1 = \text{Entropy}(\text{Air}, T=T_1, P=P_1)$  “J/kg.K ... entropy at inlet”

$s_2 = \text{Entropy}(\text{Air}, P=P_2, h=h_2)$  “J/kg.K ... entropy at exit”

$dS_{\text{air}} = m_{\text{air}} * (s_2 - s_1)$  “W/K ...entropy change for air”

$dS_{\text{surr}} = 0$  “...since  $Q = 0$ ,  $W = 0$  for the throttle valve”

**“Therefore: entropy generated:”**

$dS_{\text{gen}} = dS_{\text{air}} + dS_{\text{surr}}$  “W/K .... entropy generated”

**“Therefore: Exergy loss or, power potential wasted:”**

$e_{\text{loss}} = (T_0 + 273) * dS_{\text{gen}}$  “W”

**“Second Law efficiency:”**

**“ $\eta_{\text{II}}$  is defined as:**

$\eta_{\text{II}} = (e_{\text{fl}} - e_{\text{loss}}) / e_{\text{fl}}$ ”

$\text{IdealGas\$} = \text{'Air'}$

$V = 0$  “m/s”

$Z = 0$  “m”

$e_{\text{fl}} = m_{\text{air}} * \text{Exergy\_massflow\_IdealGas}(\text{IdealGas\$}, T_1, P_1, V, Z, T_0, P_0)$  “W”

**“Therefore:”**

$\eta_{\text{II}} = (e_{\text{fl}} - e_{\text{loss}}) / e_{\text{fl}}$



**Results:**

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

$dS_{\text{air}} = 215.9 \text{ [W/K]}$

$dS_{\text{gen}} = 215.9 \text{ [W/K]}$

$dS_{\text{surr}} = 0 \text{ [W/K]}$

$\eta_{II} = 0.3265$

$e_{f1} = 95514 \text{ [J/kg]}$

$e_{\text{loss}} = 64325 \text{ [W]}$

$h1 = 343838 \text{ [J/kg]}$

$h2 = 343838 \text{ [J/kg]}$

$\text{IdealGas\$} = \text{'Air'}$

$m_{\text{air}} = 0.5 \text{ [kg/s]}$

$P0 = 100000 \text{ [Pa]}$

$P1 = 900000 \text{ [Pa]}$

$P2 = 200000 \text{ [Pa]}$

$s1 = 5210 \text{ [J/kg-K]}$

$s2 = 5642 \text{ [J/kg-K]}$

$T0 = 25 \text{ [C]}$

$T1 = 70 \text{ [C]}$

$V = 0 \text{ [m/s]}$

$Z = 0 \text{ [m]}$

**Thus:**

**Power potential wasted = exergy destroyed =  $e_{\text{loss}} = 64.325 \text{ kW} \dots \text{Ans.}$**

**Second Law efficiency =  $\eta_{II} = 0.3265 \dots \text{Ans.}$**

=====



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**“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  $c_p$  for air as 1100 J/kg.K, and ambient temp as 27 C.”

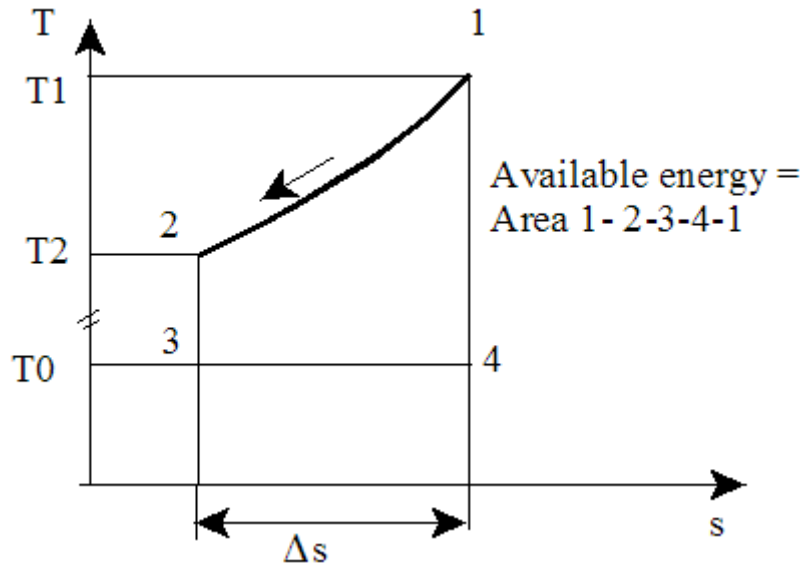


Fig.Prob.8.15

**“EES Solution:”**

**“Data:”**

$$T1 = 600 \text{ "C"}$$

$$T2 = 590 \text{ "C"}$$

$$P0 = 1E05 \text{ "Pa"}$$

$$T0 = 27 \text{ "C"}$$

$$m_{\text{air}} = 1 \text{ "kg/s"}$$

$$c_{p_{\text{air}}} = 1100 \text{ "J/kg.K"}$$

**“Calculations:”**

$$Q_{\text{lost}} = m_{\text{air}} * c_{p_{\text{air}}} * (T1 - T2) \text{ "W ... heat lost at constant pressure"}$$

$$dS_{\text{air}} = m_{\text{air}} * c_{p_{\text{air}}} * \ln((T1+273) / (T2 + 273)) \text{ "J/kg.K .... entropy change during the heat loss at const. pressure"}$$

$$e_{\text{loss}} = Q_{\text{lost}} - (T0 + 273) * dS_{\text{air}} \text{ "W"}$$

## Results:

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

$c_{p,air} = 1100$	$dS_{air} = 12.67 \text{ [W/K]}$	$e_{loss} = 7198 \text{ [W]}$	$m_{air} = 1 \text{ [kg/s]}$
$P_0 = 100000 \text{ [Pa]}$	$Q_{lost} = 11000$	$T_0 = 27 \text{ [C]}$	$T_1 = 600 \text{ [C]}$
$T_2 = 590 \text{ [C]}$			

## Thus:

Exergy lost or energy degradation due to heat loss in pipe =  $e_{loss} = 7.198 \text{ kW}$  ..... Ans.

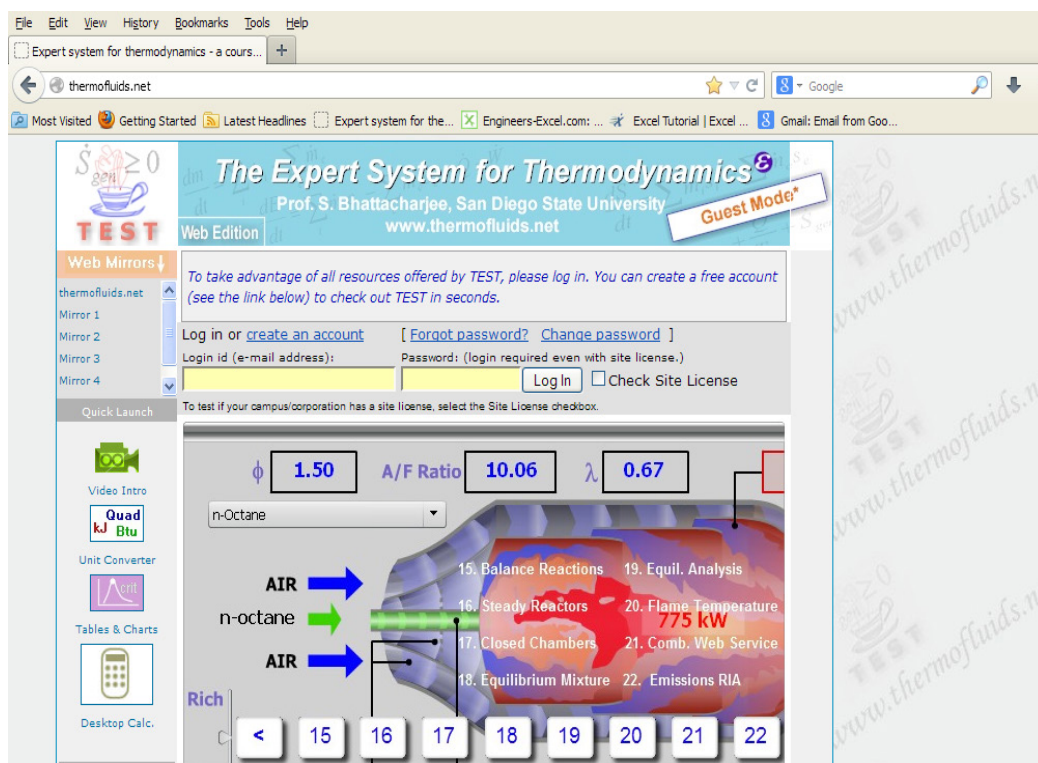
## 8.3 Problems solved with TEST:

**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]

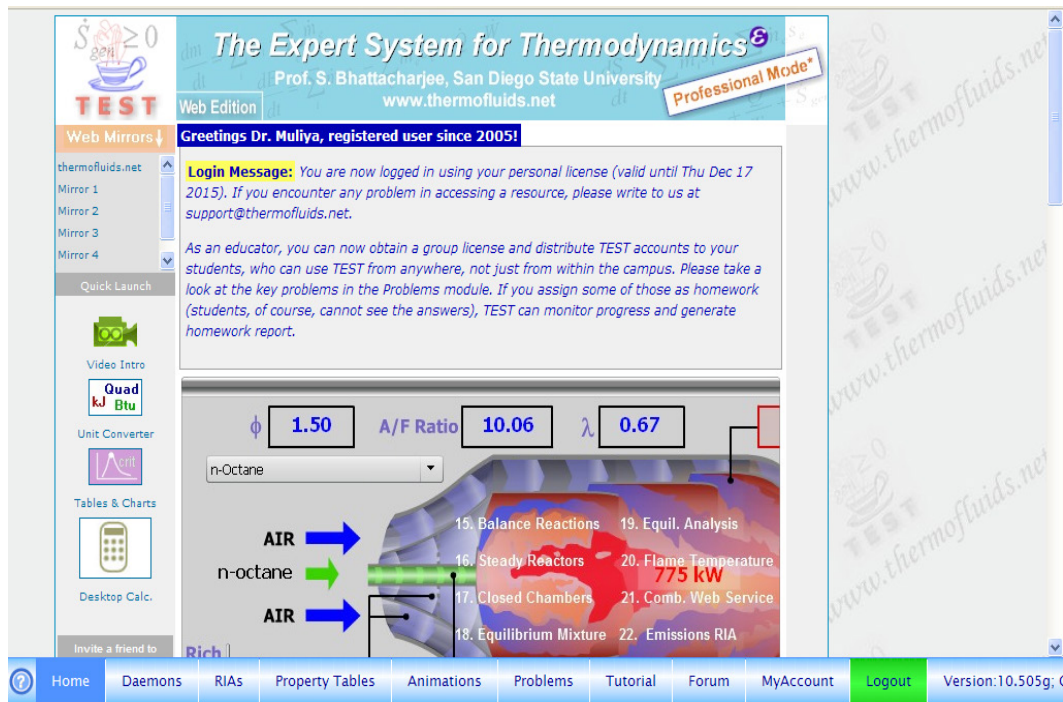
## TEST Solution:

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



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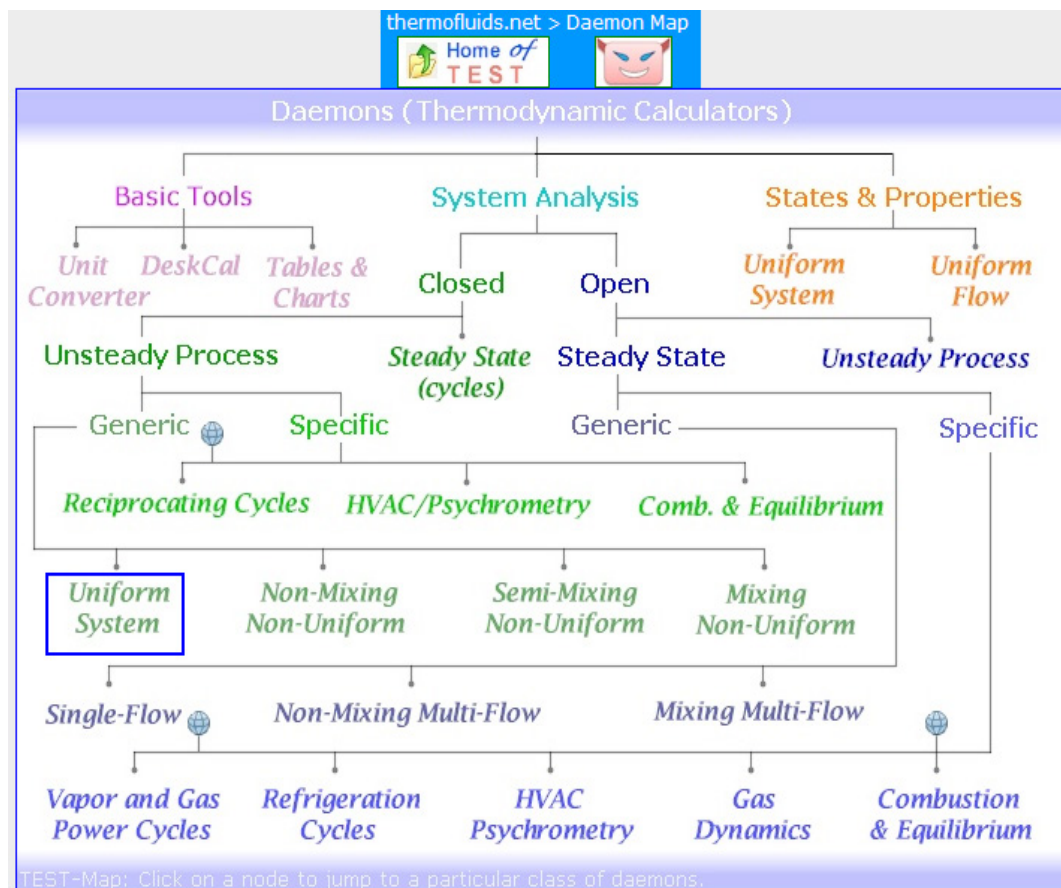
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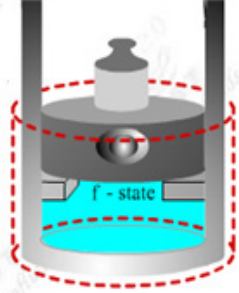
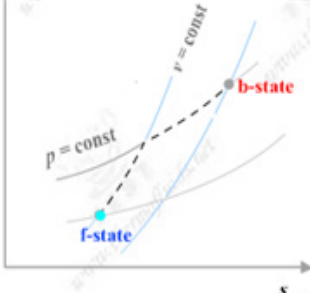
- Click on Daemons at the bottom of screen above. We get the Daemon tree and click on System Analysis–Closed–Uniform System as shown below:



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*

thermofluids.net > Daemons > Systems > Closed > Process > Generic > Uniform

Select a material model to launch the daemon.

 <p>PC Model</p>	<p><b>Pure Phase-Transition Fluid:</b> 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 <i>saturation</i> and <i>super-heated</i> 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.</p> <p>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.</p> <p><b>Examples:</b> R-134a vapor is compressed in a piston-cylinder device from a <i>beginning-state</i> to a <i>final-state</i>. 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.</p>
 <p>SL Model</p>	<p><b>Pure Solid and Pure Liquid:</b> Constant density and constant specific heats (<math>c_p = c_v = c</math>) characterize the solid/liquid (SL) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p><b>Examples:</b> A block of copper is heated from a <i>beginning-state</i> to a <i>final-state</i>. To find the heat transfer necessary for the process. For specific examples, click on the help icon at the bottom margin of the daemon.</p>

5. Select R134a for the substance. Then, enter for State '0', the ambient conditions, viz.  $p_0 = 100$  kPa,  $T_0 = 24$  C. This will be required to make exergy calculations. Hit Enter. We get:

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

thermofluids.net > Daemons > Systems > Closed > Process > Generic > Uniform > PC-Model

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel		Process Panel		Exergy Panel		I/O Panel	
<span>State-0</span> <span>Calculate</span> <span>No-Plots</span> <span>Initialize</span> <span>Superheated Vapor</span> <span>R-134a</span>							
<input checked="" type="checkbox"/> $p_0$	<input checked="" type="checkbox"/> $T_0$	$x_0$	$y_0$	$v_0$			
100.0 kPa	24.0 deg-C			0.23734 m <sup>3</sup> /kg			
$u_0$	$h_0$	$s_0$	$Vel_0$	$z_0$			
250.73116 kJ/kg	274.46548 kJ/kg	1.09921 kJ/kg.K	0.0 m/s	0.0 m			
$e_0$	$j_0$	$\phi_0$	$\psi_0$	$m_0$			
250.73116 kJ/kg	274.46548 kJ/kg	0.0 kJ/kg	0.0 kJ/kg				
$Vol_0$	$MM_0$						
	102.03 kg/kmol						

6. Now, go to State 1, and enter the data, i.e.  $p_1 = 700$  kPa,  $T_1 = 60$  C,  $m_1 = 5$  kg. Hit Enter. Immediately, all State properties are calculated:

p1 = 700.0 kPa [Absolute pressure]

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

< State-1 > Calculate No-Plots Initialize Superheated Vapor R-134a

<input checked="" type="checkbox"/> p1	<input checked="" type="checkbox"/> T1	x1	y1	v1
700.0 kPa	60.0 deg-C	fraction	fraction	0.03493 m³/kg
u1	h1	s1	Vel1	z1
273.34018 kJ/kg	297.7901 kJ/kg	1.02287 kJ/kg.K	0.0 m/s	0.0 m
e1	j1	phi1	psi1	m1
273.34018 kJ/kg	297.7901 kJ/kg	25.05234 kJ/kg	46.00942 kJ/kg	5.0 kg
Vol1	MM1			
0.17464 m³	102.03 kg/kmol			

7. Now, go to State 2, enter  $p_2 = p_1$  (since i-2 is a constant pressure process),  $T_2 = 24$  C,  $m_2 = m_1$ . Hit Enter. We get:

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

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

< State-2 > Calculate No-Plots Initialize Subcooled Liquid R-134a

<input checked="" type="checkbox"/> p2	<input checked="" type="checkbox"/> T2	x2	y2	v2
=p1 kPa	24.0 deg-C	fraction	fraction	8.3E-4 m³/kg
u2	h2	s2	Vel2	z2
83.65508 kJ/kg	84.2337 kJ/kg	0.31624 kJ/kg.K	0.0 m/s	0.0 m
e2	j2	phi2	psi2	m2
83.65508 kJ/kg	84.2337 kJ/kg	41.93217 kJ/kg	42.42814 kJ/kg	=m1 kg
Vol2	MM2			
0.00413 m³	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.  $3.14 \times 9.5^2$ ,  $h_2 - h_1$ ,  $p_1 \cdot (\text{Vol1/Vol2})^{1.3}$ , etc.)

Mixed SI English ©Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

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

Q	W <sub>B</sub>	W <sub>O</sub>	T <sub>B</sub>
-1067.782 kJ	-119.35648 kJ	0.0 kJ	298.15 K
S <sub>gen</sub>	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:  $m(e_f - e_b) = Q - (W_B + W_O)$   
 $\Delta E = E_f - E_b$   $W_{\text{ext}}$

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

Diagram: A closed system (State-1 to State-2) with heat input Q, work output W<sub>ext</sub>, and boundary temperature T<sub>B</sub>.  
 $W_{\text{ext}} = W_B + W_O$ ;  $W_O = W_{\text{sh}} + W_{\text{cl}}$

WinHip: Work in negative Heat in positive

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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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel Exergy Panel I/O Panel

Calculate Initialize Exergy Analysis for Process - A

Delta_Phi	W_u	I	S_gen.univ	W_rev
84.39914 kJ	-102.30556 kJ	17.90641 kJ	0.06026 kJ/K	-84.39914 kJ

W	W_atm	Q_0	T_0	Q_1
-119.35648 kJ	-17.05093 kJ	-1067.782 kJ	24.0 deg-C	0.0 kJ

T\_1 298.15 K

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

$$m(\phi_f - \phi_b) = Q_0 \left(1 - \frac{T_0}{T_1}\right) - (W_u + I)$$

$$W_{ext} = W_B + W_O = W_{atm} + W_u$$

$$W_{rev} = W_u + I; I = T_0 S_{gen.univ}; \eta_{II} = \frac{\text{Desired exergy output}}{\text{Required exergy input}}$$

Q = Q\_0 + Q\_1;

WinHip: Work in negative Heat in positive

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;
```

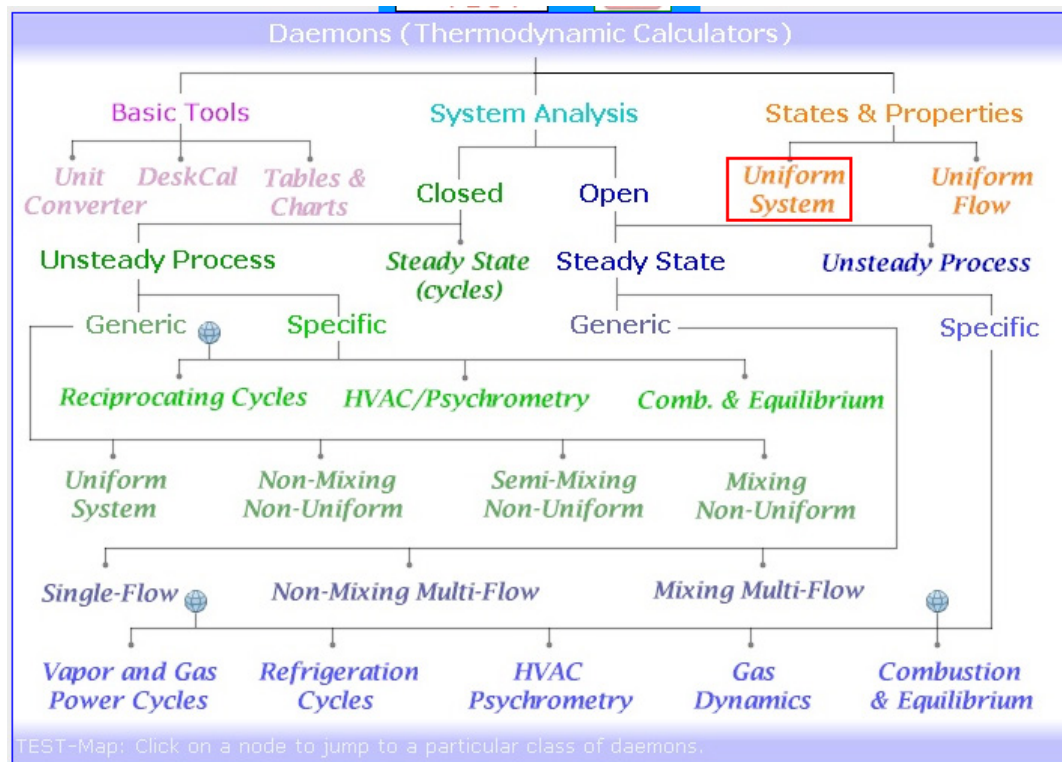
**Prob.8.17.** A rigid container with 200 L volume is divided in to two equal volumes by a partition. Both sides contain nitrogen, one side is at 2 MPa, 300 C, and the other at 1 MPa, 50 C. The partition ruptures, and the nitrogen comes to a uniform state at 100 C. Assuming the surroundings are at 25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



"I studied English for 16 years but...  
...I finally learned to speak it in just six lessons"

Jane, Chinese architect

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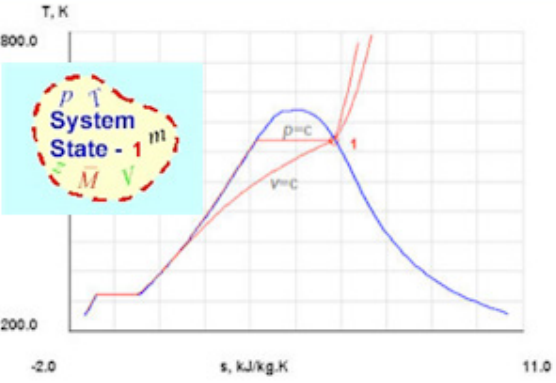
Hovering the mouse pointer on Uniform system brings up:

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.

 <p>SL Model</p>	<p>Any model beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p><b>Examples:</b> 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.</p>
 <p>PG Model</p>	<p><b>Pure Perfect Gas:</b> The perfect gas (PG) model is the simplest gas model. It obeys the ideal gas equation of state (<math>p\nu=RT</math>); 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.</p> <p><b>Examples:</b> 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.</p>
 <p>IG Model</p>	<p><b>Pure Ideal Gas:</b> An ideal gas (IG) is a gas that obeys the ideal gas equation of state (<math>p\nu=RT</math>). 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.</p> <p><b>Examples:</b> 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.</p>



3. Choose N2 for substance and enter for State 1,  $p_1$ ,  $T_1$  and  $\text{Vol}_1$ . Hit Enter. We get:

System State Daemon: *Ideal Gas (IG) Model*  
thermofluids.net > Daemons > States > System > IG-Model

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< State-1 Calculate No-Plots Initialize Formation Enthalpy: No Yes N2

<input checked="" type="checkbox"/> $p_1$	<input checked="" type="checkbox"/> $T_1$	$\rho_1$	$v_1$	$u_1$
2.0 MPa	300.0 deg-C	11.75194 kg/m <sup>3</sup>	0.08509 m <sup>3</sup> /kg	119.74717 kJ/kg
$h_1$	$s_1$	<input checked="" type="checkbox"/> $\text{Vel}_1$	<input checked="" type="checkbox"/> $z_1$	$e_1$
289.9318 kJ/kg	6.64387 kJ/kg.K	0.0 m/s	0.0 m	119.74717 kJ/kg
$j_1$	$\phi_1$	$\psi_1$	$m_1$	<input checked="" type="checkbox"/> $\text{Vol}_1$
289.9318 kJ/kg			1.17519 kg	100.0 L
$MM_1$	$R_1$	$c_{p1}$		
28.0 kg/kmol	0.29693 kJ/kg.K	1.08281 kJ/kg.K		

Note that mass,  $m_1$ , Int. energy,  $u_1$ , entropy,  $s_1$  etc are immediately calculated.

4. Similarly, for State 2, enter  $p_2$ ,  $T_2$  and  $\text{Vol}_2$ . 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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< State-2 Calculate No-Plots Initialize Formation Enthalpy: No Yes N2

<input checked="" type="checkbox"/> $p_2$	<input checked="" type="checkbox"/> $T_2$	$\rho_2$	$v_2$	$u_2$
1.0 MPa	50.0 deg-C	10.42183 kg/m <sup>3</sup>	0.09595 m <sup>3</sup> /kg	-70.51565 kJ/kg
$h_2$	$s_2$	<input checked="" type="checkbox"/> $\text{Vel}_2$	<input checked="" type="checkbox"/> $z_2$	$e_2$
25.43681 kJ/kg	6.24475 kJ/kg.K	0.0 m/s	0.0 m	-70.51565 kJ/kg
$j_2$	$\phi_2$	$\psi_2$	$m_2$	<input checked="" type="checkbox"/> $\text{Vol}_2$
25.43681 kJ/kg			1.04218 kg	10.0 L
$MM_2$	$R_2$	$c_{p2}$		
28.0 kg/kmol	0.29693 kJ/kg.K	1.03473 kJ/kg.K		

Note that mass,  $m_2$ , Int. energy,  $u_2$ , entropy,  $s_2$  etc are immediately calculated.

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

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

• Mixed • SI • English < @Case-0 > ✓ Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel I/O Panel

< @State-3 > Calculate No-Plots Initialize Formation Enthalpy: No • Yes N2

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

$$\#Q = dU + W \text{ and, } W = 0$$

$$= m_3 \cdot u_3 - (m_1 \cdot u_1 + m_2 \cdot u_2)$$

$$\text{i.e. } Q = m_3 \cdot u_3 - (m_1 \cdot u_1 + m_2 \cdot u_2) = -141.336 \text{ kJ ... Ans... heat rejected to ambient}$$

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```
# 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

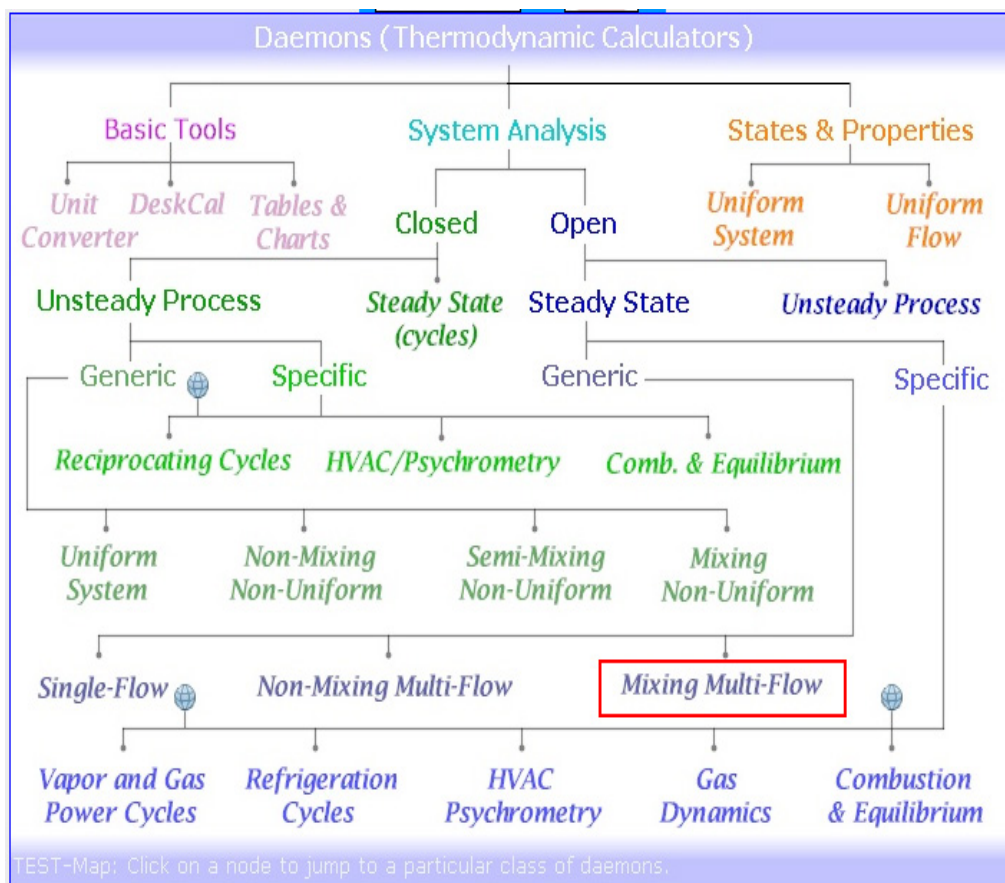
**Prob.8.18.** Two flows of air, both at 200 kPa, of equal flow rates mix in an insulated mixing chamber. One flow is at 1500 K, and the other at 300 K. Find the Irreversibility in the process per kg of air flowing out. [Ref: 2]

**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.

- Choose PG model for material model, select Air as the substance, and enter  $p_1$ ,  $T_1$  and  $\dot{m}dt_1$  for State 1. Hit Enter. We get:

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

thermofluids.net > Daemons > Systems > Open > Steady > Generic > Mixing > PG-Model

Home of TEST

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

☒ Mixed ☐ SI ☐ English  ☒ Help Messages On

State Panel Device Panel I/O Panel

☒ State-1  No-Plots  Formation Enthalpy: ☐ No ☒ Yes Air

<input checked="" type="checkbox"/> $p_1$	<input checked="" type="checkbox"/> $T_1$	$v_1$	$u_1$	$h_1$
200.0 kPa	1500.0 K	2.1524 m <sup>3</sup> /kg	775.56946 kJ/kg	1206.0493 kJ/kg
$s_1$	<input checked="" type="checkbox"/> $Vel_1$	$z_1$	$e_1$	$j_1$
8.30903 kJ/kg.K	0.0 m/s	0.0 m	775.56946 kJ/kg	1206.0493 kJ/kg
$\phi_{i1}$	$\psi_{i1}$	<input checked="" type="checkbox"/> $\dot{m}dt_1$	$\dot{V}dt_1$	$A_1$
		0.5 kg/s	1.0762 m <sup>3</sup> /s	107619.95 m <sup>2</sup>
$MM_1$	$R_1$	$c_{p1}$	$c_{v1}$	$k_1$
28.97 kg/kmol	0.28699 kJ/kg.K	1.00349 kJ/kg.K	0.71651 kJ/kg.K	1.40054 UnitLess

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3. For State 2, enter  $p_2$ ,  $T_2$  and  $\dot{m}_{d2}$ , and hit Enter. We get:

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel I/O Panel

State-2 Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> $p_2$	<input checked="" type="checkbox"/> $T_2$	$v_2$	$u_2$	$h_2$
200.0 kPa	300.0 K	0.43048 m <sup>3</sup> /kg	-84.2395 kJ/kg	1.85646 kJ/kg
$s_2$	<input checked="" type="checkbox"/> $Vel_2$	<input checked="" type="checkbox"/> $z_2$	$e_2$	$j_2$
6.69397 kJ/kg.K	0.0 m/s	0.0 m	-84.2395 kJ/kg	1.85646 kJ/kg
$\phi_{i2}$	$\psi_{i2}$	<input checked="" type="checkbox"/> $\dot{m}_{d2}$	$Vol_{d2}$	$A_2$
		0.5 kg/s	0.21524 m <sup>3</sup> /s	21523.99 m <sup>2</sup>
$MM_2$	$R_2$	$c_{p2}$	$c_{v2}$	$k_2$
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 3, enter  $p_3$ ,  $h_3 = (m_1 \cdot h_1 + m_2 \cdot h_2) / (m_1 + m_2)$ , and  $\dot{m}_{d3} = (\dot{m}_{d1} + \dot{m}_{d2})$  and hit Enter. We get:

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel I/O Panel

State-3 Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> $p_3$	$T_3$	$v_3$	$u_3$	<input checked="" type="checkbox"/> $h_3$
200.0 kPa	900.0 K	1.29144 m <sup>3</sup> /kg	345.66498 kJ/kg	$=(m_1 \cdot h_1 + m_2 \cdot h_2) / (m_1 + m_2)$ kJ/kg
$s_3$	<input checked="" type="checkbox"/> $Vel_3$	<input checked="" type="checkbox"/> $z_3$	$e_3$	$j_3$
7.79642 kJ/kg.K	0.0 m/s	0.0 m	345.66498 kJ/kg	603.9529 kJ/kg
$\phi_{i3}$	$\psi_{i3}$	<input checked="" type="checkbox"/> $\dot{m}_{d3}$	$Vol_{d3}$	$A_3$
		$=\dot{m}_{d1} + \dot{m}_{d2}$ kg/s	1.29144 m <sup>3</sup> /s	129143.945 m <sup>2</sup>
$MM_3$	$R_3$	$c_{p3}$	$c_{v3}$	$k_3$
28.97 kg/kmol	0.28699 kJ/kg.K	1.00349 kJ/kg.K	0.71651 kJ/kg.K	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,  $\dot{Q} = 0$ , since chamber is insulated, and  $\dot{W}_{\text{ext}} = 0$ , 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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel I/O Panel

Initialize Device-A [1,2-3] Calculate 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:

$$0 = (\dot{m}_1 + \dot{m}_2) - (\dot{m}_e1 + \dot{m}_e2)$$

$$0 = (\dot{m}_1 h_1 + \dot{m}_2 h_2) - (\dot{m}_e1 h_{e1} + \dot{m}_e2 h_{e2}) + \dot{Q} - \dot{W}_{\text{ext}}$$

$$0 = (\dot{m}_1 s_1 + \dot{m}_2 s_2) - (\dot{m}_e1 s_{e1} + \dot{m}_e2 s_{e2}) + \frac{\dot{Q}}{T_B} + \dot{S}_{\text{gen}}$$

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

WinHip: Work in negative Heat in positive

Note that  $\dot{S}_{\text{gen}}$  is calculated as 0.29492 kW/K.

Calculate the Irreversibility as shown below:

$$\# \text{Exergy lost} = \text{Irreversibility} = T_0 * \dot{S}_{\text{gen}}$$

$$\text{i.e. Irreversibility} = (25+273) * 0.29492 = 87.886 \text{ kW} \dots \text{Ans.}$$



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; }

}



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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 <sup>3</sup> /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;

=====

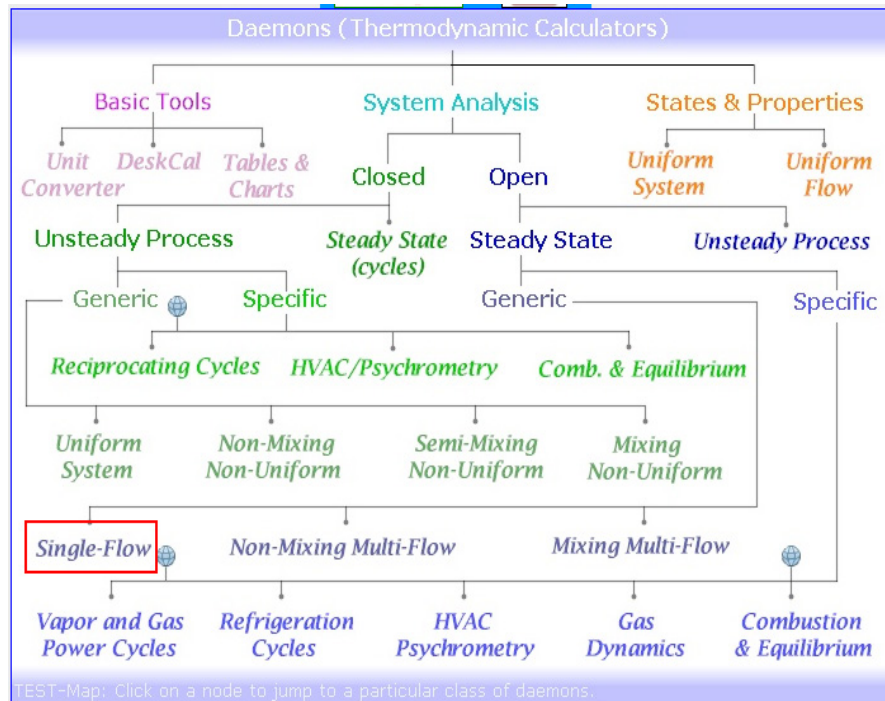
**Prob.8.19.** A steady stream of R-22 at ambient temp 10 C and at 750 kPa enters a solar collector. The stream exits at 80 C and 700 kPa. Calculate the change in availability of R-22 between these two states. [Ref: 2]



## TEST Solution:

Following are the steps:

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



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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.

<p>PC Model</p>	<p><b>Pure Phase-Transition Fluid:</b> 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 <i>saturation</i> and <i>super-heated</i> tables, the model is quite accurate. Sub-cooled liquid is modeled with the compressed-liquid sub-model, except for species with an asterisk (H<sub>2</sub>O* as opposed to H<sub>2</sub>O), which uses compressed liquid table for better accuracy.</p> <p>Working fluids such as H<sub>2</sub>O, R-12, NH<sub>3</sub>, R-134a, N<sub>2</sub>, CO<sub>2</sub>, etc., should be treated as PC fluids if there is any possibility of a phase transition.</p> <p><b>Examples:</b> 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.</p>
<p>SL Model</p>	<p><b>Pure Solid and Pure Liquid:</b> Constant density and constant specific heats (<math>c_p = c_v = c</math>) characterize the solid/liquid (SL) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p><b>Examples:</b> Liquid water is pumped steadily from a given <i>inlet-state</i> to a given <i>exit-state</i> with no possibility of a phase change. For specific examples, click on the help icon at the bottom margin of the daemon.</p>

3. And, select R-22 for the substance and enter  $p_0 = 100$  kPa and  $T_0 = 10$  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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< State-0 > Calculate No-Plots Initialize Superheated Vapor R-22

<input checked="" type="checkbox"/> $p_0$	$T_0$	$x_0$	$y_0$	$v_0$
100.0 kPa	10.0 deg-C			0.26748 m <sup>3</sup> /kg
$u_0$	$h_0$	$s_0$	$Vel_0$	$z_0$
237.59563 kJ/kg	264.3436 kJ/kg	1.12558 kJ/kg.K	0.0 m/s	0.0 m
$e_0$	$j_0$	$\phi_0$	$\psi_0$	$\dot{m}_{dot0}$
237.59563 kJ/kg	264.3436 kJ/kg	0.0 kJ/kg	0.0 kJ/kg	
$Vol_{dot0}$	$A_0$	$MM_0$		
		86.476 kg/kmol		

4. For State 1: Enter  $p_1$ ,  $T_1$  and  $\dot{m}_{dot1}$  as shown, and hit Enter. We get:

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

Mixed SI English < @Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< @State-1 > Calculate No-Plots Initialize Subcooled Liquid R-22

$p_1$	$T_1$	$x_1$	$y_1$	$v_1$
750.0 kPa	10.0 deg-C	fraction	fraction	8.0E-4 m <sup>3</sup> /kg
$u_1$	$h_1$	$s_1$	$Vel_1$	$z_1$
55.91544 kJ/kg	56.51544 kJ/kg	0.2173 kJ/kg.K	0.0 m/s	0.0 m
$e_1$	$j_1$	$\phi_1$	$\psi_1$	$\dot{m}_{dot1}$
55.91544 kJ/kg	56.51544 kJ/kg	48.83044 kJ/kg	49.35046 kJ/kg	1.0 kg/s
$V_{oldot1}$	$A_1$	$MM_1$		
8.0E-4 m <sup>3</sup> /s	80.0 m <sup>2</sup>	kg/kmol		

Note that all properties such as  $h_1$ ,  $s_1$  etc at State 1 are calculated.

5. Now, for State 2: enter  $p_2$ ,  $T_2$  and  $\dot{m}_{dot2}$ , 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 Exergy Panel I/O Panel

< @State-2 > Calculate No-Plots Initialize Superheated Vapor R-22

$p_2$	$T_2$	$x_2$	$y_2$	$v_2$
700.0 kPa	30.0 deg-C	fraction	fraction	0.04565 m <sup>3</sup> /kg
$u_2$	$h_2$	$s_2$	$Vel_2$	$z_2$
273.94855 kJ/kg	305.90244 kJ/kg	1.07608 kJ/kg.K	0.0 m/s	0.0 m
$e_2$	$j_2$	$\phi_2$	$\psi_2$	$\dot{m}_{dot2}$
273.94855 kJ/kg	305.90244 kJ/kg	28.18535 kJ/kg	55.57442 kJ/kg	= $\dot{m}_{dot1}$ kg/s
$V_{oldot2}$	$A_2$	$MM_2$		
0.04565 m <sup>3</sup> /s	4564.84 m <sup>2</sup>	86.476 kg/kmol		

Again note that all properties such as  $h_2$ ,  $s_2$  are calculated.

6. Now, go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. And,  $\dot{W}_{\text{ext}} = 0$ . 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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< Device-A [1-2] > i-State: State-1 e-State: State-2 Calculate Initialize

$\dot{Q}_{\text{dot}}$	$\dot{W}_{\text{dot\_ext}}$	$T_B$	$\dot{S}_{\text{dot\_gen}}$
249.387 kW	0.0 kW	298.15 K	0.02233 kW/K
$\dot{J}_{\text{dot\_net}}$	$\dot{S}_{\text{dot\_net}}$		
-249.387 kW	-0.85878 kW/K		

**Single-Flow Steady Device - A**

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

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

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

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

WinHip: Work in negative Heat in positive

Note that  $\dot{S}_{\text{dot\_gen}}$  and  $\dot{Q}_{\text{dot}}$  are calculated.  $\dot{Q}_{\text{dot}}$  is +ve...means that heat is entering in to the system.

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

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 **Exergy Panel** I/O Panel

Calculate Initialize Exergy Analysis for Device - A

Psidot_net	Wdot_u	Idot	Sdot_gen,univ	Wdot_rev
-6.22396 kW	0.0 kW	-6.22396 kW	-0.02198 kW/K	-6.22396 kW

Qdot_0	T_0	Qdot_1	T_1
249.387 kW	283.15 K	0.0 kW	298.15 K

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

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

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

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

**WinHip:**  
Work in negative  
Heat in positive

$\eta_a$  (Exergetic Efficiency)  
Desired exergy output  
Required exergy input

Note that exergy difference between inlet and exit is Psidot\_net = -6.22396 kW .... Ans.

Remember: Exergy difference =  $\dot{m} \cdot \{(h_2 - h_1) - T_0 \cdot (s_2 - s_1)\}$

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: {  $\dot{W}_{\text{ext}} = 0.0 \text{ kW}$ ;  $T_B = 298.15 \text{ K}$ ; }

}

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

#-----Property spreadsheet starts:

#

# State	p(kPa)	T(K)	x	v(m <sup>3</sup> /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:  $\dot{W}_{\text{ext}} = 0.0 \text{ kW}$ ;  $T_B = 298.15 \text{ K}$ ;

# Calculated:  $\dot{Q} = 249.387 \text{ kW}$ ;  $\dot{S}_{\text{gen}} = 0.022330081 \text{ kW/K}$ ;  $\dot{J}_{\text{net}} = -249.387 \text{ kW}$ ;  
 $\dot{S}_{\text{net}} = -0.8587782 \text{ kW/K}$ ;

#### # Exergy Analysis Results:

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

# Given:  $\dot{Q} = 249.387 \text{ kW}$ ;  $T_0 = 283.15 \text{ K}$ ;  $\dot{Q}_{\text{1}} = 0.0 \text{ kW}$ ;

#  $T_1 = 298.15 \text{ K}$ ;

# Calculated:  $\dot{P}_{\text{sidot\_net}} = -6.22396 \text{ kW}$ ;  $\dot{W}_{\text{u}} = 0.0 \text{ kW}$ ;  $\dot{I}_{\text{dot}} = -6.22396 \text{ kW}$ ;

#  $\dot{S}_{\text{gen,univ}} = -0.02198 \text{ kW/K}$ ;  $\dot{W}_{\text{dot\_rev}} = -6.22396 \text{ kW}$ ;  $\dot{Q}_{\text{dot\_0}} = 249.387 \text{ kW}$ ;

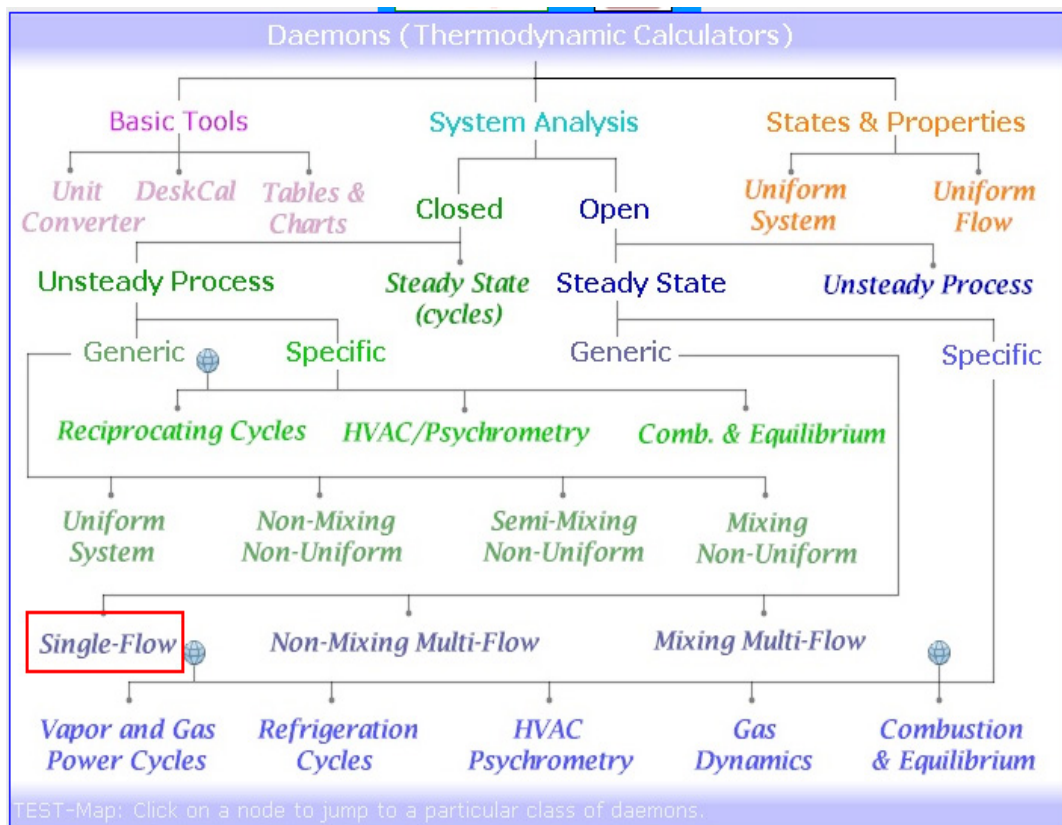
=====

**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.

	<p><b>Pure Phase-Transition Fluid:</b> The phase-change (PC) model can be used to determine states of (compressed) liquid, super-heated vapor, and saturated mixture of liquid and vapor phases. Based on saturation and super-heated tables, the model is quite accurate. Sub-cooled liquid is modeled with compressed-liquid sub-model, except for species with an asterisk (H<sub>2</sub>O* as opposed to H<sub>2</sub>O), with a compressed liquid table for better accuracy.</p> <p>Working fluids such as H<sub>2</sub>O, R-12, NH<sub>3</sub>, R-134a, N<sub>2</sub>, CO<sub>2</sub>, etc., should be treated as PC fluids if there is a possibility of a phase transition.</p> <p><b>Examples:</b> 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.</p>
	<p><b>Pure Solid and Pure Liquid:</b> Constant density and constant specific heats (<math>c_p = c_v = c</math>) characterize solid/liquid (SL) model. Besides a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be used to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be modeled with the SL model.</p> <p><b>Examples:</b> Liquid water is pumped steadily from a given inlet-state to a given exit-state without a phase change. For specific examples, click on the help icon at the bottom margin of the daemon.</p>

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3. And, select H<sub>2</sub>O for substance, enter for State – '0' values of  $p_0$ ,  $T_0$  (for exergy calculations).  
Hit Enter:

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

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

Home of TEST

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

State-0 Calculate No-Plots Initialize Subcooled Liquid H2O

$p_0$	100.0	kPa	$T_0$	25.0	deg-C	$x_0$		fraction	$y_0$		fraction	$v_0$	0.001	m <sup>3</sup> /kg
$u_0$	104.87847	kJ/kg	$h_0$	104.97879	kJ/kg	$s_0$	0.36732	kJ/kg.K	$Vel_0$	0.0	m/s	$z_0$	0.0	m
$e_0$	104.87847	kJ/kg	$j_0$	104.97879	kJ/kg	$\phi_0$	0.0	kJ/kg	$\psi_0$	0.0	kJ/kg	$\dot{m}_{dot0}$		kg/s
$V_{oldot0}$		m <sup>3</sup> /s	$A_0$		m <sup>2</sup>	$MM_0$		kg/kmol						

4. Enter  $p_1$ ,  $T_1$  and  $\dot{m}_{dot1}$  for State 1, hit Enter. We get:

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

State-1 Calculate No-Plots Initialize Superheated Vapor H2O

$p_1$	25.0	MPa	$T_1$	550.0	deg-C	$x_1$		fraction	$y_1$		fraction	$v_1$	0.01272	m <sup>3</sup> /kg
$u_1$	3017.4932	kJ/kg	$h_1$	3335.5854	kJ/kg	$s_1$	6.17636	kJ/kg.K	$Vel_1$	0.0	m/s	$z_1$	0.0	m
$e_1$	3017.4932	kJ/kg	$j_1$	3335.5854	kJ/kg	$\phi_1$	1181.8214	kJ/kg	$\psi_1$	1498.6414	kJ/kg	$\dot{m}_{dot1}$	70.0	kg/s
$V_{oldot1}$	0.89066	m <sup>3</sup> /s	$A_1$	89065.76	m <sup>2</sup>	$MM_1$	18.0	kg/kmol						

5. Similarly, for State 2: enter  $p_2$ ,  $T_2$  and  $\dot{m}_{dot2}$ , and hit Enter:

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 Exergy Panel I/O Panel

State-2 Calculate No-Plots Initialize Superheated Vapor H2O

$p_2$	5.0	MPa	$T_2$	325.0	deg-C	$x_2$		fraction	$y_2$		fraction	$v_2$	0.04863	m <sup>3</sup> /kg
$u_2$	2753.2876	kJ/kg	$h_2$	2996.4312	kJ/kg	$s_2$	6.3287	kJ/kg.K	$Vel_2$	0.0	m/s	$z_2$	0.0	m
$e_2$	2753.2876	kJ/kg	$j_2$	2996.4312	kJ/kg	$\phi_2$	875.78467	kJ/kg	$\psi_2$	1114.0653	kJ/kg	$\dot{m}_{dot2}$	= $\dot{m}_{dot1}$	kg/s
$V_{oldot2}$	3.40401	m <sup>3</sup> /s	$A_2$	340400.72	m <sup>2</sup>	$MM_2$	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:  $p_3 = p_2$ ,  $s_3 = s_1$  and  $\dot{m}_3 = \dot{m}_1$ . Hit Enter. We get:

Note that if the expansion were isentropic,  $h_3$  would be:  $h_3 = 2906.832$  kJ/kg

7. Go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. Also,  $\dot{Q}_{dot} = 0$ . Click on Calculate and then SuperCalculate. 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 Exergy Panel I/O Panel

Device-A [1-2] i-State: State-1 e-State: State-2 Calculate Initialize

$\dot{Q}_{dot}$	0.0 kW	$\dot{W}_{dot\_ext}$	23740.8 kW	$T_B$	298.15 K	$\dot{S}_{dot\_gen}$	10.66416 kW/K
$\dot{J}_{dot\_net}$	23740.8 kW	$\dot{S}_{dot\_net}$	-10.66416 kW/K				

**Single-Flow Steady Device - A**

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

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

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

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

WinHip: Work in negative Heat in positive

Note that  $\dot{W}_{dot\_ext} = 23740.8 \text{ kW}$  ... actual work output .... Ans.

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

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 Exergy Panel I/O Panel

Calculate Initialize Exergy Analysis for Device - A

$\dot{P}_{s_{dot\_net}}$	26920.32 kW	$\dot{W}_{dot\_u}$	23740.8 kW	$\dot{I}_{dot}$	3179.52 kW	$\dot{S}_{dot\_gen,univ}$	10.66416 kW/K	$\dot{W}_{dot\_rev}$	26920.32 kW
$\dot{Q}_{dot\_0}$	0.0 kW	$T_0$	298.15 K	$\dot{Q}_{dot\_1}$	0.0 kW	$T_1$	298.15 K		

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

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

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

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

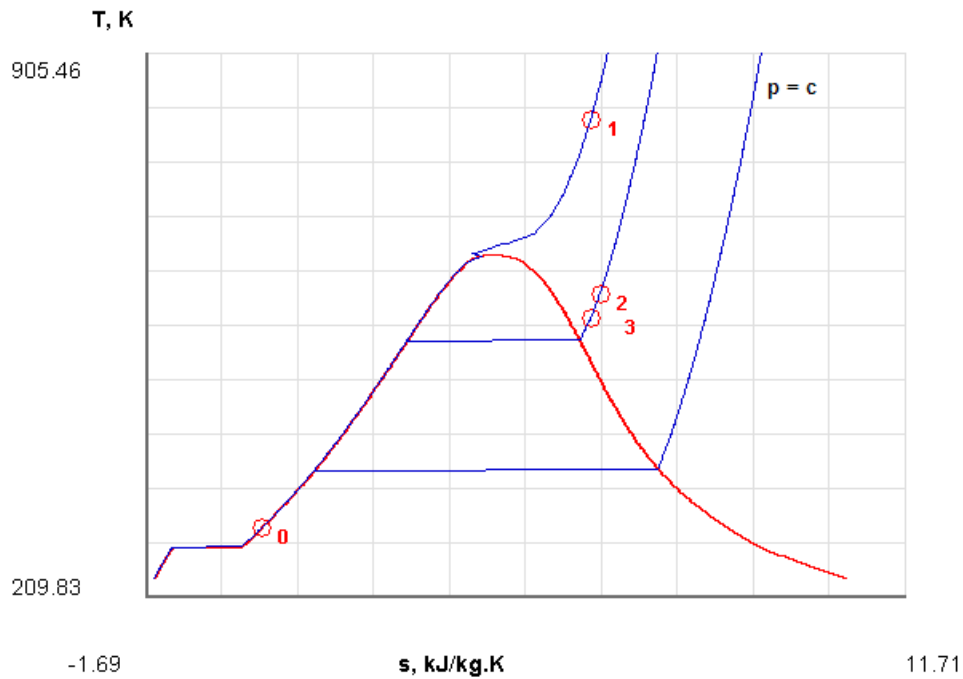
WinHip: Work in negative Heat in positive

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

Note that  $\dot{W}_{dot\_rev} = \text{rev. work} = 26920.32 \text{ kW}$ . ... 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 =  $\eta_{iso} = (h_1 - h_2) / (h_1 - h_3) = 0.791$**

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: H<sub>2</sub>O;

Given: {  $p_2 = 5.0$  MPa;  $T_2 = 325.0$  deg-C;  $Vel_2 = 0.0$  m/s;  $z_2 = 0.0$  m;  $\dot{m}_2 = \text{"mdot1"}$  kg/s; }

State-3: H<sub>2</sub>O;

Given: {  $p_3 = \text{"P2"}$  MPa;  $s_3 = \text{"s1"}$  kJ/kg.K;  $Vel_3 = 0.0$  m/s;  $z_3 = 0.0$  m;  $\dot{m}_3 = \text{"mdot1"}$  kg/s; }  
}

Analysis {

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

Given: {  $\dot{Q} = 0.0$  kW;  $T_B = 298.15$  K; }  
}

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

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

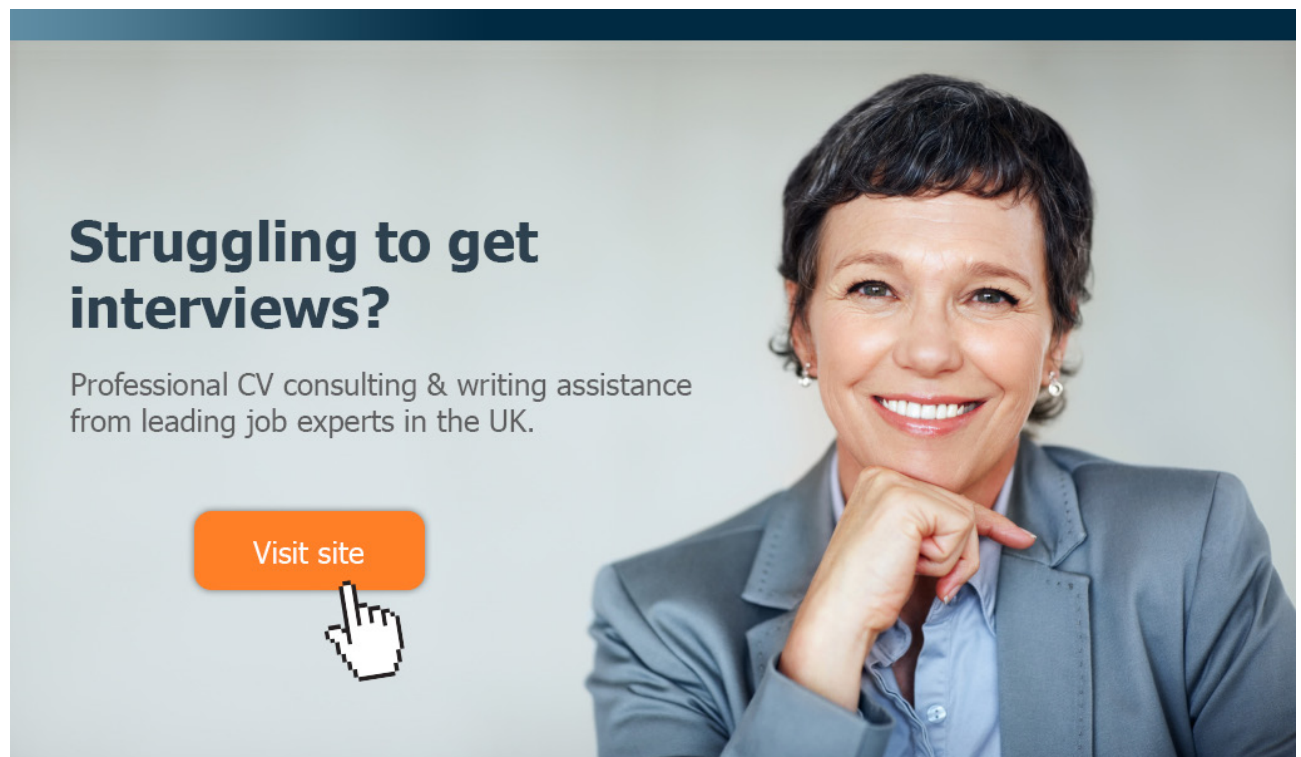
# Evaluated States:

```
#      State-0: H2O > Subcooled Liquid;
#          Given:  $p_0 = 100.0$  kPa;  $T_0 = 25.0$  deg-C;  $Vel_0 = 0.0$  m/s;
#               $z_0 = 0.0$  m;
#          Calculated:  $v_0 = 0.001$  m3/kg;  $u_0 = 104.8785$  kJ/kg;  $h_0 = 104.9788$  kJ/kg;
#               $s_0 = 0.3673$  kJ/kg.K;  $e_0 = 104.8785$  kJ/kg;  $j_0 = 104.9788$  kJ/kg;
#               $\phi_0 = 0.0$  kJ/kg;  $\psi_0 = 0.0$  kJ/kg;
#      State-1: H2O > Superheated Vapor;
#          Given:  $p_1 = 25.0$  MPa;  $T_1 = 550.0$  deg-C;  $Vel_1 = 0.0$  m/s;
#               $z_1 = 0.0$  m;  $\dot{m}_1 = 70.0$  kg/s;
#          Calculated:  $v_1 = 0.0127$  m3/kg;  $u_1 = 3017.4932$  kJ/kg;  $h_1 = 3335.5854$  kJ/kg;
#               $s_1 = 6.1764$  kJ/kg.K;  $e_1 = 3017.4932$  kJ/kg;  $j_1 = 3335.5854$  kJ/kg;
#               $\phi_1 = 1181.8214$  kJ/kg;  $\psi_1 = 1498.6414$  kJ/kg;  $\dot{V}_1 = 0.8907$  m3/s;
#               $A_1 = 89065.76$  m2;  $MM_1 = 18.0$  kg/kmol;
#      State-2: H2O > Superheated Vapor;
#          Given:  $p_2 = 5.0$  MPa;  $T_2 = 325.0$  deg-C;  $Vel_2 = 0.0$  m/s;
#               $z_2 = 0.0$  m;  $\dot{m}_2 = \text{"mdot1"}$  kg/s;
#          Calculated:  $v_2 = 0.0486$  m3/kg;  $u_2 = 2753.2876$  kJ/kg;  $h_2 = 2996.4312$  kJ/kg;
#               $s_2 = 6.3287$  kJ/kg.K;  $e_2 = 2753.2876$  kJ/kg;  $j_2 = 2996.4312$  kJ/kg;
#               $\phi_2 = 875.7846$  kJ/kg;  $\psi_2 = 1114.0653$  kJ/kg;  $\dot{V}_2 = 3.404$  m3/s;
#               $A_2 = 340400.72$  m2;  $MM_2 = 18.0$  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



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

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

# Given:  $\dot{Q} = 0.0 \text{ kW}$ ;  $T_B = 298.15 \text{ K}$ ;

# Calculated:  $\dot{W}_{\text{ext}} = 23740.8 \text{ kW}$ ;  $\dot{S}_{\text{gen}} = 10.664163 \text{ kW/K}$ ;  $\dot{J}_{\text{net}} = 23740.8 \text{ kW}$ ;  $\dot{S}_{\text{net}} = -10.664163 \text{ kW/K}$ ;

### # Exergy Analysis Results:

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

# Given:  $\dot{Q} = 0.0 \text{ kW}$ ;  $T_0 = 298.15 \text{ K}$ ;  $\dot{Q}_1 = 0.0 \text{ kW}$ ;

#  $T_1 = 298.15 \text{ K}$ ;

# Calculated:  $\dot{P}_{\text{sid,net}} = 26920.32 \text{ kW}$ ;  $\dot{W}_u = 23740.8 \text{ kW}$ ;  $\dot{I} = 3179.52 \text{ kW}$ ;

#  $\dot{S}_{\text{gen,univ}} = 10.66416 \text{ kW/K}$ ;  $\dot{W}_{\text{rev}} = 26920.32 \text{ kW}$ ;  $\dot{Q}_0 = 0.0 \text{ kW}$ ;

=====

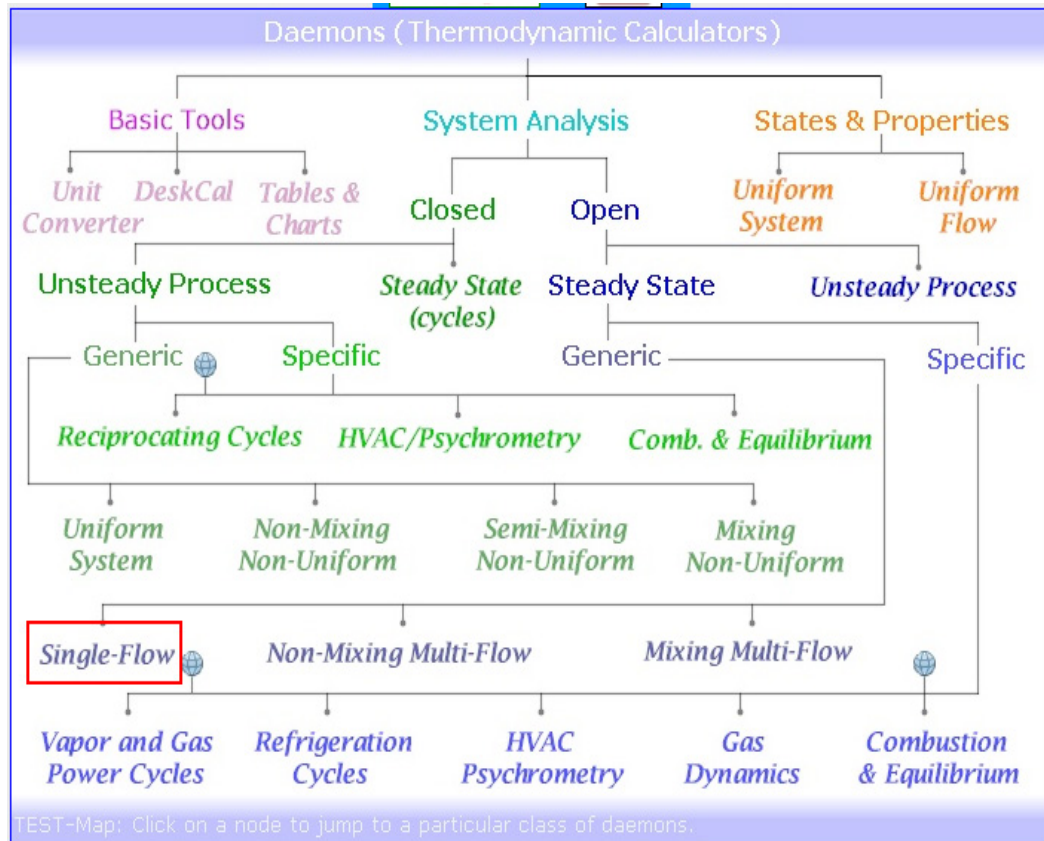
**Prob.8.21.** Air is compressed by a compressor from 101 kPa and 27 °C to 400 kPa and 220 °C at a rate of 0.15 kg/s. Neglecting the changes in K.E. and P.E. and assuming the surroundings to be at 25 °C, determine the reversible power input for this process

(b) Also , plot the reversible power against compressor exit pressure  $p_2$ , as  $p_2$  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  $p_0 = 100$  kPa and  $T_0 = 25$  C for State '0'. (This is required for exergy calculations.). Hit Enter. We get:

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

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

Home of TEST

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

State: State-0 Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

$p_0$	$T_0$	$v_0$	$u_0$	$h_0$
100.0 kPa	25.0 deg-C	0.85565 m <sup>3</sup> /kg	-85.56504 kJ/kg	0.0 kJ/kg
$s_0$	$Vel_0$	$z_0$	$e_0$	$j_0$
6.88669 kJ/kg.K	0.0 m/s	0.0 m	-85.56504 kJ/kg	0.0 kJ/kg
$\phi_0$	$\psi_0$	$\dot{m}d_0$	$\dot{V}d_0$	$A_0$
0.0 kJ/kg	0.0 kJ/kg	kg/s	m <sup>3</sup> /s	m <sup>2</sup>
$MM_0$	$R_0$	$c_{p0}$	$c_{v0}$	$k_0$
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  $p_1$ ,  $T_1$  and  $\dot{m}_{dot1}$  as shown below, and hit Enter. We get:

$p_1 = 101.0$  kPa [Absolute pressure]

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< State-1 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> $p_1$	<input checked="" type="checkbox"/> $T_1$	<input type="checkbox"/> $v_1$	<input type="checkbox"/> $u_1$	<input type="checkbox"/> $h_1$
101.0 kPa	27.0 deg-C	0.85286 m <sup>3</sup> /kg	-84.13202 kJ/kg	2.00699 kJ/kg
<input type="checkbox"/> $s_1$	<input checked="" type="checkbox"/> $Vel_1$	<input checked="" type="checkbox"/> $z_1$	<input type="checkbox"/> $e_1$	<input type="checkbox"/> $j_1$
6.89054 kJ/kg.K	0.0 m/s	0.0 m	-84.13202 kJ/kg	2.00699 kJ/kg
<input type="checkbox"/> $\phi_{i1}$	<input type="checkbox"/> $\psi_{i1}$	<input checked="" type="checkbox"/> $\dot{m}_{dot1}$	<input type="checkbox"/> $\dot{V}_{oldot1}$	<input type="checkbox"/> $A_1$
0.00524 kJ/kg	0.8581 kJ/kg	0.15 kg/s	0.12793 m <sup>3</sup> /s	12792.922 m <sup>2</sup>
<input type="checkbox"/> $MM_1$	<input type="checkbox"/> $R_1$	<input type="checkbox"/> $c_{p1}$	<input type="checkbox"/> $c_{v1}$	<input type="checkbox"/> $k_1$
28.97 kg/kmol	0.28699 kJ/kg.K	1.00349 kJ/kg.K	0.71851 kJ/kg.K	1.40054 UnitLess

Note that all properties at State 1 are immediately calculated.



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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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< @State-2 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> p2	<input checked="" type="checkbox"/> T2	<input type="checkbox"/> v2	<input type="checkbox"/> u2	<input type="checkbox"/> h2
400.0 kPa	220.0 deg-C	0.35382 m³/kg	54.15392 kJ/kg	195.68134 kJ/kg
<input type="checkbox"/> s2	<input checked="" type="checkbox"/> Vel2	<input checked="" type="checkbox"/> z2	<input type="checkbox"/> e2	<input type="checkbox"/> j2
6.99382 kJ/kg.K	0.0 m/s	0.0 m	54.15392 kJ/kg	195.68134 kJ/kg
<input type="checkbox"/> phi2	<input type="checkbox"/> psi2	<input checked="" type="checkbox"/> mdot2	<input type="checkbox"/> Voldot2	<input type="checkbox"/> A2
57.59583 kJ/kg	163.7414 kJ/kg	=mdot1 kg/s	0.05307 m³/s	5307.278 m²
<input type="checkbox"/> MM2	<input type="checkbox"/> R2	<input type="checkbox"/> c_p2	<input type="checkbox"/> c_v2	<input type="checkbox"/> k2
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 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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< Device-A [1-2] > i-State: State-1 e-State: State-2 Calculate Initialize

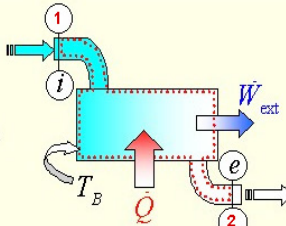
<input type="checkbox"/> Qdot	<input type="checkbox"/> Wdot_ext	<input checked="" type="checkbox"/> T_B	<input type="checkbox"/> Sdot_gen
		298.15 K	
<input type="checkbox"/> Jdot_net	<input type="checkbox"/> Sdot_net		
-29.05115 kW	-0.01549 kW/K		

**Single-Flow Steady Device - A**

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

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

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



**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:

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

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

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

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

WinHip: Work in negative, Heat in positive

$\eta_u$  (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: {  $p_2 = 400.0$  kPa;  $T_2 = 220.0$  deg-C;  $Vel_2 = 0.0$  m/s;  $z_2 = 0.0$  m;  $\dot{m}_2 = \text{"mdot1"}$  kg/s; }

}

Analysis {

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

Given: {  $T_B = 298.15$  K; }

}

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

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\*\*\*\*\*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:  $T_B = 298.15 \text{ K}$ ;

# Calculated:  $\dot{J}_{\text{net}} = -29.051151 \text{ kW}$ ;  $\dot{S}_{\text{net}} = -0.015491056 \text{ kW/K}$ ;

### # Exergy Analysis Results:

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

#

# Given:  $T_0 = 298.15 \text{ K}$ ;  $\dot{Q}_{\text{dot}_1} = 0.0 \text{ kW}$ ;  $T_1 = 298.15 \text{ K}$ ;

# Calculated:  $\dot{\Psi}_{\text{net}} = -24.43249 \text{ kW}$ ;  $\dot{W}_{\text{rev}} = -24.43249 \text{ kW}$ ;

### (b) To plot $\dot{W}_{\text{rev}}$ against compressor exit pressure, with the exit temp maintained at 220 C:

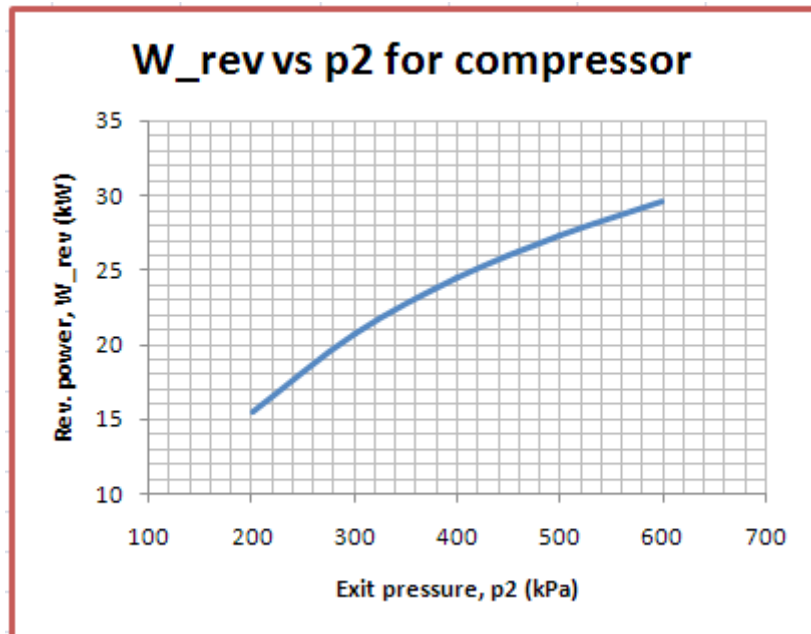
To do this, following are the simple steps:

- Go to States panel, select State 2.
- Change the  $p_2$  to the desired value
- Click on Calculate, and then SuperCalculate
- Go to Exergy panel and read the value of  $\dot{W}_{\text{rev}}$
- Repeat this procedure for other desired values of  $p_2$
- Tabulate the results, i.e.  $\dot{W}_{\text{rev}}$  against  $p_2$ .

$p_2 \text{ (kPa)}$	$\dot{W}_{\text{rev}} \text{ (kW)}$
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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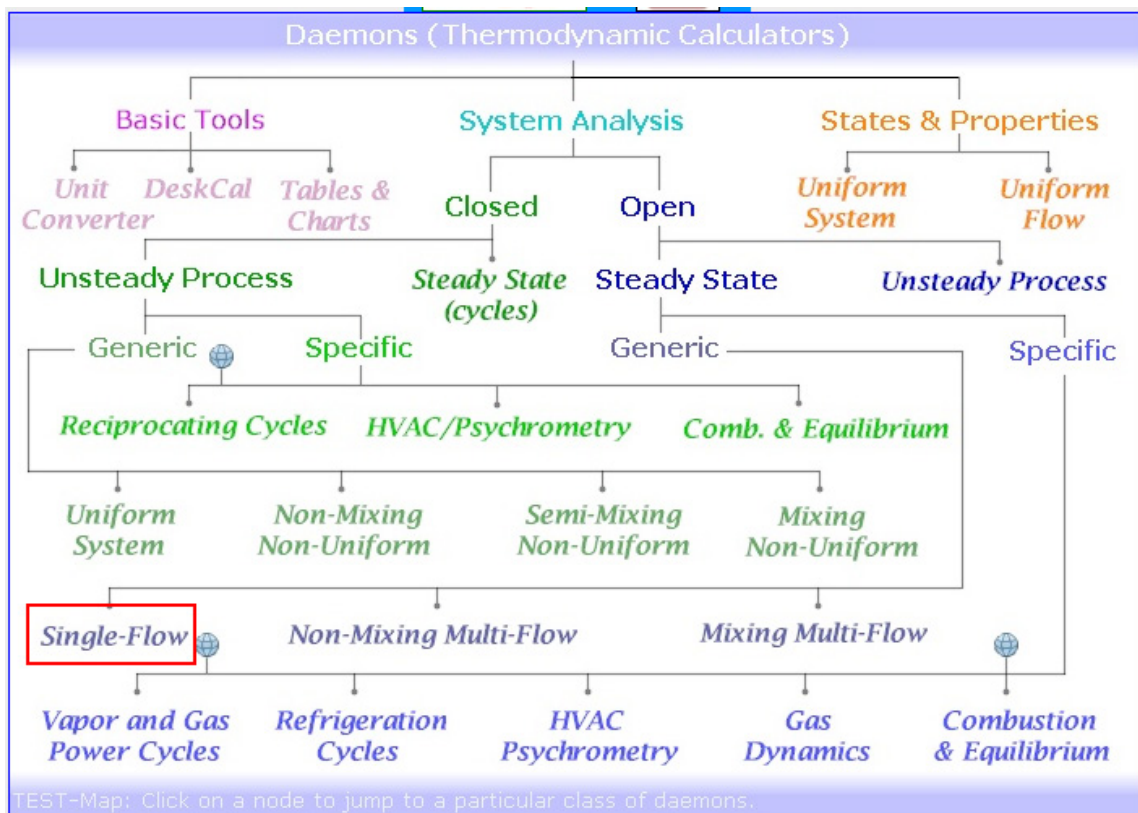


**Prob.8.22.** Air enters a compressor at ambient conditions of 100 kPa and 17 C with a low velocity and exits at 1 MPa, 327 C, and 105 m/s. The compressor is cooled by the ambient air at 17 C at a rate of 1500 kJ/min. The power input to the compressor is 300 kW. Determine (a) the mass flow rate of air,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





- Choose the PG model for material model, and select air as the working substance. Enter  $p_0 = 100$  kPa and  $T_0 = 17$  C for State '0'. (This is required for exergy calculations.). Hit Enter. We get:

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

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

$p_0 = 100.0$  kPa [Absolute pressure]

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< State-0 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

$p_0$	$T_0$	$v_0$	$u_0$	$h_0$
100.0 kPa	17.0 deg-C	0.83269 m <sup>3</sup> /kg	-91.2971 kJ/kg	-8.02795 kJ/kg
$s_0$	$Vel_0$	$z_0$	$e_0$	$j_0$
6.8594 kJ/kg.K	0.0 m/s	0.0 m	-91.2971 kJ/kg	-8.02795 kJ/kg
$\phi_0$	$\psi_0$	$\dot{m}d_0$	$\dot{V}d_0$	$A_0$
0.0 kJ/kg	0.0 kJ/kg	kg/s	m <sup>3</sup> /s	m <sup>2</sup>
$MM_0$	$R_0$	$c_{p0}$	$c_{v0}$	$k_0$
28.97 kg/kmol	0.28699 kJ/kg.K	1.00349 kJ/kg.K	0.71651 kJ/kg.K	1.40054 UnitLess

- For State 1: enter  $p_1$ ,  $T_1$  as shown below, and hit Enter. Note that  $\dot{m}d_1$  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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< State-1 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

$p_1$	$T_1$	$v_1$	$u_1$	$h_1$
100.0 kPa	17.0 deg-C	0.83269 m <sup>3</sup> /kg	-91.2971 kJ/kg	-8.02795 kJ/kg
$s_1$	$Vel_1$	$z_1$	$e_1$	$j_1$
6.8594 kJ/kg.K	0.0 m/s	0.0 m	-91.2971 kJ/kg	-8.02795 kJ/kg
$\phi_1$	$\psi_1$	$\dot{m}d_1$	$\dot{V}d_1$	$A_1$
0.0 kJ/kg	0.0 kJ/kg	0.86861587 kg/s	0.72329 m <sup>3</sup> /s	72328.9 m <sup>2</sup>
$MM_1$	$R_1$	$c_{p1}$	$c_{v1}$	$k_1$
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  $p_2$ ,  $T_2$ ,  $Vel_2$  and  $\dot{m}_{dot2} = \dot{m}_{dot1}$ . Again, value of  $\dot{m}_{dot2}$  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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

< State-2 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> $p_2$	<input checked="" type="checkbox"/> $T_2$	<input type="checkbox"/> $v_2$	<input type="checkbox"/> $u_2$	<input type="checkbox"/> $h_2$
1000.0 kPa	327.0 deg-C	0.17223 m <sup>3</sup> /kg	130.82022 kJ/kg	303.05518 kJ/kg
<input type="checkbox"/> $s_2$	<input checked="" type="checkbox"/> $Vel_2$	<input checked="" type="checkbox"/> $z_2$	<input type="checkbox"/> $e_2$	<input type="checkbox"/> $j_2$
6.92791 kJ/kg.K	105.0 m/s	0.0 m	136.33272 kJ/kg	308.5677 kJ/kg
$\phi_{i2}$	$\psi_{i2}$	<input checked="" type="checkbox"/> $\dot{m}_{dot2}$	$\dot{V}_{dot2}$	$A_2$
141.70598 kJ/kg	296.71744 kJ/kg	= $\dot{m}_{dot1}$ kg/s	m <sup>3</sup> /s	m <sup>2</sup>
$MM_2$	$R_2$	$c_{p2}$	$c_{v2}$	$k_2$
28.97 kg/kmol	0.28699 kJ/kg.K	1.00349 kJ/kg.K	0.71651 kJ/kg.K	1.40054 UnitLess



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5. Go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. Enter  $\dot{W}_{\text{dot\_ext}} = -300 \text{ kW}$  (negative sign since work is supplied...remember: WinHip ... see screen shot below), and  $\dot{Q}_{\text{dot}} = -1500 \text{ kJ/min}$ . 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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

Device-A [1-2] i-State: State-1 e-State: State-2 Calculate Initialize

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

**Single-Flow Steady Device - A**

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

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

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

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

WinHip: Work in negative Heat in positive

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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

Calculate Initialize 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

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

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

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

$\dot{W}_u = \dot{W}_{\text{ext}} - \dot{W}_{\text{atn}} = \dot{W}_{\text{ext}}; \quad \dot{Q} = \sum \dot{Q}_k = \dot{Q}_0 + \dot{Q}_1$

WinHip: Work in negative Heat in positive

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

Note that  $\dot{W}_{\text{dot\_rev}} = -257.73 \text{ kW}$  whereas actual work required was  $\dot{W}_{\text{dot\_u}} = -300 \text{ kW}$ .

And, Irreversibility =  $\dot{W}_{\text{dot\_rev}} - \dot{W}_{\text{dot\_u}} = 42.27 \text{ kW}$  .... Ans.

7. Now, go back to State 2 and look for value of  $\dot{m}_2$ :

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 Exergy Panel I/O Panel

< State-2 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

$p_2$	$T_2$	$v_2$	$u_2$	$h_2$
1000.0 kPa	327.0 deg-C	0.17223 m³/kg	130.82022 kJ/kg	303.05518 kJ/kg
$s_2$	$Vel_2$	$z_2$	$e_2$	$j_2$
6.92791 kJ/kg.K	105.0 m/s	0.0 m	136.33272 kJ/kg	308.5677 kJ/kg
$\phi_2$	$\psi_2$	$\dot{m}_2$	$\dot{V}_2$	$A_2$
141.70598 kJ/kg	296.71744 kJ/kg	0.86861587 kg/s	0.14961 m³/s	0.00142 m²
$MM_2$	$R_2$	$c_{p_2}$	$c_{v_2}$	$k_2$
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 =  $\dot{I}_{\text{dot}}$  = 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: {  $p_0$ = 100.0 kPa;  $T_0$ = 17.0 deg-C;  $Vel_0$ = 0.0 m/s;  $z_0$ = 0.0 m; }

State-1: Air;

Given: {  $p_1$ = 100.0 kPa;  $T_1$ = 17.0 deg-C;  $Vel_1$ = 0.0 m/s;  $z_1$ = 0.0 m; }

State-2: Air;

Given: {  $p_2$ = 1000.0 kPa;  $T_2$ = 327.0 deg-C;  $Vel_2$ = 105.0 m/s;  $z_2$ = 0.0 m; }

}

Analysis {

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

Given: {  $\dot{Q} = -1500.0$  kJ/min;  $\dot{W}_{\text{ext}} = -300.0$  kW;  $T_B = 298.15$  K; }

}

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

#

#-----Property spreadsheet starts: #

#	State	p(kPa)	T(K)	v(m <sup>3</sup> /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-----



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

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

# Given:  $\dot{Q} = -1500.0 \text{ kJ/min}$ ;  $\dot{W}_{\text{ext}} = -300.0 \text{ kW}$ ;  $T_B = 298.15 \text{ K}$ ;

# Calculated:  $\dot{S}_{\text{gen}} = 0.14335933 \text{ kW/K}$ ;  $\dot{J}_{\text{net}} = -275.0 \text{ kW}$ ;  $\dot{S}_{\text{net}} = -0.059508912 \text{ kW/K}$ ;

#

**# Exergy Analysis Results:**

#

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

# Given:  $\dot{Q} = -25.0 \text{ kW}$ ;  $T_0 = 290.15 \text{ K}$ ;  $\dot{Q}_1 = 0.0 \text{ kW}$ ;

#  $T_1 = 298.15 \text{ K}$ ;

# Calculated:  $\dot{P}_{\text{net}} = -257.7335 \text{ kW}$ ;  $\dot{W}_u = -300.0 \text{ kW}$ ;  **$\dot{I} = 42.26651 \text{ kW}$** ;

#  $\dot{S}_{\text{gen,univ}} = 0.14567 \text{ kW/K}$ ;  **$\dot{W}_{\text{rev}} = -257.7335 \text{ kW}$** ;  $\dot{Q}_0 = -25.0 \text{ kW}$ ;

=====

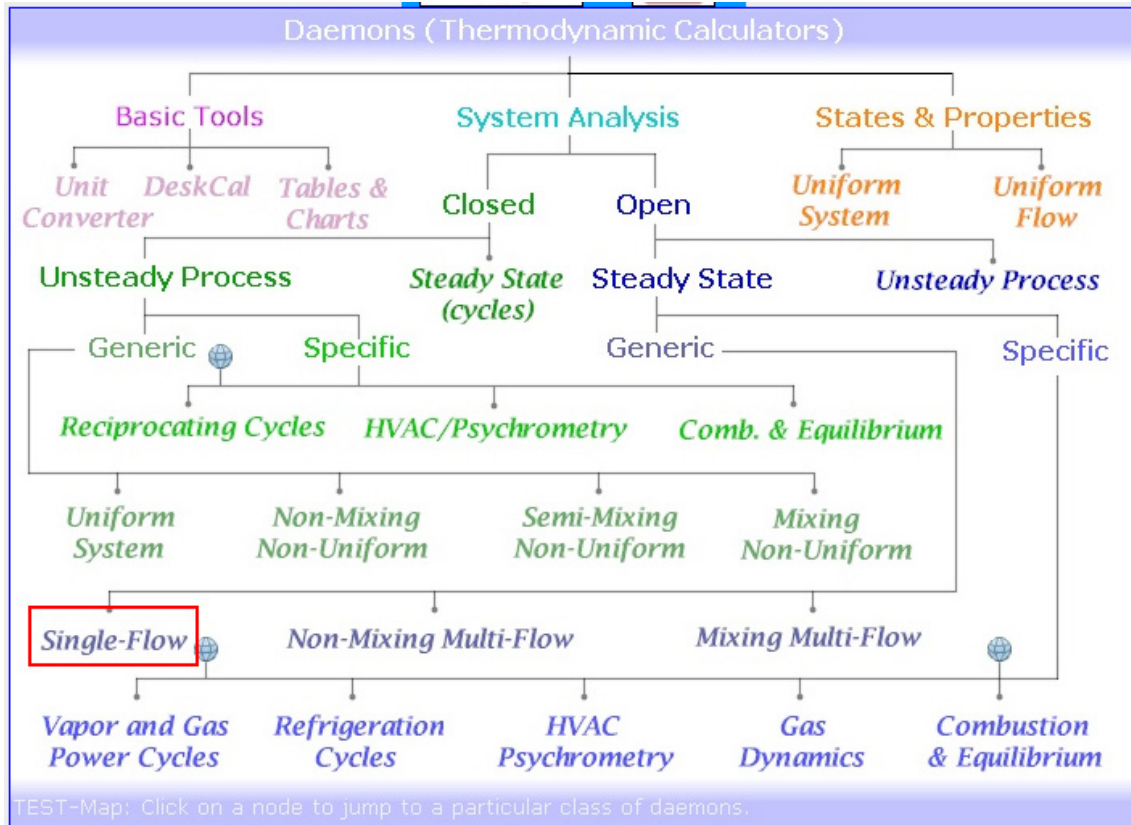
**Prob.8.23.** Refrigerant R134a enters an expansion valve at 1200 kPa as a sat. liquid and leaves at 200 kPa. Determine: (a) the temp of R134a at the exit (b) the entropy generation and the exergy destruction during this process. Take  $T_0 = 25 \text{ C}$ . [Ref:1]



## 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.

<p>PC Model</p>	<p><b>Pure Phase-Transition Fluid:</b> 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 (H<sub>2</sub>O* as opposed to H<sub>2</sub>O), which uses compressed liquid table for better accuracy.</p> <p>Working fluids such as H<sub>2</sub>O, R-12, NH<sub>3</sub>, R-134a, N<sub>2</sub>, CO<sub>2</sub>, etc., should be treated as PC fluids if there is any possibility of a phase transition.</p> <p><b>Examples:</b> 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.</p>
<p>SL Model</p>	<p><b>Pure Solid and Pure Liquid:</b> Constant density and constant specific heats (<math>c_p = c_v = c</math>) characterize the solid/liquid (SL) model. Beside a wide selection to choose from, a new solid or liquid can be created by assigning custom material properties.</p> <p>Working substances such as steel, iron, copper, aluminum, wood, water, oil, etc., which can be assumed to maintain their condensed (solid or liquid) phase when a system undergoes other changes, can be analyzed with the SL model.</p> <p><b>Examples:</b> 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.</p>

- Choose R134a for substance and enter  $T_0 = 0$  on State '0' i.e. 'dead state'. This is required for exergy calculations.

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

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

Home of TEST

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

State-0 Calculate No-Plots Initialize Superheated Vapor R-134a

$p_0$	$T_0$	$x_0$	$y_0$	$v_0$
100.0 kPa	25.0 deg-C	fraction	fraction	0.2382 m <sup>3</sup> /kg
$u_0$	$h_0$	$s_0$	$Vel_0$	$z_0$
251.49637 kJ/kg	275.31653 kJ/kg	1.10207 kJ/kg.K	0.0 m/s	0.0 m
$e_0$	$j_0$	$\phi_0$	$\psi_0$	$\dot{m}_{dot0}$
251.49637 kJ/kg	275.31653 kJ/kg	0.0 kJ/kg	0.0 kJ/kg	kg/s
$V_{oldot0}$	$A_0$	$MM_0$		
m <sup>3</sup> /s	m <sup>2</sup>	102.03 kg/kmol		

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4. Now, for State 1: enter values for  $p_1$ , and  $x_1 = 0$  (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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

State: State-1 Calculate No-Plots Initialize Saturated Liquid R-134a

$p_1$	$T_1$	$x_1$	$y_1$	$v_1$
1200.0 kPa	46.29141 deg-C	0.0 fraction	0.0 fraction	8.9E-4 m <sup>3</sup> /kg
$u_1$	$h_1$	$s_1$	$Vel_1$	$z_1$
116.05018 kJ/kg	117.12393 kJ/kg	0.4215 kJ/kg.K	0.0 m/s	0.0 m
$e_1$	$j_1$	$\phi_1$	$\psi_1$	$\dot{m}$
116.05018 kJ/kg	117.12393 kJ/kg			
$\dot{V}$	$A$	$MM$		
		102.03 kg/kmol		

Note that properties such as temp =  $T_1$ , entropy =  $s_1$ , enthalpy =  $h_1$  etc. are immediately calculated.

5. And, for State 2: enter values of  $p_2$  and  $h_2 = h_1$  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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

State: State-2 Calculate No-Plots Initialize Sat.Mixture: Liq.+Vap. R-134a

$p_2$	$T_2$	$x_2$	$y_2$	$v_2$
200.0 kPa	-10.22257 deg-C	0.38731 fraction	0.98821 fraction	0.03923 m <sup>3</sup> /kg
$u_2$	$h_2$	$s_2$	$Vel_2$	$z_2$
109.28457 kJ/kg	=h1 kJ/kg	0.45355 kJ/kg.K	0.0 m/s	0.0 m
$e_2$	$j_2$	$\phi_2$	$\psi_2$	$\dot{m}$
109.28457 kJ/kg	117.12393 kJ/kg			
$\dot{V}$	$A$	$MM$		
		102.03 kg/kmol		

Immediately note that temp after throttling,  $T_2$  is calculated as:

$T_2 = -10.22 \text{ C} \dots \text{Ans.}$

6. Now, go to Device Panel. Enter State 1 and State 2 for i-state and e-state respectively. Also, enter  $\dot{Q} = 0$  and  $\dot{W}_{\text{ext}} = 0$ , 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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

Device-A [1-2] i-State: State-1 e-State: State-2 Calculate Initialize

$\dot{Q}$  0.0 kW  $\dot{W}_{\text{ext}}$  0.0 kW  $T_B$  298.15 K  $\dot{S}_{\text{gen}}$  kW/K

$\dot{J}_{\text{dot\_net}}$  kW  $\dot{S}_{\text{dot\_net}}$  kW/K

**Single-Flow Steady Device - A**

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

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

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

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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel Exergy Panel I/O Panel

Calculate Initialize Exergy Analysis for Device - A

$\dot{P}_{\text{sidot\_net}}$  9.55602 kW  $\dot{W}_{\text{dot\_u}}$  0.0 kW  $\dot{I}_{\text{dot}}$  9.55602 kW  $\dot{S}_{\text{dot\_gen,univ}}$  0.03205 kW/K  $\dot{W}_{\text{dot\_rev}}$  9.55602 kW

$\dot{Q}_{\text{dot\_0}}$  0.0 kW  $T_0$  298.15 K  $\dot{Q}_{\text{dot\_1}}$  0.0 kW  $T_1$  298.15 K

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

$0 = \dot{m}(\psi_i - \psi_e) + \dot{Q}_i \left(1 - \frac{T_0}{T_1}\right) - (\dot{W}_u + \dot{I})$

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

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

WinHip: Work in negative Heat in positive

$\eta_u$  (Exergetic Efficiency) = Desired exergy output / Required exergy input

Thus:

Temp at the outlet of expansion valve =  $T_2 = -10.22^\circ\text{C}$  .....Ans. .... From State 2

Entropy generation =  $\dot{S}_{\text{dot\_gen,univ}} = 0.03205 \text{ kW/K}$  ...Ans.... From Exergy Panel

Exergy destruction =  $\dot{I}_{\text{dot}} = 9.556 \text{ kW}$  .... 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; }
```



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State-2: R-134a;

Given: {  $p_2 = 200.0$  kPa;  $h_2 = "h_1"$  kJ/kg;  $Vel_2 = 0.0$  m/s;  $z_2 = 0.0$  m; }  
}

Analysis {

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

Given: {  $\dot{Q} = 0.0$  kW;  $\dot{W}_{ext} = 0.0$  kW;  $T_B = 298.15$  K; }  
}

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

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

#### # Evaluated States:

```
#      State-0: R-134a > Superheated Vapor;
#          Given:  $p_0 = 100.0$  kPa;  $T_0 = 25.0$  deg-C;  $Vel_0 = 0.0$  m/s;
#               $z_0 = 0.0$  m;
#          Calculated:  $v_0 = 0.2382$  m3/kg;  $u_0 = 251.4964$  kJ/kg;  $h_0 = 275.3165$  kJ/kg;
#               $s_0 = 1.1021$  kJ/kg.K;  $e_0 = 251.4964$  kJ/kg;  $j_0 = 275.3165$  kJ/kg;
#               $\phi_0 = 0.0$  kJ/kg;  $\psi_0 = 0.0$  kJ/kg;  $MM_0 = 102.03$  kg/kmol;
#      State-1: R-134a > Saturated Mixture;
#          Given:  $p_1 = 1200.0$  kPa;  $x_1 = 0.0$  fraction;  $Vel_1 = 0.0$  m/s;
#               $z_1 = 0.0$  m;
#          Calculated:  $T_1 = 46.2914$  deg-C;  $y_1 = 0.0$  fraction;  $v_1 = 9.0E-4$  m3/kg;
#               $u_1 = 116.0502$  kJ/kg;  $h_1 = 117.1239$  kJ/kg;  $s_1 = 0.4215$  kJ/kg.K;
#               $e_1 = 116.0502$  kJ/kg;  $j_1 = 117.1239$  kJ/kg;  $\phi_1 = 43.7369$  kJ/kg;
#               $\psi_1 = 44.7212$  kJ/kg;  $MM_1 = 102.03$  kg/kmol;
#      State-2: R-134a > Saturated Mixture;
#          Given:  $p_2 = 200.0$  kPa;  $h_2 = "h_1"$  kJ/kg;  $Vel_2 = 0.0$  m/s;
#               $z_2 = 0.0$  m;
#          Calculated:  $T_2 = -10.2226$  deg-C;  $x_2 = 0.3873$  fraction;  $y_2 = 0.9882$  fraction;
#               $v_2 = 0.0392$  m3/kg;  $u_2 = 109.2846$  kJ/kg;  $s_2 = 0.4536$  kJ/kg.K;
#               $e_2 = 109.2846$  kJ/kg;  $j_2 = 117.1239$  kJ/kg;  $\phi_2 = 31.2484$  kJ/kg;
#               $\psi_2 = 35.1651$  kJ/kg;  $MM_2 = 102.03$  kg/kmol;
#
```

#-----Property spreadsheet starts:

#

# State	p(kPa)	T(K)	x	v(m <sup>3</sup> /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:  $\dot{Q} = 0.0$  kW;  $\dot{W}_{\text{ext}} = 0.0$  kW;  $T_B = 298.15$  K;

# Calculated:

#### # Exergy Analysis Results:

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

# Given:  $\dot{Q} = 0.0$  kW;  $T_0 = 298.15$  K;  $\dot{Q}_1 = 0.0$  kW;

#  $T_1 = 298.15$  K;

# Calculated:  $\dot{P}_{\text{net}} = 9.55602$  kW;  $\dot{W}_u = 0.0$  kW;  **$\dot{I} = 9.55602$  kW**;

#  **$\dot{S}_{\text{gen,univ}} = 0.03205$  kW/K**;  **$\dot{W}_{\text{rev}} = 9.55602$  kW**;  $\dot{Q}_0 = 0.0$  kW;

=====

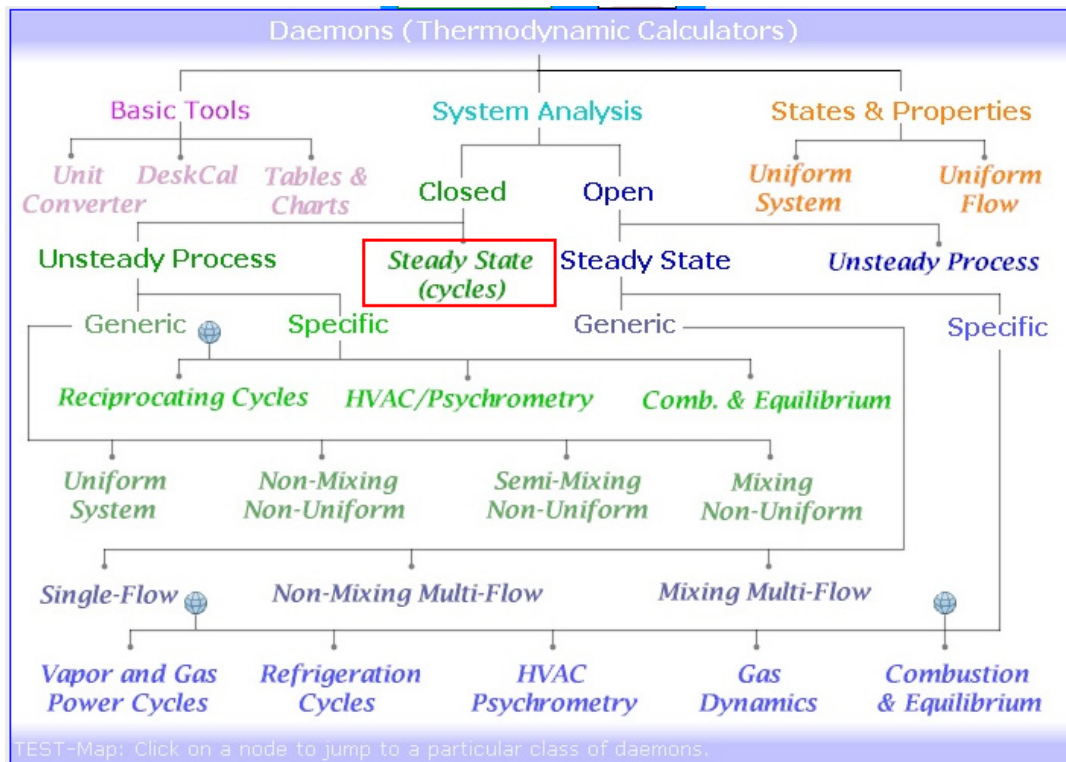
**Prob.8.24.** A freezer is maintained at -7 C by removing heat from it at a rate of 80 kJ/min. The power input to the freezer is 0.5 kW, and the surrounding air is at 25 C. Determine (a) the reversible power, (b) Irreversibility, and (c) Second Law efficiency of this freezer. [Ref: 1]



## 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:



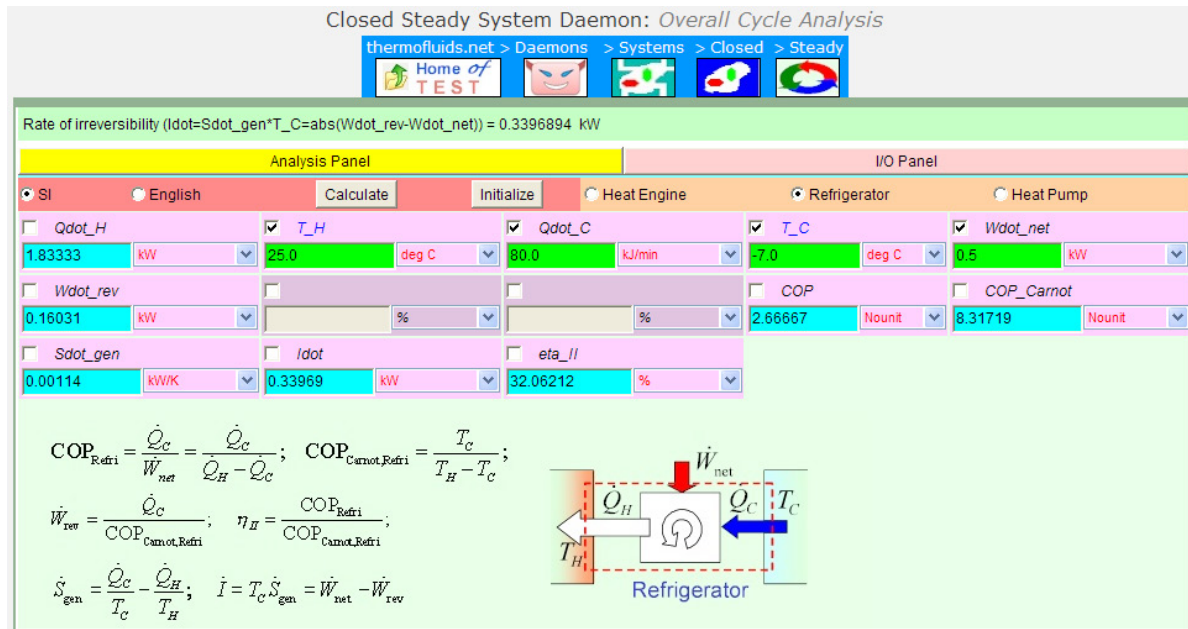
Hovering the mouse pointer over 'Steady State (cycles)' brings up the following pop up:

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.

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



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Thus:

Reversible power =  $\dot{W}_{rev} = 0.16031 \text{ kW} \dots \text{Ans.}$

Irreversibility =  $\dot{I} = 0.33969 \text{ kW} \dots \text{Ans.}$

Second Law efficiency =  $\eta_{II} = 32.06\% \dots \text{Ans.}$

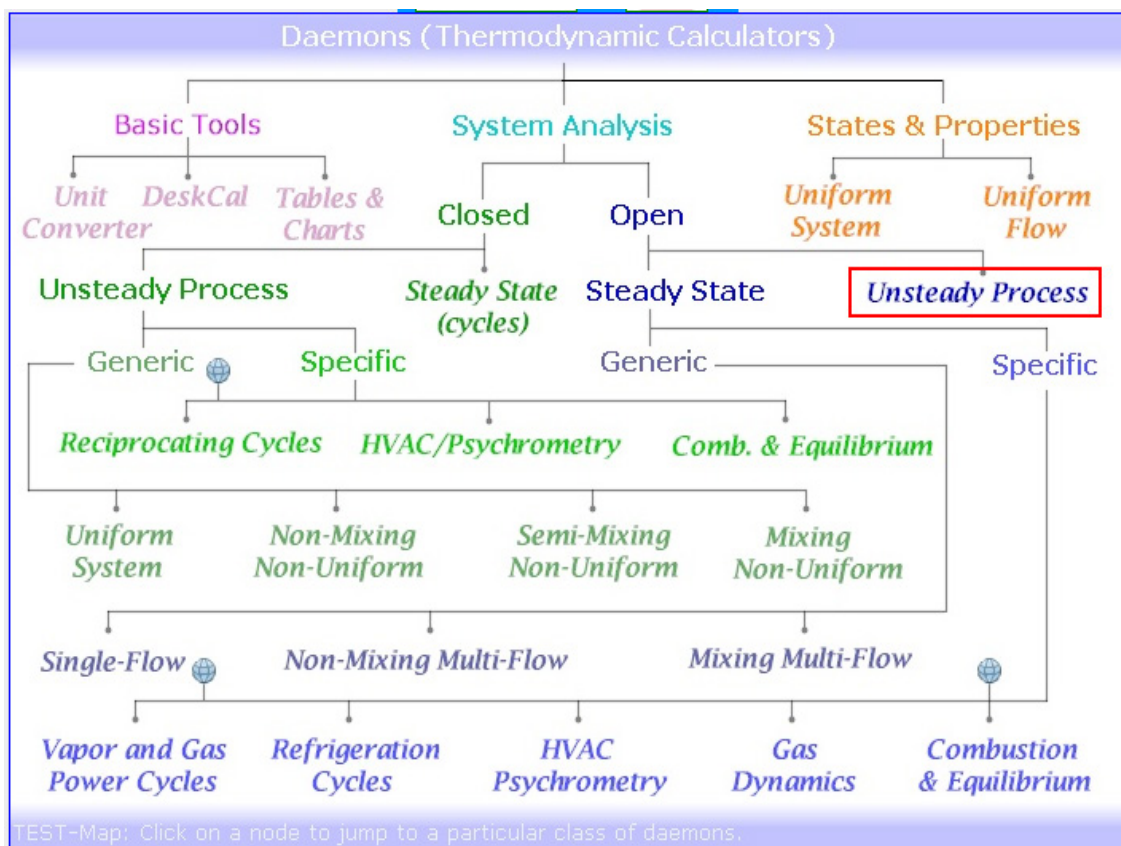
=====

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

**TEST Solution:**

Following are the steps:

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

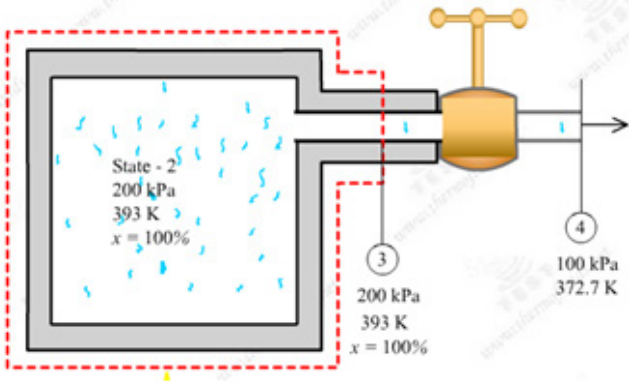


Hovering the mouse pointer on 'Unsteady Process' brings up the following explanatory pop up:

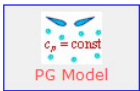
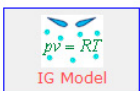
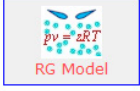
Click to go to page: TEST>Daemons>Systems>Open>Unsteady Processes

**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:

Gases:		<p><b>Pure Perfect Gas:</b> The perfect gas (PG) model is the simplest gas model. It obeys the ideal gas equation of state (<math>p\nu=RT</math>); 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.</p> <p><b>Examples:</b> 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.</p>
		<p><b>Pure Ideal Gas:</b> An ideal gas (IG) is a gas that obeys the ideal gas equation of state (<math>p\nu=RT</math>). 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.</p> <p><b>Examples:</b> 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.</p>
		<p><b>Pure Real Gas:</b> Based on the generalized <i>compressibility chart</i> (<math>p\nu=ZRT</math>), the <i>real gas</i> (RG) model can handle a large number of fluids in their liquid, vapor or gaseous states. But generality comes at the expense of accuracy.</p> <p><b>Examples:</b> 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.</p>

3. Select Air as the working substance, and enter values of properties for State 1. This is vacuum state. So, enter  $m_1 = 0$  and  $p_1 = 0$ . **Do not enter Vol1 even though it is given as  $1 \text{ m}^3$ ... 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

Home of TEST

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

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel I/O Panel

< State-1 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> $p_1$	$T_1$	$\rho_1$	$v_1$	$u_1$
0.0 kPa	298.1341 K	0.0 kg/m <sup>3</sup>	Infinity m <sup>3</sup> /kg	-85.56047 kJ/kg
$h_1$	$s_1$	<input checked="" type="checkbox"/> $Vel_1$	$z_1$	$e_1$
0.0 kJ/kg	0.0 kJ/kg.K	0.0 m/s	0.0 m	0.0 kJ/kg
$j_1$	$\phi_1$	$\psi_1$	<input checked="" type="checkbox"/> $m_1$	$Vol_1$
0.0 kJ/kg	0.0 kJ/kg	0.0 kJ/kg	0.0 kg	0.0 m <sup>3</sup>
$MM_1$	$R_1$	$c_{p1}$		
28.97 kg/kmol	0.28699 kJ/kg.K	1.00349 kJ/kg.K		

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4. Now, enter for State 2. This is the condition of gas in the volume, after it is filled up. Enter  $p_2 = 500 \text{ kPa}$ ,  $\text{Vol}_2 = 1 \text{ m}^3$ . Hit Enter. All properties are not calculated since data is not enough. However, they are calculated at the end when SuperCalculate is clicked.

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

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel I/O Panel

< State-2 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> $p_2$	$T_2$	$\rho_2$	$v_2$	$u_2$
500.0 kPa	409.224 K	4.25743 kg/m <sup>3</sup>	0.23488 m <sup>3</sup> /kg	-5.00139 kJ/kg
$h_2$	$s_2$	<input checked="" type="checkbox"/> $Vel_2$	<input checked="" type="checkbox"/> $z_2$	<input checked="" type="checkbox"/> $e_2$
112.44039 kJ/kg	6.74517 kJ/kg.K	0.0 m/s	0.0 m	-5.001388 kJ/kg
$j_2$	$\phi_2$	$\psi_2$	$m_2$	<input checked="" type="checkbox"/> $\text{Vol}_2$
112.44039 kJ/kg			4.25743 kg	1.0 m <sup>3</sup>
$MM_2$	$R_2$	$c_{p2}$		
28.97 kg/kmol	0.28699 kJ/kg.K	1.02121 kJ/kg.K		

5. Enter for State 3. This is the condition of gas flowing in the pipe line. We enter  $p_3 = 500 \text{ kPa}$ ,  $T_3 = 20 \text{ C}$ ,  $m_3 = (m_2 - m_1)$ , since this is the amount of gas that flows in to the tank.. Click on Calculate (or, hit Enter). We get:

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

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

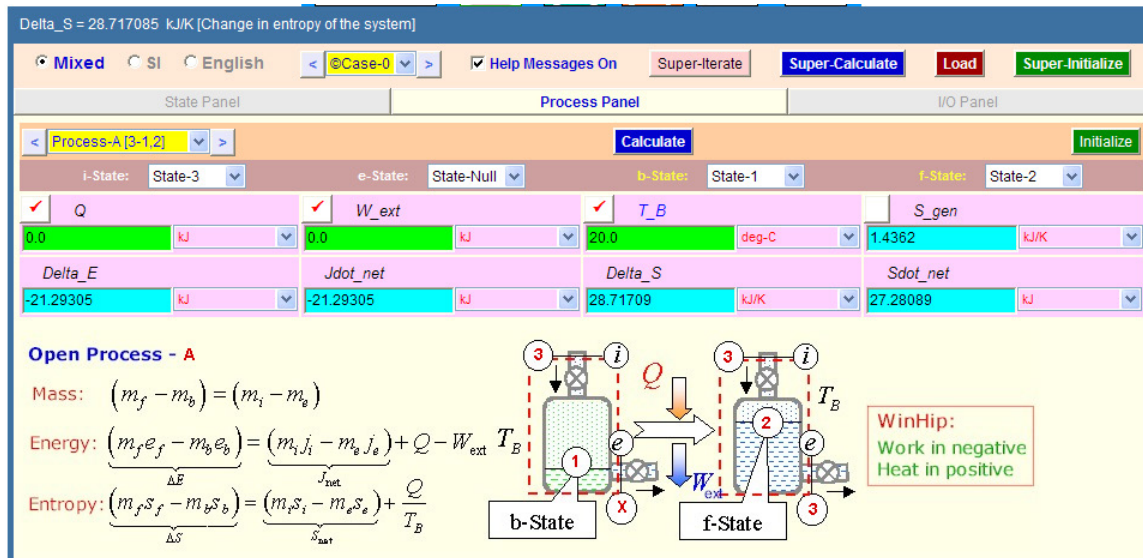
State Panel Process Panel I/O Panel

< State-3 > Calculate No-Plots Initialize Formation Enthalpy: No Yes Air

<input checked="" type="checkbox"/> $p_3$	<input checked="" type="checkbox"/> $T_3$	$\rho_3$	$v_3$	$u_3$
500.0 kPa	20.0 deg-C	5.94318 kg/m <sup>3</sup>	0.16826 m <sup>3</sup> /kg	-89.13149 kJ/kg
$h_3$	$s_3$	<input checked="" type="checkbox"/> $Vel_3$	<input checked="" type="checkbox"/> $z_3$	<input checked="" type="checkbox"/> $e_3$
-5.00139 kJ/kg	6.40763 kJ/kg.K	0.0 m/s	0.0 m	-89.13149 kJ/kg
$j_3$	$\phi_3$	$\psi_3$	<input checked="" type="checkbox"/> $m_3$	$\text{Vol}_3$
-5.00139 kJ/kg			=m2-m1 kg	0.71636 m <sup>3</sup>
$MM_3$	$R_3$	$c_{p3}$		
28.97 kg/kmol	0.28699 kJ/kg.K	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  $Q = 0$ ,  $W_{\text{ext}} = 0$ . Click on Calculate, and also SuperCalculate. We get:



Go to States Panel and in State 2, see the value of  $T_2$ , the temp after the tank is filled up. Also,  $m_2$ , the mass that has flown in can be read.

Thus:

Final temp of air =  $T_2 = 409.22 \text{ K} \dots \text{Ans.}$

Net entropy change of air =  $\Delta S = 28.717 \text{ kJ/K} \dots \text{Ans.}$

Irreversibility =  $T_0 \cdot S_{\text{gen}} = (20 + 273) \cdot 1.4362 = 392.083 \text{ kJ} \dots \text{Ans.}$

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<sup>3</sup>; }

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<sup>3</sup>; v1= Infinity m<sup>3</sup>/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<sup>3</sup>; 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<sup>3</sup>;

```
#          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-----
```



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...I finally learned to speak it in just six lessons"

Jane, Chinese architect

ENGLISH OUT THERE

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### # 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:

$$\Delta e = \phi_1 - \phi_2 = (u_1 - u_2) + p_0 \cdot (v_1 - v_2) - T_0 \cdot (s_1 - s_2)$$

Form the above Table, we have:

$$u_1 := -85.56 \text{ kJ/kg} \quad u_2 := -5 \text{ kJ/kg}$$

$$s_1 := 0 \text{ kJ/kg.K} \quad s_2 := 6.745 \text{ kJ/kg.K}$$

$$v_1 := 0 \text{ m}^3/\text{kg} \quad v_2 := 0.2349 \text{ m}^3/\text{kg}$$

$$T_0 := 293 \text{ K} \quad p_0 := 100 \text{ kPa}$$

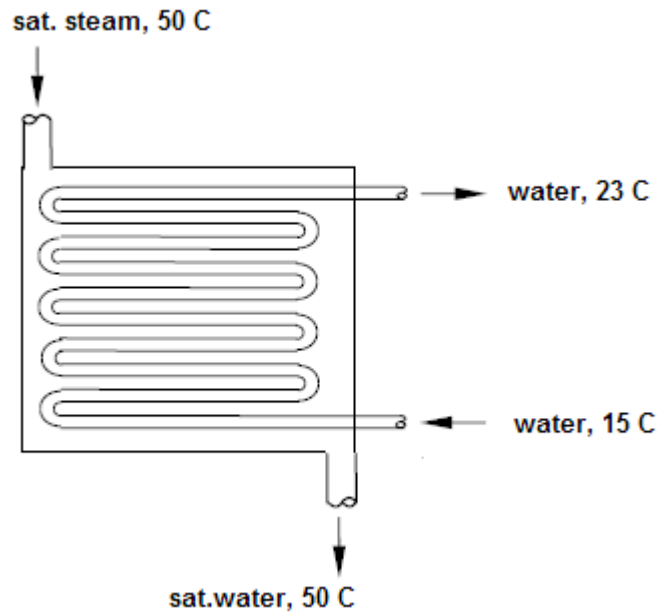
Therefore, change in Availability:

$$\Delta e := (u_1 - u_2) + p_0 \cdot (v_1 - v_2) - T_0 \cdot (s_1 - s_2)$$

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

=====

**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  $T_0 = 25$  C. [Ref:1]



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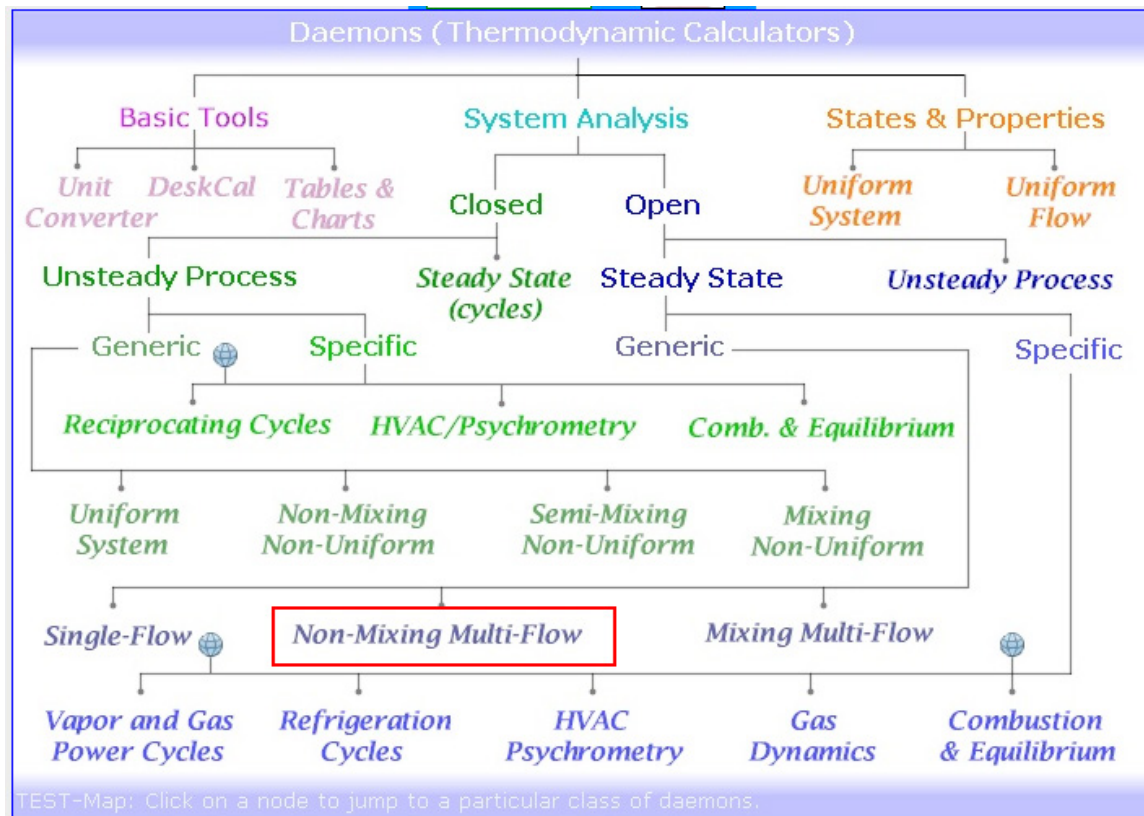
**HERE.**



## TEST Solution:

Following are the steps:

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



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

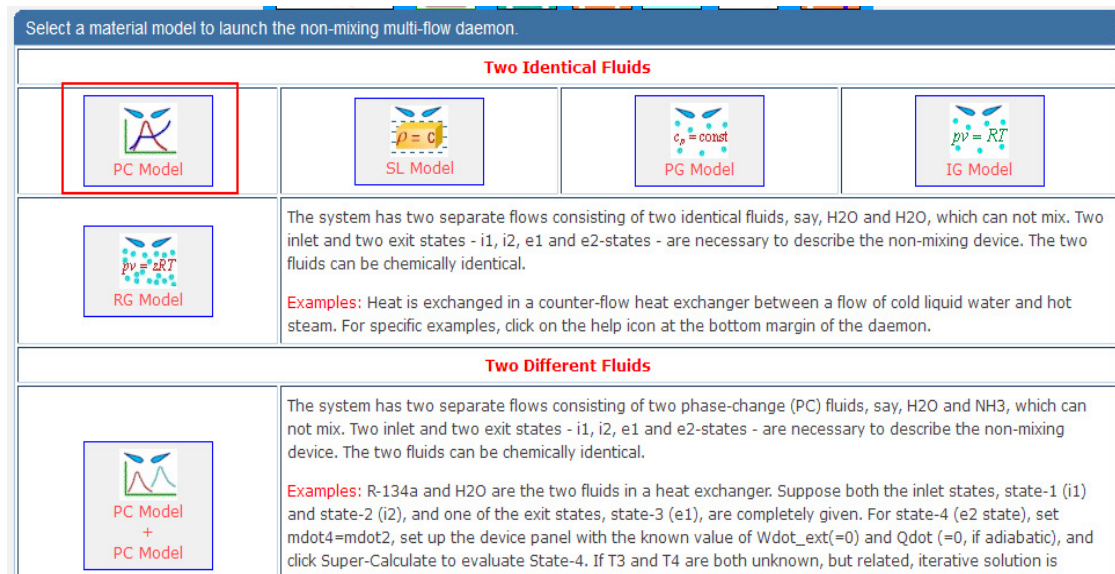
Click to go to page: [TEST>Daemons>Systems>Open>Steady>Generic>Multi-Flow Non-Mixing Systems](#)

**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.

Flow Direction: Co Flow, Counter Flow

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



3. H<sub>2</sub>O is the substance selected by default. Enter p<sub>1</sub>, x<sub>1</sub> = 0 for State 1, i.e. exit of steam condensed in the sat. liq. state. Also, enter for m<sub>dot</sub>1 = m<sub>dot</sub>3 \* (h<sub>4</sub> - h<sub>3</sub>) / (h<sub>2</sub> - h<sub>1</sub>), where States 3 and 4 are inlet and exit of water. M<sub>dot</sub>1 is unknown, as of now. But, it will be posted back here at the end, i.e. after all calculations are made by SuperCalculate. Hit Enter:



4. For State 2, i.e. sat.vapour state, inlet of steam to condenser: enter  $T_2$ ,  $x_2 = 1$  for sat. vap.  
Also,  $\dot{m}_{dot2} = \dot{m}_{dot1}$ , 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.

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 Saturated Mixture H2O

$p_2$	$T_2$	$x_2$	$y_2$	$v_2$
12.35001 kPa	50.0 deg-C	1.0 fraction	1.0 fraction	12.03 m <sup>3</sup> /kg
$u_2$	$h_2$	$s_2$	$Vel_2$	$z_2$
2443.5295 kJ/kg	2592.1 kJ/kg	8.0763 kJ/kg.K	0.0 m/s	0.0 m
$e_2$	$j_2$	$\phi_2$	$\psi_2$	$\dot{m}_{dot2}$
2443.5295 kJ/kg	2592.1 kJ/kg			0.7736996 kg/s
$Vol_{dot2}$	$A_2$	$MM_2$		
9.30761 m <sup>3</sup> /s	930760.56 m <sup>2</sup>	18.0 kg/kmol		

5. Now, for State 3: i.e. inlet of water stream in to the tubes. Enter  $p_3$ ,  $T_3$  and  $\dot{m}_{dot3}$ . 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-3 Calculate No-Plots Initialize Subcooled Liquid H2O

$p_3$	$T_3$	$x_3$	$y_3$	$v_3$
100.0 kPa	15.0 deg-C			0.001 m <sup>3</sup> /kg
$u_3$	$h_3$	$s_3$	$Vel_3$	$z_3$
62.99329 kJ/kg	63.09339 kJ/kg	0.2244 kJ/kg.K	0.0 m/s	0.0 m
$e_3$	$j_3$	$\phi_3$	$\psi_3$	$\dot{m}_{dot3}$
62.99329 kJ/kg	63.09339 kJ/kg			55.0 kg/s
$Vol_{dot3}$	$A_3$	$MM_3$		
0.05506 m <sup>3</sup> /s	5505.5005 m <sup>2</sup>			

6. And, for State 4: i.e. exit of water stream from the tubes. Enter  $p_4$ ,  $T_4$  and  $\dot{m}_{dot4} = \dot{m}_{dot3}$ .  
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-4 Calculate No-Plots Initialize Subcooled Liquid H2O

$p_4$	$T_4$	$x_4$	$y_4$	$v_4$
= $p_3$ kPa	23.0 deg-C			0.001 m <sup>3</sup> /kg
$u_4$	$h_4$	$s_4$	$Vel_4$	$z_4$
96.51218 kJ/kg	96.61245 kJ/kg	0.3392 kJ/kg.K	0.0 m/s	0.0 m
$e_4$	$j_4$	$\phi_4$	$\psi_4$	$\dot{m}_{dot4}$
96.51218 kJ/kg	96.61245 kJ/kg			= $\dot{m}_{dot3}$ kg/s
$Vol_{dot4}$	$A_4$	$MM_4$		
0.05515 m <sup>3</sup> /s	5515.1255 m <sup>2</sup>			



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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel I/O Panel

Initialize Device-A [2,3-1,4] Calculate Non-Mixing Mixing Device

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

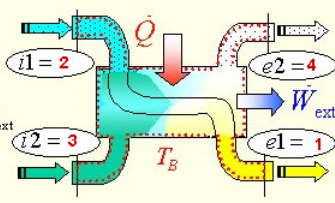
Qdot 0.0 kW Wdot\_ext 0.0 kW T\_B 298.15 K Sdot\_gen 0.6099 kW/K

Jdot\_net 0.0 kW Sdot\_net -0.6099 kW/K

**Multi-Flow Non-Mixing Device - A**  
Mass, Energy, and Entropy Equations:

$$\dot{m}_1 = \dot{m}_e; \quad \dot{m}_2 = \dot{m}_e;$$

$$0 = (\dot{m}_1 j_1 + \dot{m}_2 j_2) - (\dot{m}_e j_e) + \dot{Q} - \dot{W}_{ext}$$

$$0 = (\dot{m}_1 s_1 + \dot{m}_2 s_2) - (\dot{m}_e s_e) + \frac{\dot{Q}}{T_B} + \dot{S}_{gen}$$


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.

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**Thus:**

**$\dot{m}_1 = 0.7737 \text{ kg/s}$  = steam condensation rate.....Ans.**

**Rate of heat exchange in the heat exchanger =  $\dot{m}_1 * (h_2 - h_1) = 1843.5482 \text{ kW}$  ....Ans.**

**And, Rate of exergy destruction:  $I = T_0 * S_{\text{gen}} = (25+273)*0.6099 = 181.75 \text{ kW}$ ....Ans.**

**{Also, verify:**

Heat transferred in HX:  $Q = \dot{m}_3*(h_4-h_3) = 1843.5482 \text{ kW}$  .... 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;  $\dot{m}_1 = \frac{\dot{m}_3*(h_4-h_3)}{(h_2-h_1)}$  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;  $\dot{m}_3 = 55.0 \text{ kg/s}$ ; }

State-4: H2O;

Given: { p4= "P3" kPa; T4= 23.0 deg-C; Vel4= 0.0 m/s; z4= 0.0 m;  $\dot{m}_4 = \dot{m}_3$  kg/s; }

}



Analysis {

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

Given: {  $\dot{Q}$ = 0.0 kW;  $\dot{W}_{\text{ext}}$ = 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(m <sup>3</sup> /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:

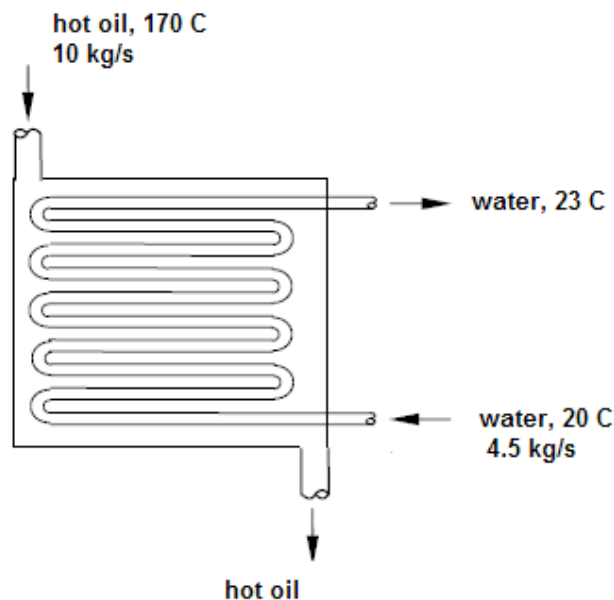
# Device-A: i-State = State-2, State-3; e-State = State-1, State-4; Mixing: false;

# Given:  $\dot{Q} = 0.0$  kW;  $\dot{W}_{\text{ext}} = 0.0$  kW;  $T_B = 298.15$  K;

# Calculated:  $\dot{S}_{\text{gen}} = 0.60990053$  kW/K;  $\dot{J}_{\text{net}} = 0.0$  kW;  $\dot{S}_{\text{net}} = -0.60990053$  kW/K;

=====

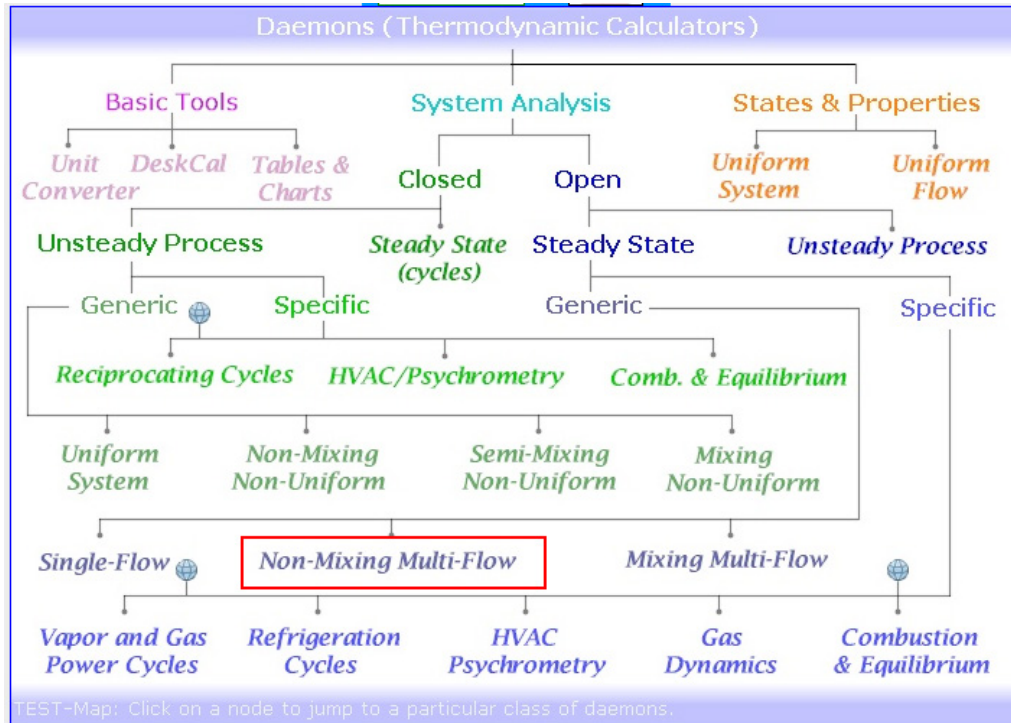
**Prob.8.27.** A well insulated shell & tube heat exchanger is used to heat water ( $c_p = 4.184$  kJ/kg.C) in the tubes from 20 to 70 C at a rate of 4.5 kg/s. Heat is supplied by hot oil ( $c_p = 1.8$  kJ/kg.C) that enters the shell side at 170 C at a rate of 10 kg/s. Neglecting the heat loss from the 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.



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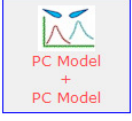

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2. For material model, select SL/SL model since we are dealing with water / oil.

Two Different Fluids	
 <p>PC Model + PC Model</p>	<p>The system has two separate flows consisting of two phase-change (PC) fluids, say, H<sub>2</sub>O and NH<sub>3</sub>, 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.</p> <p><b>Examples:</b> R-134a and H<sub>2</sub>O 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 <math>\dot{m}_{out4} = \dot{m}_{out2}</math>, set up the device panel with the known value of <math>\dot{W}_{dot\_ext} (=0)</math> and <math>\dot{Q}_{dot} (=0, \text{ if adiabatic})</math>, and click Super-Calculate to evaluate State-4. If T3 and T4 are both unknown, but related, iterative solution is necessary in which <math>\dot{Q}_{dot}</math> is left as an unknown, T3 is guessed until <math>\dot{Q}_{dot}</math> approaches the known value. For specific examples, click on the help icon at the bottom margin of the daemon.</p>
 <p>SL Model + SL Model</p>	<p>Same as above except the solid/liquid (SL) model is used for the two flows.</p> <p><b>Examples:</b> A <u>heat exchanger with liquid water and oil being the two fluids.</u> For specific examples, click on the help icon at the bottom margin of the daemon.</p>

3. For State 1: Select water. Enter  $p_1 = 100$  kPa (assumed, but it does not matter, since it is a liquid),  $T_1 = 20$  C, and  $\dot{m}_{dot1} = 4.5$  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

<input checked="" type="checkbox"/> $p_1$	100.0 kPa	<input checked="" type="checkbox"/> $T_1$	20.0 deg-C	<input checked="" type="checkbox"/> $\rho_{ho1}$	997.0 kg/m <sup>3</sup>	<input checked="" type="checkbox"/> $v_1$	0.001 m <sup>3</sup> /kg	<input checked="" type="checkbox"/> $u_1$	-21.02163 kJ/kg
<input checked="" type="checkbox"/> $h_1$	-20.92133 kJ/kg	<input checked="" type="checkbox"/> $s_1$	3.81204 kJ/kg.K	<input checked="" type="checkbox"/> $Vel_1$	0.0 m/s	<input checked="" type="checkbox"/> $z_1$	0.0 m	<input checked="" type="checkbox"/> $e_1$	-21.02163 kJ/kg
<input checked="" type="checkbox"/> $j_1$	-20.92133 kJ/kg	<input checked="" type="checkbox"/> $\dot{m}_{dot1}$	4.5 kg/s	<input checked="" type="checkbox"/> $\dot{V}_{dot1}$	0.00451 m <sup>3</sup> /s	<input checked="" type="checkbox"/> $A_1$	451.35406 m <sup>2</sup>	<input checked="" type="checkbox"/> $MM_1$	18.0 kg/kmol
<input checked="" type="checkbox"/> $c_{v1}$	4.184 kJ/kg.K	<input checked="" type="checkbox"/> $Model_1$	1.0 UnitLess						

4. Similarly, for State 2, exit of water: enter  $p_2$ ,  $T_2$ ,  $\dot{m}_{dot2}$ . 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)

<input checked="" type="checkbox"/> $p_2$	100.0 kPa	<input checked="" type="checkbox"/> $T_2$	70.0 deg-C	<input checked="" type="checkbox"/> $\rho_{ho2}$	997.0 kg/m <sup>3</sup>	<input checked="" type="checkbox"/> $v_2$	0.001 m <sup>3</sup> /kg	<input checked="" type="checkbox"/> $u_2$	188.17838 kJ/kg
<input checked="" type="checkbox"/> $h_2$	188.27867 kJ/kg	<input checked="" type="checkbox"/> $s_2$	4.47095 kJ/kg.K	<input checked="" type="checkbox"/> $Vel_2$	0.0 m/s	<input checked="" type="checkbox"/> $z_2$	0.0 m	<input checked="" type="checkbox"/> $e_2$	188.17838 kJ/kg
<input checked="" type="checkbox"/> $j_2$	188.27867 kJ/kg	<input checked="" type="checkbox"/> $\dot{m}_{dot2}$	= $\dot{m}_{dot1}$ kg/s	<input checked="" type="checkbox"/> $\dot{V}_{dot2}$	0.00451 m <sup>3</sup> /s	<input checked="" type="checkbox"/> $A_2$	451.35406 m <sup>2</sup>	<input checked="" type="checkbox"/> $MM_2$	18.0 kg/kmol
<input checked="" type="checkbox"/> $c_{v2}$	4.184 kJ/kg.K	<input checked="" type="checkbox"/> $Model_2$	2.0 UnitLess						



5. For State 3: Select oil. Enter  $p_2$ ,  $T_3$  and  $\dot{m}_{\text{oil}}$ . Note that sp. heat value is built-in. Hit Enter.  
We get:

p3 = 100.0 kPa [Absolute pressure]

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel I/O Panel

< @State-3 > Calculate No-Plots Initialize A: Oil(L) B: Oil(L)

<input checked="" type="checkbox"/> p3	<input checked="" type="checkbox"/> T3	<input checked="" type="checkbox"/> rho3	<input checked="" type="checkbox"/> v3	<input checked="" type="checkbox"/> u3
100.0 kPa	170.0 deg-C	910.0 kg/m³	0.0011 m³/kg	260.88864 kJ/kg
<input checked="" type="checkbox"/> h3	<input checked="" type="checkbox"/> s3	<input checked="" type="checkbox"/> Vel3	<input checked="" type="checkbox"/> z3	<input checked="" type="checkbox"/> e3
260.99854 kJ/kg	0.71336 kJ/kg.K	0.0 m/s	0.0 m	260.88864 kJ/kg
<input checked="" type="checkbox"/> j3	<input checked="" type="checkbox"/> mdot3	<input checked="" type="checkbox"/> Voldot3	<input checked="" type="checkbox"/> A3	<input checked="" type="checkbox"/> MM3
260.99854 kJ/kg	10.0 kg/s	0.01099 m³/s	1098.9011 m²	114.0 kg/kmol
<input checked="" type="checkbox"/> c_v3	<input checked="" type="checkbox"/> Model3			
1.8 kJ/kg.K	2.0 UnitLess			

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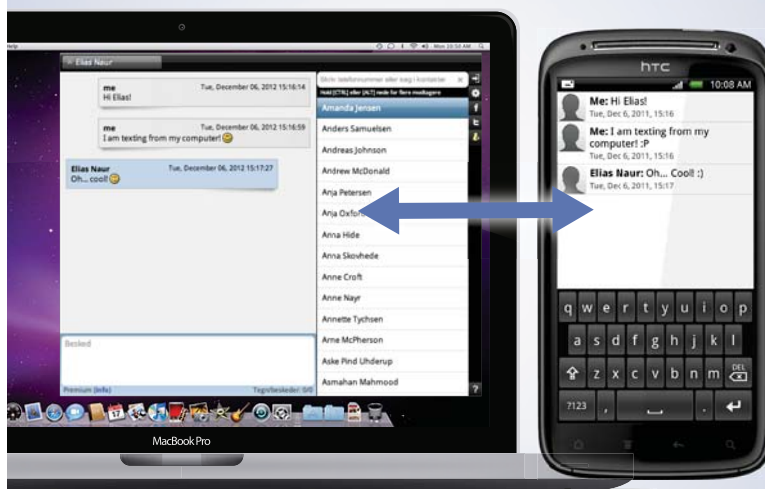
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6. For State 4: Enter  $p_4$ ,  $\dot{m}_{o4}$ , and  $T_4 = T_3 - (\dot{m}_{o1} * c_{v1}) * (T_2 - T_1) / (\dot{m}_{o3} * c_{v3})$ .  
Hit Enter. We get:

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-4 Calculate No-Plots Initialize A: Oil(L) B: Oil(L)

$p_4$	$T_4$	$\rho_{o4}$	$v_4$	$u_4$
100.0 kPa	$=T_3 - (\dot{m}_{o1} * c_{v1}) \text{ deg-C}$	910.0 kg/m <sup>3</sup>	0.0011 m <sup>3</sup> /kg	166.74866 kJ/kg
$h_4$	$s_4$	$Vel_4$	$z_4$	$e_4$
166.85854 kJ/kg	0.48731 kJ/kg.K	0.0 m/s	0.0 m	166.74866 kJ/kg
$j_4$	$\dot{m}_{o4}$	$Vol_{o4}$	$A_4$	$MM_4$
166.85854 kJ/kg	$=\dot{m}_{o3}$ kg/s	0.01099 m <sup>3</sup> /s	1098.9011 m <sup>2</sup>	114.0 kg/kmol
$c_{v4}$	$Model_4$			
1.8 kJ/kg.K	2.0 UnitLess			

Immediately, we get: exit temp of oil,  $T_4 = 117.7 \text{ C} \dots \text{Ans.}$

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  $\dot{Q}_{dot} = 0$  (since the HX is insulated) and  $\dot{W}_{dot\_ext} = 0$ . Click on Calculate. Immediately, we get:

Use the I/O Panel as a scientific calculator that recognizes state properties (e.g.  $3.14 * 9.5^2$ ,  $h_2 - h_1$ ,  $p_1 * (Vol_1 / Vol_2)^{1.3}$ , etc.)

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Device Panel I/O Panel

Initialize Device-A [1,3-2,4] Calculate Non-Mixing Mixing Device

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

$\dot{Q}_{dot}$	$\dot{W}_{dot\_ext}$	$T_B$	$\dot{S}_{dot\_gen}$
0.0 kW	0.0 kW	298.15 K	0.70457 kW/K
$\dot{J}_{dot\_net}$	$\dot{S}_{dot\_net}$		
0.0 kW	-0.70457 kW/K		

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

Mass, Energy, and Entropy Equations:

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

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

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

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,  $Q = c_v * \dot{m}_{o1} * (T_2 - T_1)$ :

$$Q = 4.184 * 4.5 * (70 - 20) = 941.4 \text{ kW} \dots \text{Ans.}$$

### #Exergy destroyed:

Note that entropy gen. rate =  $S_{\dot{\text{gen}}} = 0.70457 \text{ kW/K}$

Then, exergy destroyed =  $\Delta e = T_0 * S_{\text{gen}}$

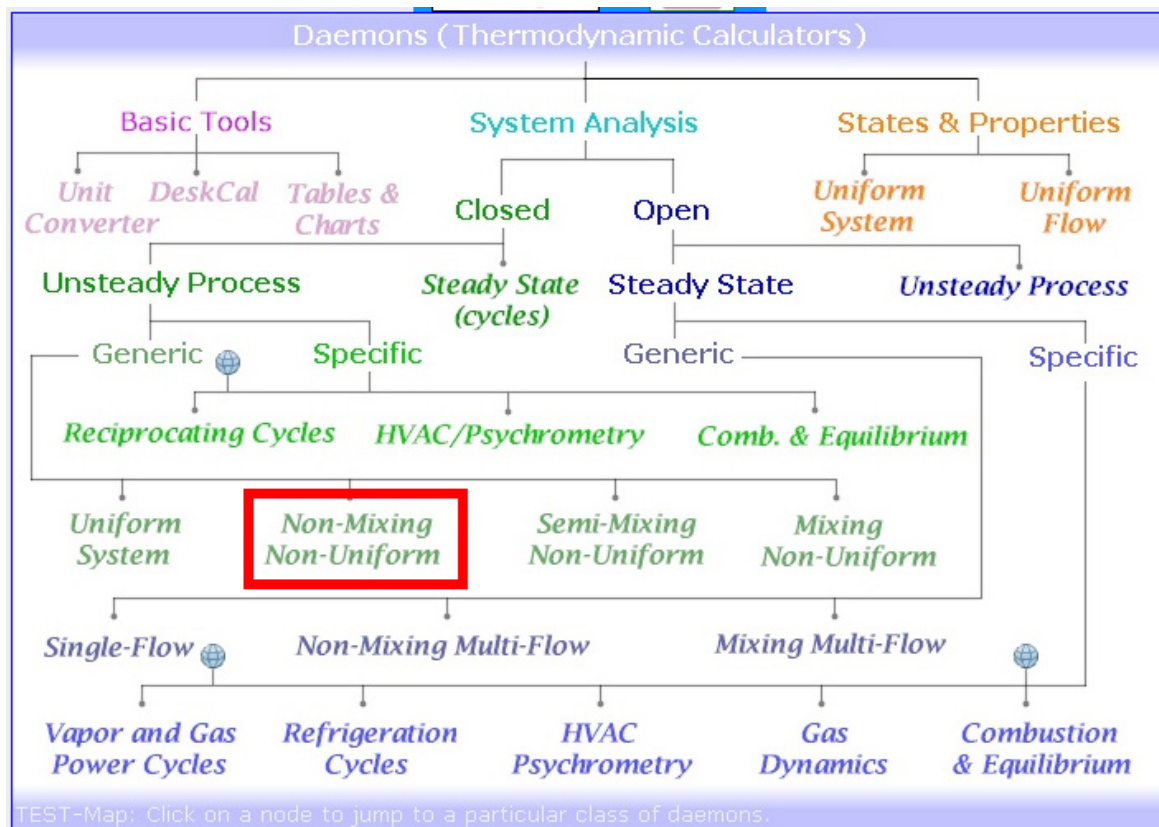
i.e.  $\Delta e = T_0 * S_{\text{gen}} = (25+273) * 0.70457 = 209.96 \text{ kW} \dots \text{Ans.}$

**Prob.8.28.** 70 kg of iron at 80 C is dropped in to an insulated tank containing 0.1 m<sup>3</sup> of water at 20 C. Find out the final, equilibrium temp. Also, what is the entropy generation and the exergy destruction? Take  $T_0 = 20 \text{ C}$ .

### TEST Solution:

Following are the steps:

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

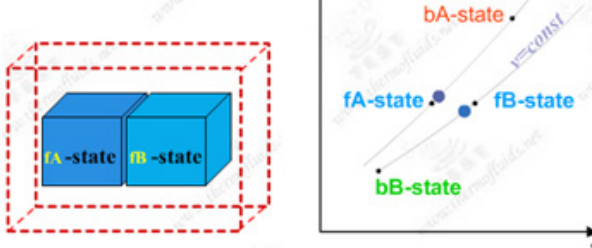




Hover the mouse pointer over 'Non-Mixing Non-Uniform' and we get the following pop-up:

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.

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

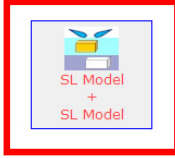
The system has two uniform sub-systems, each with the same working fluid (say, H<sub>2</sub>O and H<sub>2</sub>O). While the two sub-systems exchange energy, they maintain their individual identities as they do not mix. We will need two states, bA and bB, to describe the composite beginning-state and 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 m<sub>3</sub>=m<sub>1</sub>, and leave T<sub>3</sub> as an unknown. For State-4 (fB state) enter m<sub>4</sub>=m<sub>2</sub> and T<sub>4</sub>=T<sub>3</sub>. Set up the process panel for the known value of W(=0) and an unknown Q (even if Q is given). Now guess T<sub>3</sub> and Super-Calculate T<sub>4</sub> 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.



- Now, for State 1: choose Iron (Fe). See the yellow background color. Note that sp. heat value is built-in. Enter T<sub>1</sub>, m<sub>1</sub> and hit Enter. We get:

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

thermofluids.net > Daemons > Systems > Closed > Process > Generic > UnMixed > SL/SL

Home of TEST

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

Mixed SI English Case-0 Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel I/O Panel

State-1 Calculate No-Plots Initialize A: Select a Solid/Liq. A B: Iron(Fe)

p1	T1	rho1	v1	u1
kPa	80.0 deg-C	7840.0 kg/m³	1.3E-4 m³/kg	24.73708 kJ/kg
h1	s1	Vel1	z1	e1
kJ/kg	0.56498 kJ/kg.K	0.0 m/s	0.0 m	24.73708 kJ/kg
j1	m1	Vol1	MM1	c_v1
kJ/kg	70.0 kg	0.00893 m³	55.85 kg/kmol	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  $p_1 = 100 \text{ kPa}$ ,  $T_2 = 20 \text{ C}$ , and  $\text{Vol}_2 = 0.1 \text{ m}^3$ . 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 Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel I/O Panel

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

<input checked="" type="checkbox"/> $p_2$	<input checked="" type="checkbox"/> $T_2$	$\rho_2$	$v_2$	$u_2$
100.0 kPa	20.0 deg-C	997.0 kg/m <sup>3</sup>	0.001 m <sup>3</sup> /kg	-21.02163 kJ/kg
$h_2$	$s_2$	<input checked="" type="checkbox"/> $Vel_2$	<input checked="" type="checkbox"/> $z_2$	$e_2$
-20.92133 kJ/kg	3.81204 kJ/kg.K	0.0 m/s	0.0 m	-21.02163 kJ/kg
$j_2$	$m_2$	<input checked="" type="checkbox"/> $\text{Vol}_2$	$MM_2$	$c_{v2}$
-20.92133 kJ/kg	99.7 kg	0.1 m <sup>3</sup>	18.0 kg/kmol	4.184 kJ/kg.K
Model2				
1.0 UnitLess				

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5. Next, for State 3: Select Iron. (see the yellow color). Enter  $m_3 = m_1$ , and  $T_3 = (m_1 \cdot c_{v1} \cdot T_1 + m_2 \cdot c_{v2} \cdot T_2) / (m_1 \cdot c_{v1} + m_2 \cdot c_{v2})$ . Hit Enter. We get:

$T_3 = (m_1 \cdot c_{v1} \cdot T_1 + m_2 \cdot c_{v2} \cdot T_2) / (m_1 \cdot c_{v1} + m_2 \cdot c_{v2}) = 24.212687 \text{ deg-C [Absolute temperature]}$

Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel I/O Panel

< State-3 > Calculate No-Plots Initialize A: Water(L) B: Iron(Fe)

p3	T3	rho3	v3	u3
kPa	deg-C	kg/m³	m³/kg	kJ/kg
h3	s3	Vel3	z3	e3
kJ/kg	kJ/kg.K	m/s	m	kJ/kg
j3	m3	Vol3	MM3	c_v3
kJ/kg	kg	m³	kg/kmol	kJ/kg.K
Model3				
2.0	UnitLess			

**Note: Equilibrium temp,  $T_3 = 24.213 \text{ C} \dots \text{Ans.}$**

6. Now, for State 4: Select water, see the yellow color. Enter  $p_4 = 100 \text{ kPa}$ ,  $T_4 = T_3$ , and hit Enter. We get:

$T_4 = T_3 = 24.212687 \text{ deg-C [Absolute temperature]}$

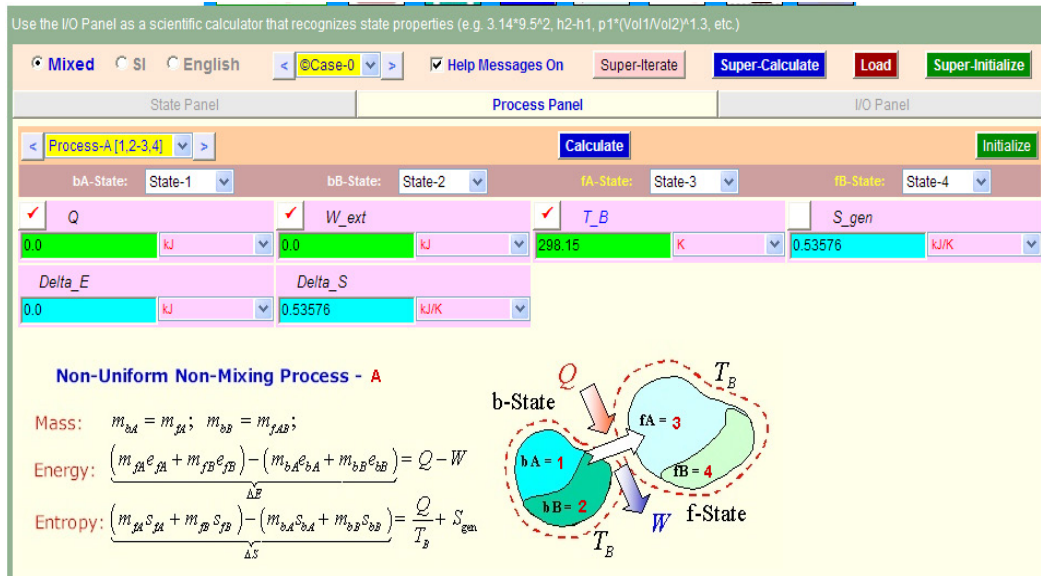
Mixed SI English < Case-0 > Help Messages On Super-Iterate Super-Calculate Load Super-Initialize

State Panel Process Panel I/O Panel

< State-4 > Calculate No-Plots Initialize A: Water(L) B: Water(L)

p4	T4	rho4	v4	u4
kPa	deg-C	kg/m³	m³/kg	kJ/kg
h4	s4	Vel4	z4	e4
kJ/kg	kJ/kg.K	m/s	m	kJ/kg
j4	m4	Vol4	MM4	c_v4
kJ/kg	kg	m³	kg/kmol	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,  $W_{\text{ext}} = 0$ . Click on Calculate and then SuperCalculate. We get:



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

# Exergy destruction:  $\Delta e = T_0 \cdot S_{\text{gen}}$ :

i.e. :  $\Delta e = (20+273) \cdot 0.53576 = 156.978 \text{ kJ} \dots \text{Ans.}$

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: {  $T_1 = 80.0 \text{ deg-C}$ ;  $V_{el1} = 0.0 \text{ m/s}$ ;  $z_1 = 0.0 \text{ m}$ ;  $m_1 = 70.0 \text{ kg}$ ;  $\text{Model1} = 2.0 \text{ UnitLess}$ ; }

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<sup>3</sup>; 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-----
```

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**# 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;  $W_{\text{ext}} = 0.0$  kJ;  $T_B = 298.15$  K;

# Calculated:  **$S_{\text{gen}} = 0.535759$  kJ/K**;  $\Delta E = -4.5474735 \times 10^{-12}$  kJ;  $\Delta S = 0.535759$  kJ/K;

=====

## 8.4 References:

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6. *M. Thirumaleshwar*, Exergy method of analysis and its application to a helium cryorefrigerator, CRYOGENICS, June 1979
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