***Engineering Equation Solver Program for Engineering Applications***

# *(EES)*

## *Engineering Applications*

## *Thermo-Fluid Implementations*

## Explanations with many Exercises

***You will be a professional programmer!***


Prepared by

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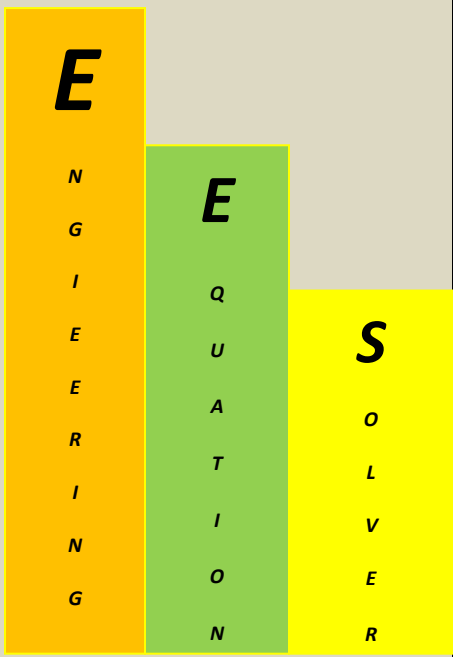

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## *1.0. Getting started*

Engineering Equation Solver has been designed to solve any type of problems which have materials properties such as Material thermal conductivity, specific heat …..etc.

It is an important computer program, particularly in thermodynamics problems since they rely on materials properties e.g. enthalpy, entropy, pressure, temperature …..etc. All these properties are measured by materials characteristics based on their physical or chemical properties.

## *1.1. Tools or Commands Bar.*



| | |
|---|---|
| | **This icon is used to save a program.** |
| | This icon is used to print out a program. |
| | This icon is used to cut a program. |
| | This icon is used to past a program. |
| | |
| | This icon is used to show thermodynamics diagrams / Property Plot icon |
| | Calculation command, it is used to calculate a program, or an equation. |
| | This icon is used to show window equations. |
| | This icon is used to show formatted equations. |
| | This icon is used to create a parametric table. |
| | Drawing icon, it is used to draw a layout or sketch. |
| | This icon is used to show materials properties or Functions info. |
| | This icon is used to show a solution window. |
| | This icon is used to change the system from International to English system and vice versa. |
| | This icon is used to insert a plot or add more than one plotting. It is called overlap plot. |
| | This icon is used to draw a plot and it is called new window plot. |
| | This icon is used to show or hide a tool bar on the plotting area. |
| | This icon is used to draw a diagram, it is called diagram window. |



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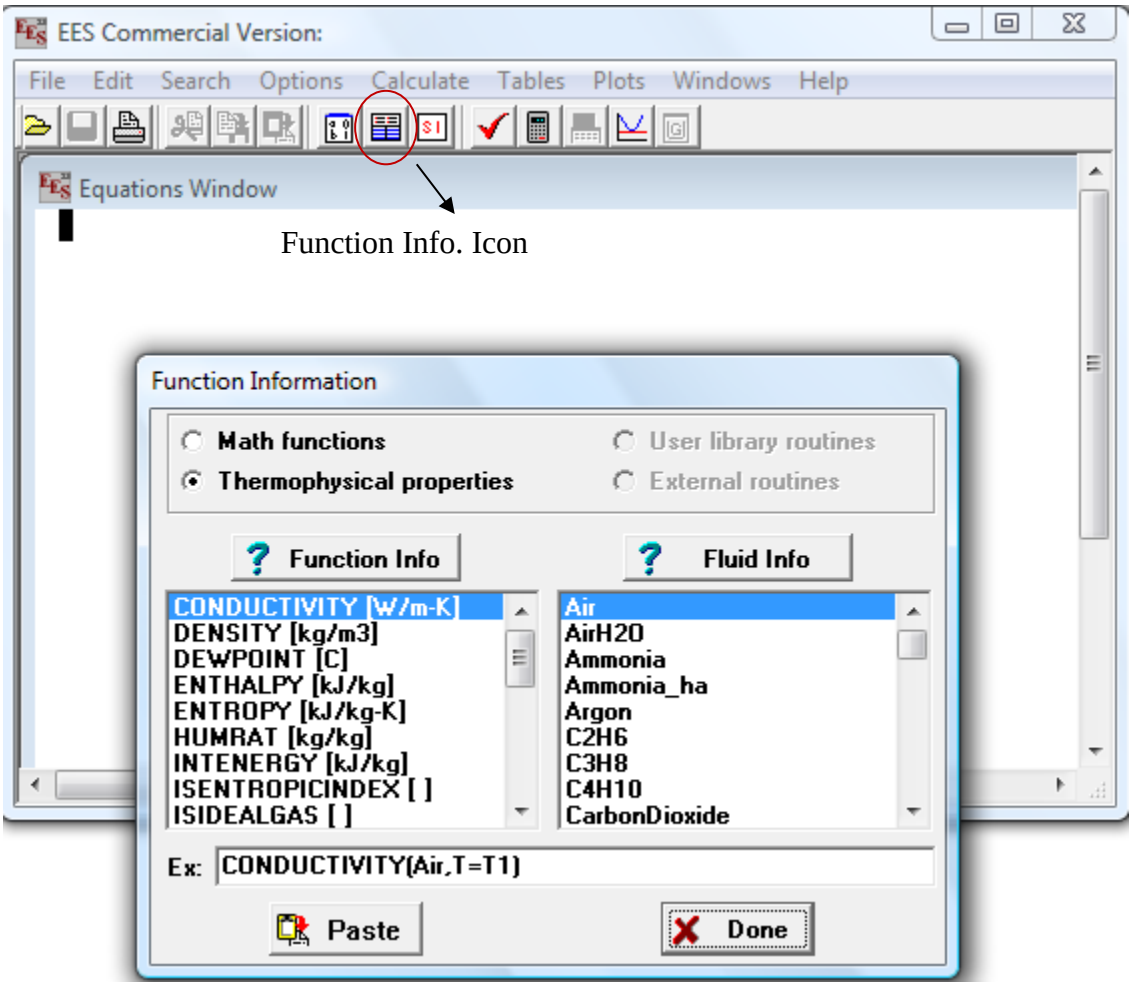
### *1.2. Materials Properties*

Materials properties are an important key to start to write a program in equation window; therefore, users have to learn how to write correct materials properties by using an icon which is used to show materials properties (see table of icons) or by write them down if a user knows how he /she can write them with correct format.

#### *1.2.1. Writing Materials Properties by using Function information*




As we saw in the previous window, there are two types of functions information (Math Functions and Thermo-physical Properties) and Fluid information (Type of the fluid). I have selected the thermo-physical properties.

***Example (1):*** Find the density of water at 0°C, 50 °C, and 100°C, if the P=101.325kPa?

Ans.



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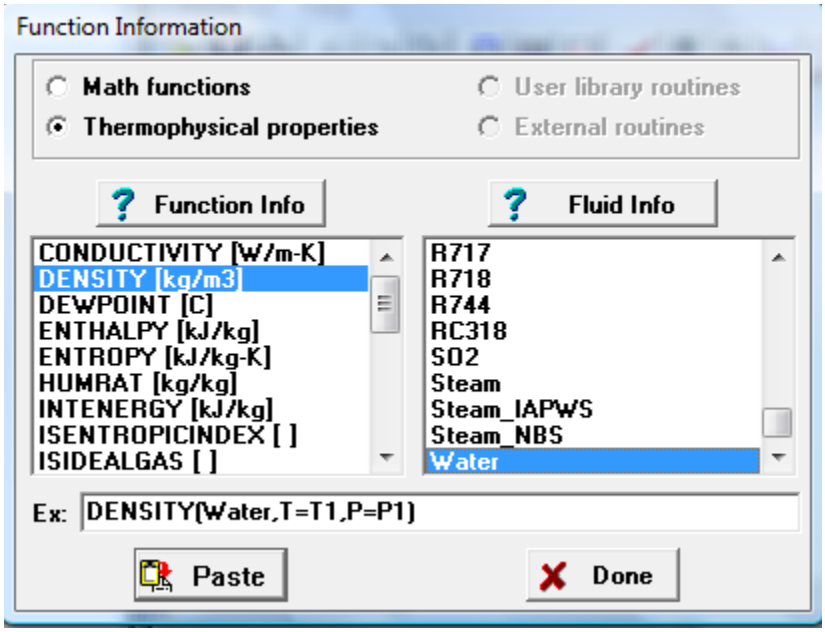
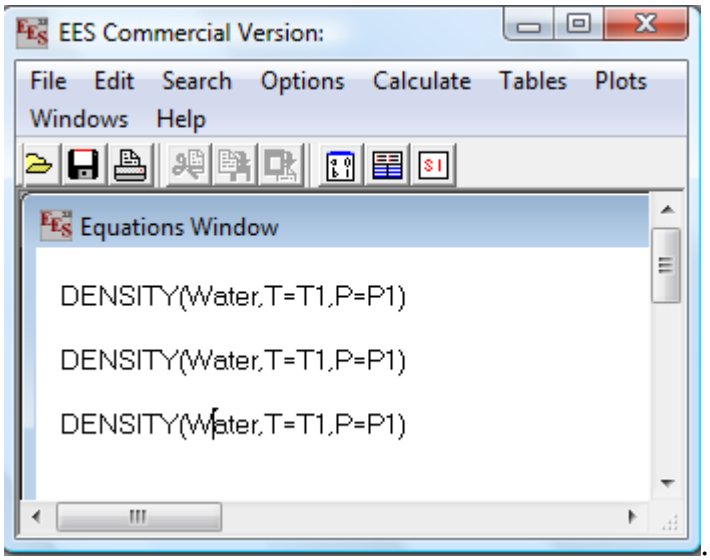
Step#1: Select the Function info. and Fluid info,




*Step#2: Paste the material Properties*




Let us putting d1, d2 ,d3 referring to each density and add T1,T2,T3 as they are given.



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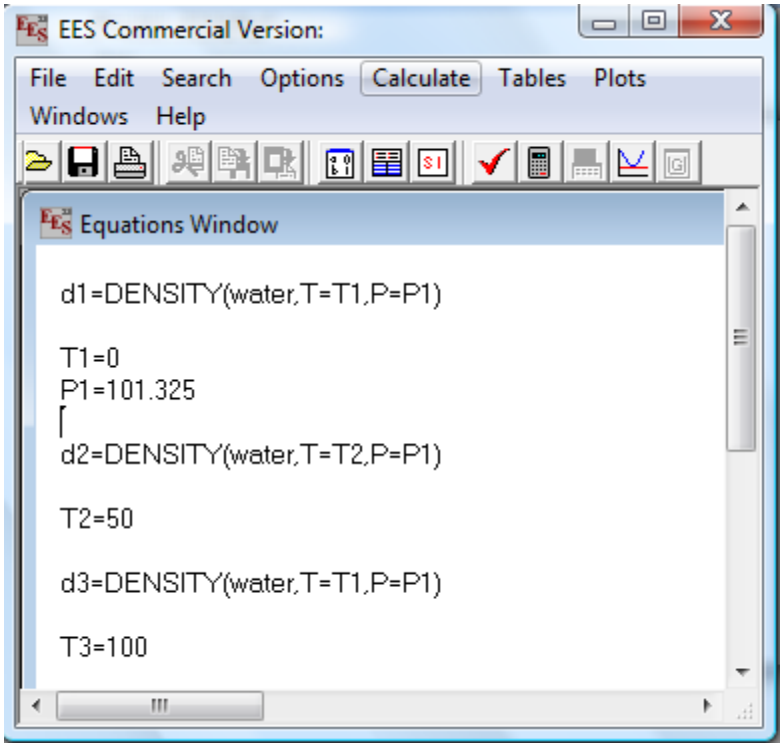
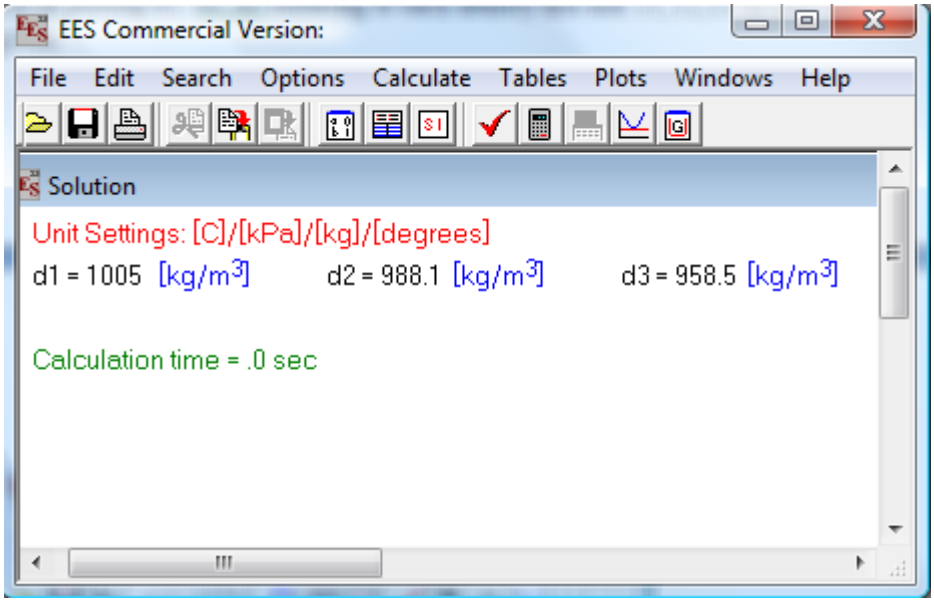



Then, press calculate icon to solve the problem.




As you can see, the results show that if the temperature increases, the density decreases. It is true.



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## 1.3. Adding and Deleting Materials Properties on Equations Window

Adding or deleting a Material property is easy. You can use cut and paste icon to do that or you can delete by using delete button from a keyboard.




# *Chapter#2: Evaluation of Materials Properties by using Materials Properties icon*

This chapter will discuss thermo-physics properties such as enthalpy, entropy, temperature, pressure, specific heat, thermal conductivity…..ets.

## *2.1. Enthalpy and Entropy*

Enthalpy (h) is the amount of heat of a matter and Entropy (s) is a property of a substance, $s = \frac{q}{T}$ . We can find the enthalpy or the entropy based on the pressure (P) and the temperature (T) or other independent properties.

Example (2): Find the enthalpy and entropy Properties at T=150C,P=170kPa for the following substances:

1. R-134a,
2. R22, and
3. Water

***Solution:***

Before starting the solution, we must know the unit system (SI or English system) by



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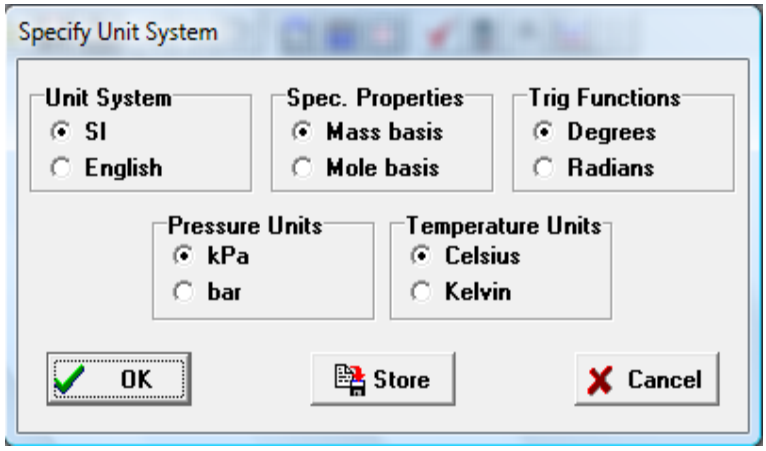
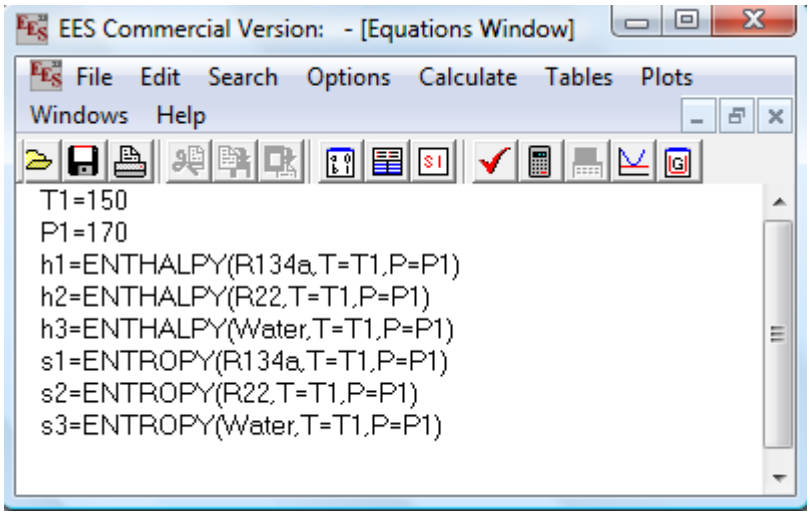
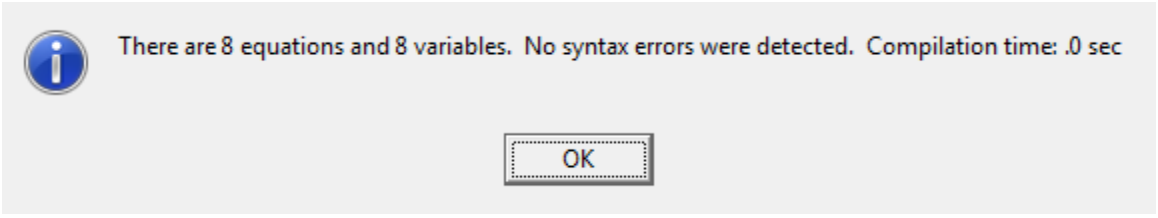



Use check icon to see if the numbers of variables are equal to the numbers of equations, if so your program is correct; otherwise re-correct your program.




***The solution:***



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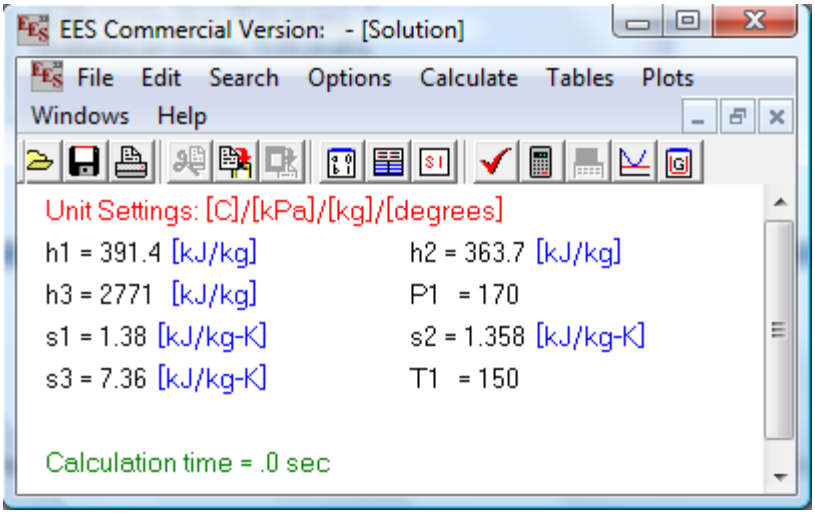


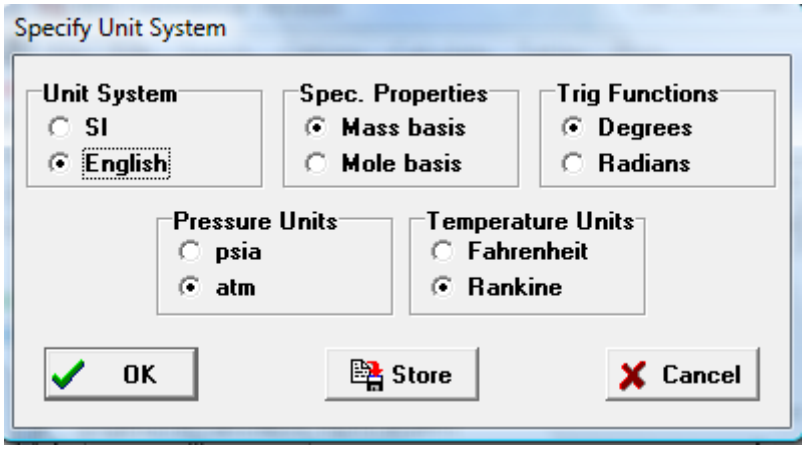

## 2.2. Specific Heat and Specific Volume

Example (3): Find the specific heat and specific volume at T=375K,P=150 bar for the following substances.

1. R123, and
2. Propane

Ans.

Change the unit of the system into English system and press OK.



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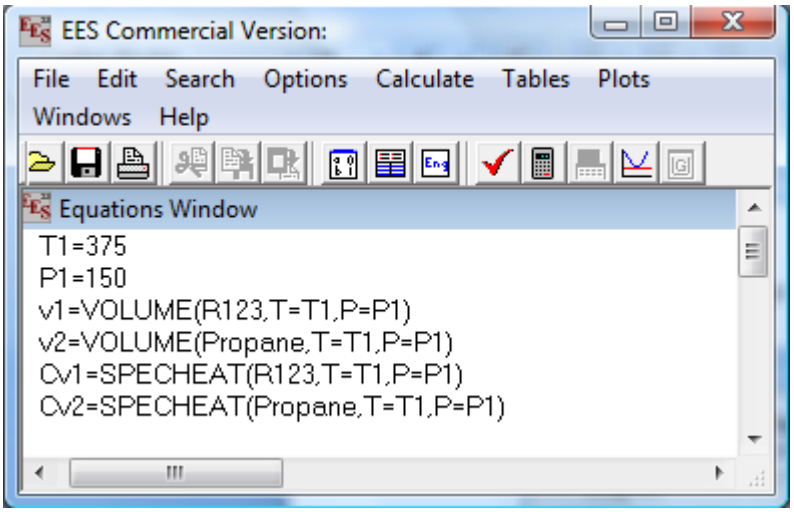
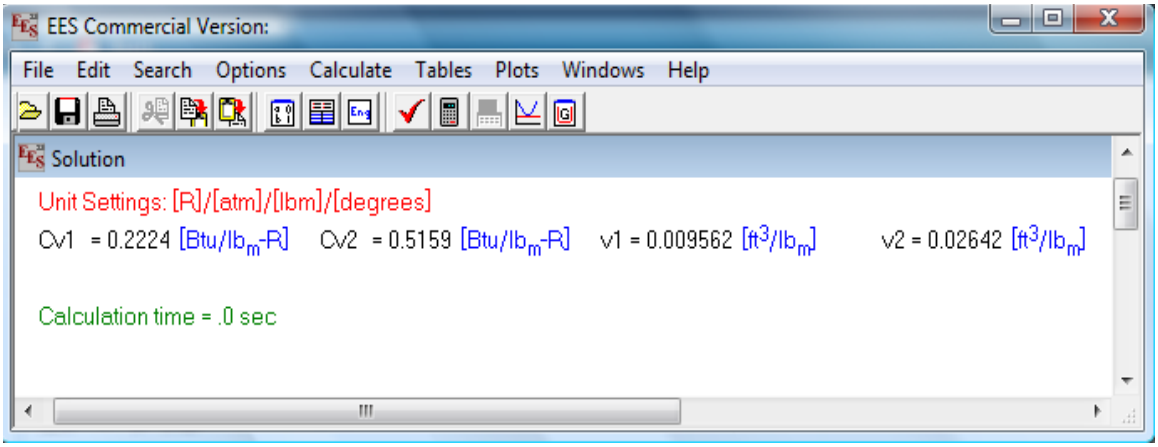


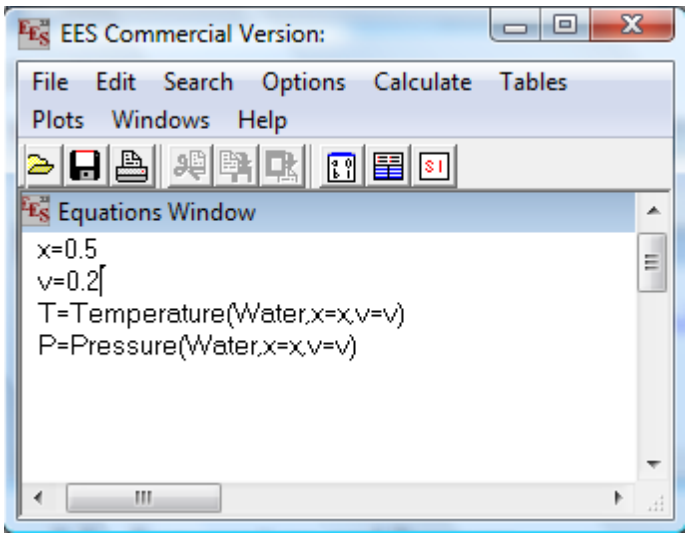

*The solution is*




### *2.3. Temperature and Pressure*

Example (4): Find the pressure and temperature of water at v = 0.2 $m^3$/kg, x=0.5 (x is the quality $x = \frac{mv}{m_{tot}}$)

***The solution:***



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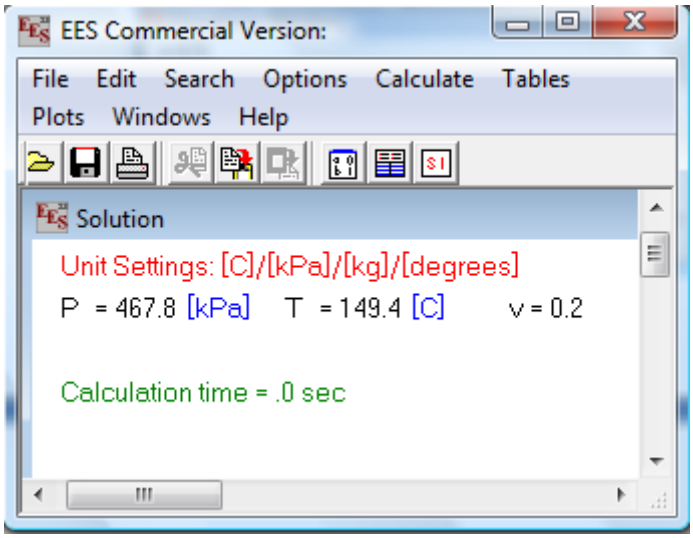
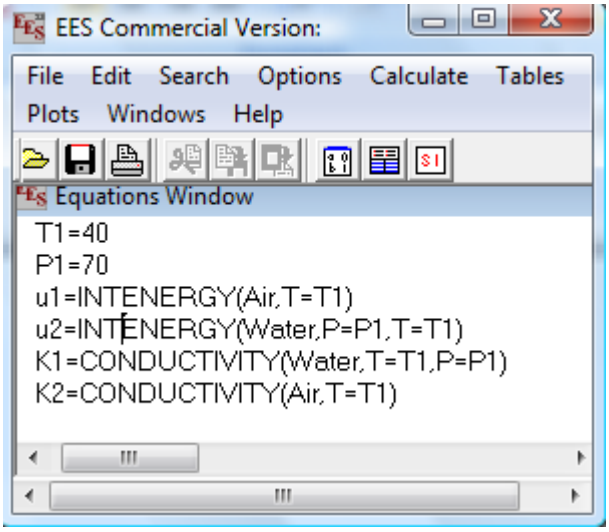



## 2.4. Internal energy and Thermal Conductivity

Example (5): Find the internal energey(u) and the thermal conductivity for the following substznces at T=40C and P= 70kPa.

1. Air, and
2. Water

***The solution:***



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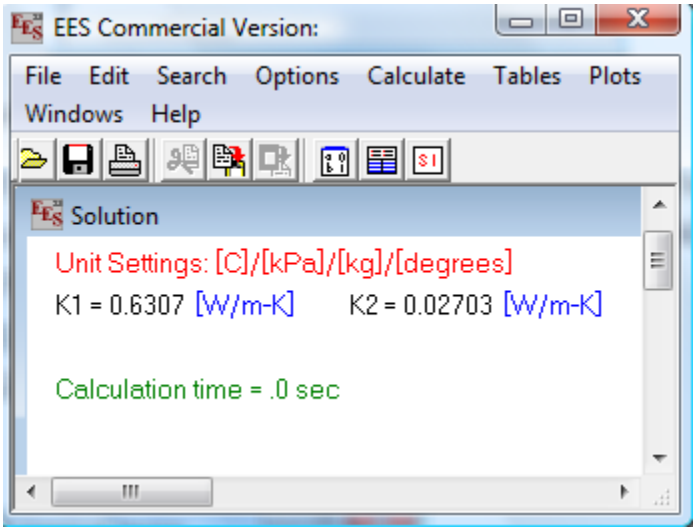


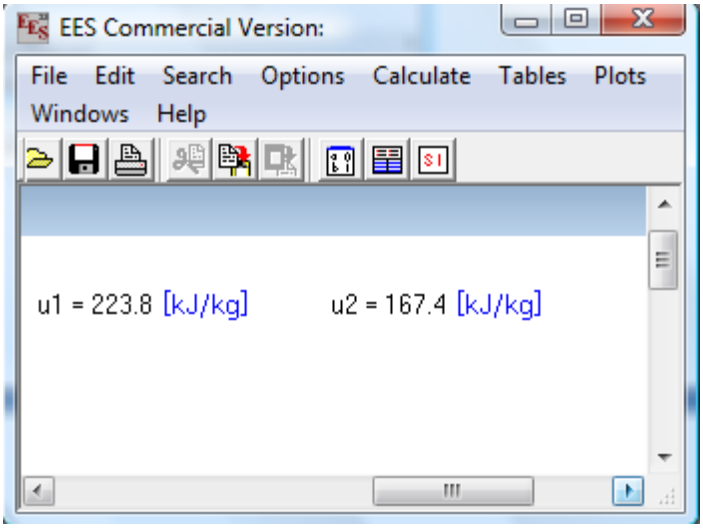




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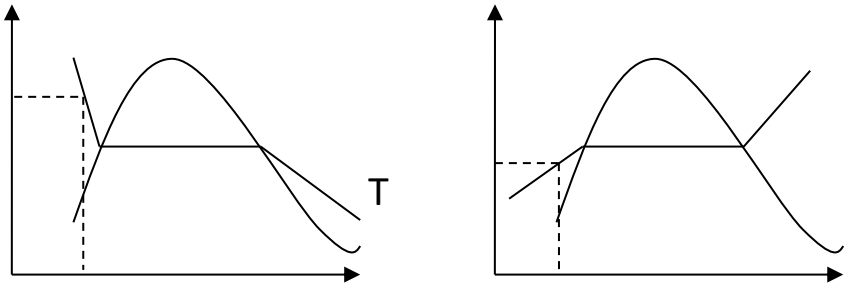
# *Chapter#3: Description of All Thermodynamics Properties*

Thermodynamics Properties Criteria (Definitions and Explanations)

### 3.1. Compressed Liquid Properties

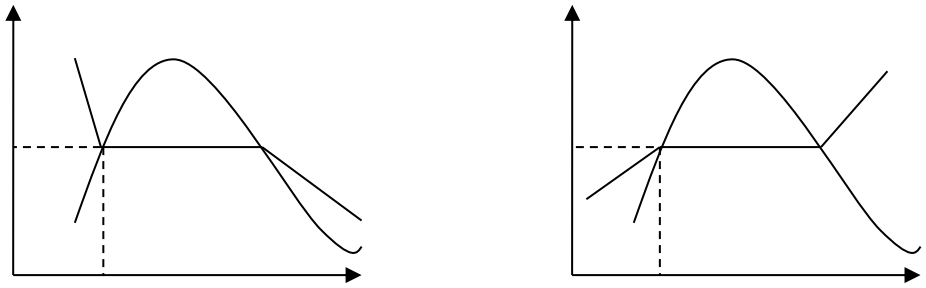
If the temperature of the liquid is lower than the saturation temperature for the existing pressure, it is called either a sub cooled liquid or compressed liquid. Substances Properties such as $P_f$, $T_f$,$v_f$,$h_f$,$u_f$, and entropy can be found by compressed thermodynamics tables or at a compressed liquid temperature from saturated tables.




P-v diagram T-s diagram

### 3.2. Saturated Liquid Properties

If a substance exists as a liquid at the saturation temperature and pressure, it is called a saturated liquid such as $P_{sat}$,$T_{sat}$…etc. Also we cand find saturated liquid properties at x=0.



*P-v diagram* *T-s diagram*

### 3.3. Liquid-Vapor Mixture Properties

When a substance exists as part liquid and part vapor at saturation conditions, its *quality* (x) is defined as the ratio of the mass of the vapor to the total mass of both vapor and liquid.



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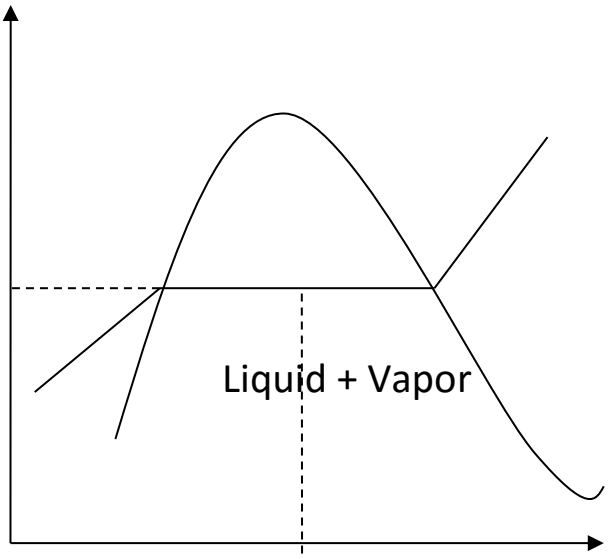
T-s diagram




$$x = \frac{m_v}{m_{tot}}$$

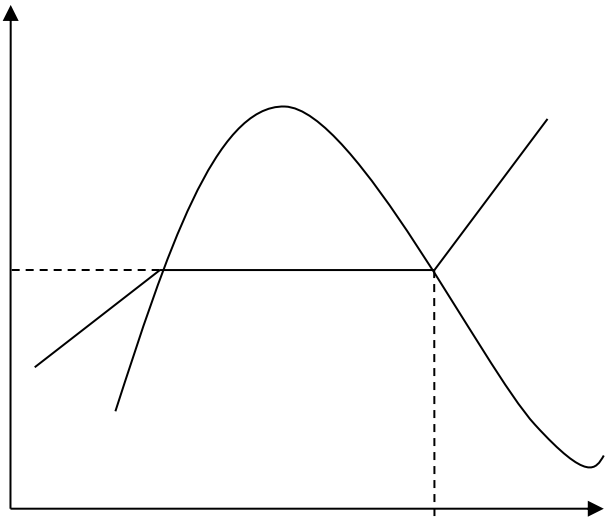
$$h = h_f + xh_{fg}, u = u_f + xu_{fg}, v = v_f + xv_{fg}, s = s_f + xs_{fg}$$

if $x = 0$, the phase is saturated liquid, but if $x = 1$, the phase is saturated vapor.

## *3.4. Saturated Vapor Properties*

If a substance exists entirely as vapor at saturation temperature, it is called *saturated vapor*. Sometimes the term dry saturated vapor is used to emphasize that the quality is 100%. The thermal properties will be $v_g$, $h_g$, $u_g$,…..etc.

T-s diagram





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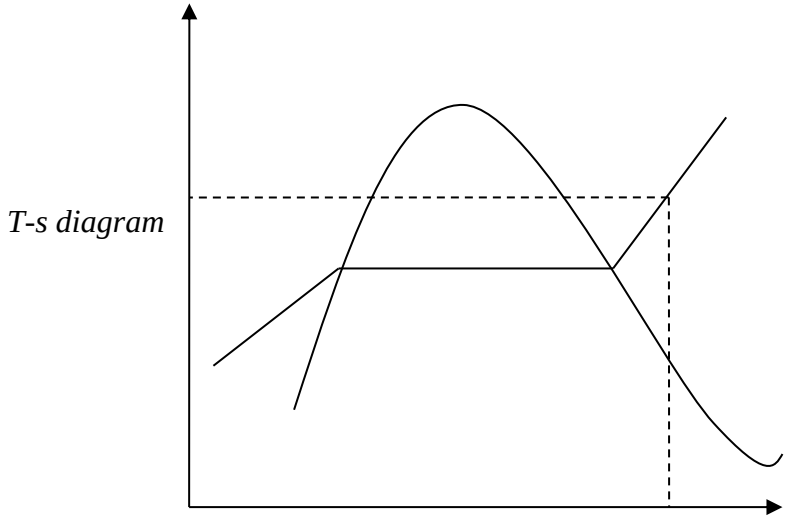
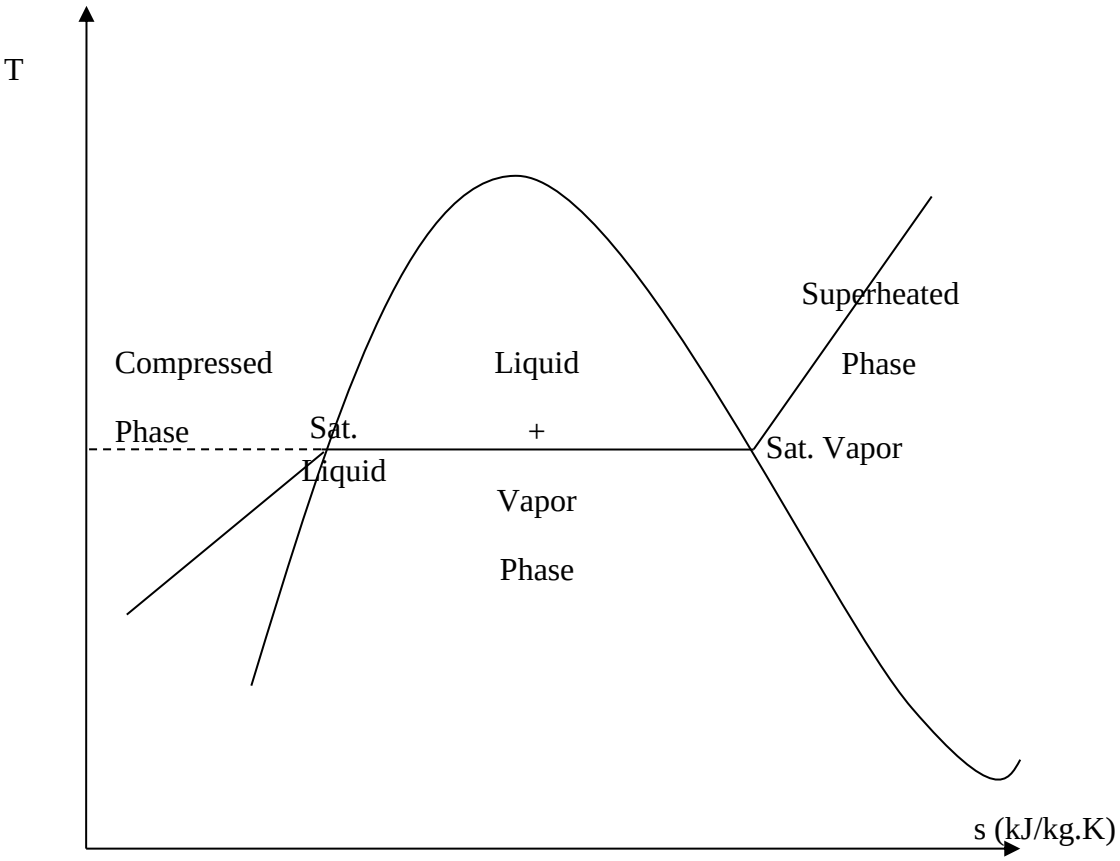
### *3.5. Superheated Vapor (Steam)*

When a vapor is at a temperature greater than the saturation temperature, it is said to exist as *superheated vapor*.




All phases Criteria are shown in T-s diagram



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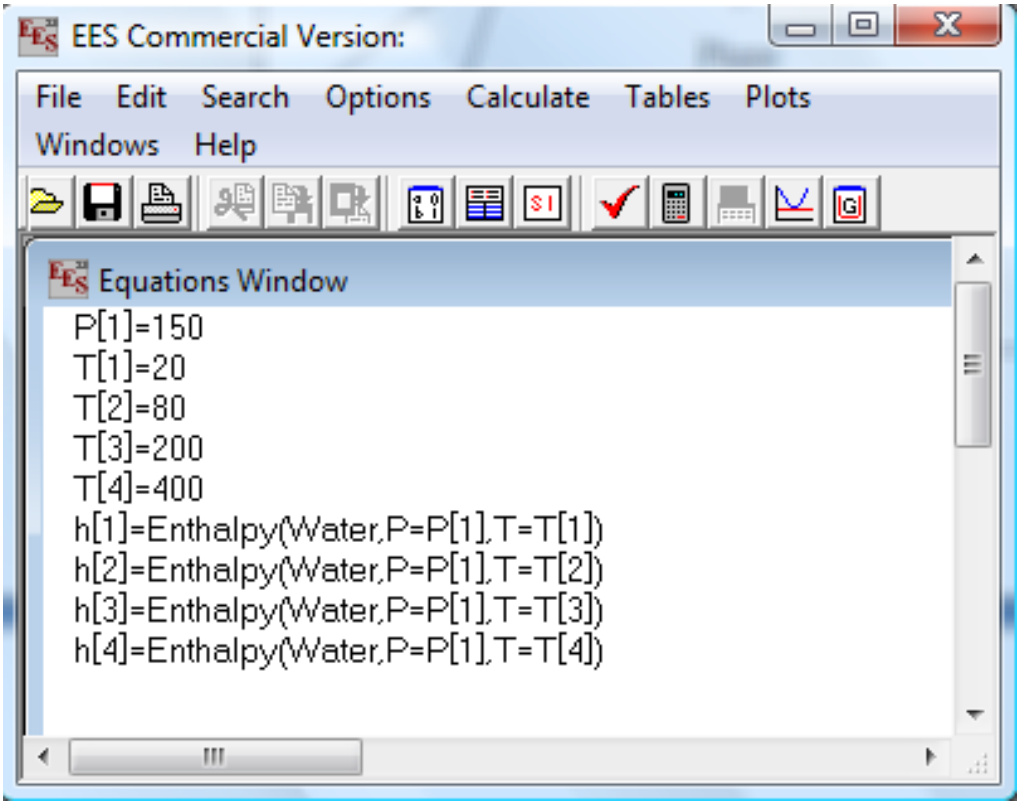
Example (6): Find the enthalpies of water during the isobaric process at P=150 and T=20 C , 80C,200C,400C and put all enthalpies in array table.

Ans. Isobaric process means the given pressure is constant.

Showing the enthalpies inside arrays by using square parentheses [ ]



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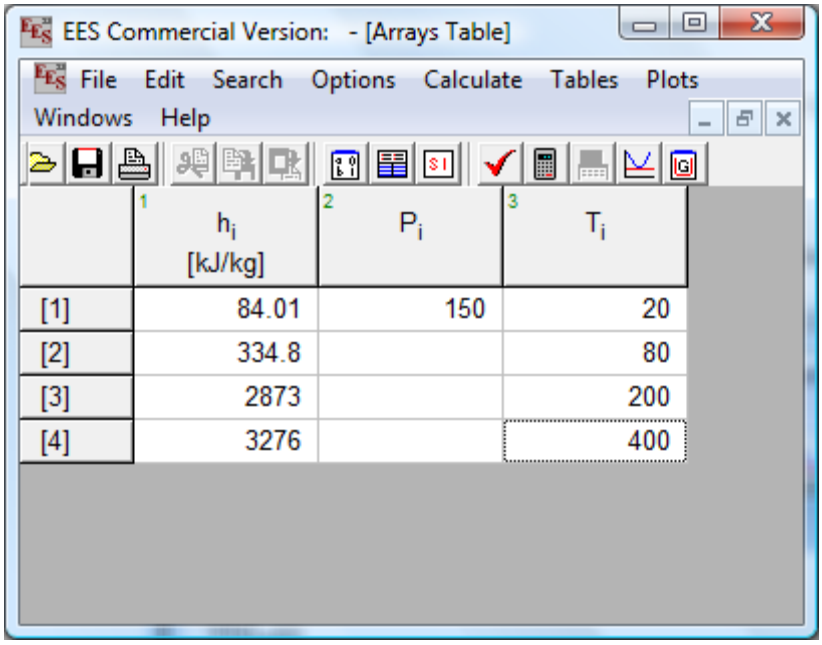
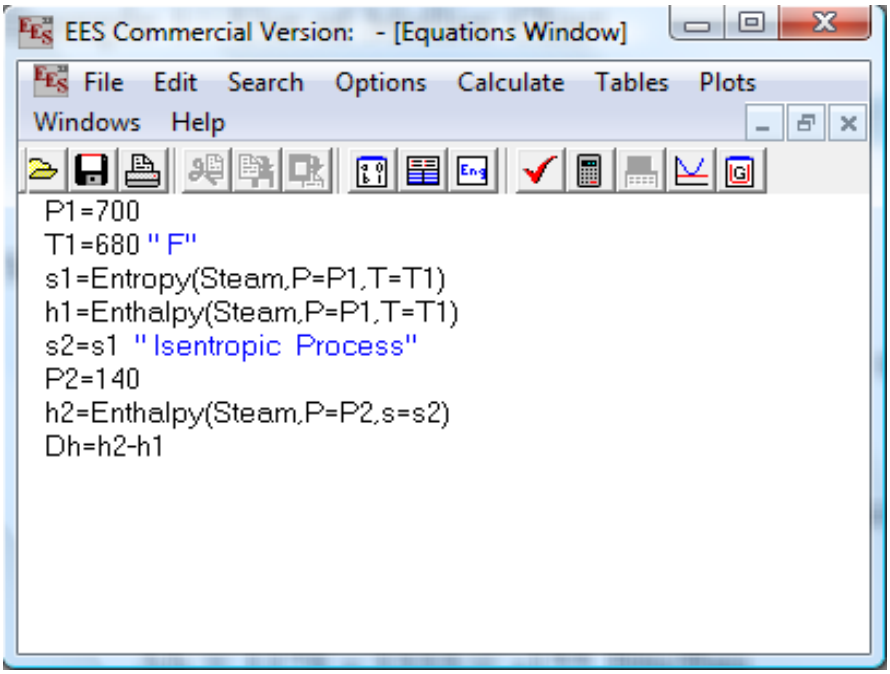
The arrays table press F2 or calculate icon to see the arrays table




| | 1 $h_i$ [kJ/kg] | 2 $P_i$ | 3 $T_i$ |
|---|---|---|---|
| [1] | 84.01 | 150 | 20 |
| [2] | 334.8 | | 80 |
| [3] | 2873 | | 200 |
| [4] | 3276 | | 400 |

Example (7): Superheated steam at 700 psia and 680°F is expanded at constant entropy to 140 psia. What is the change in enthalpy?

Ans.



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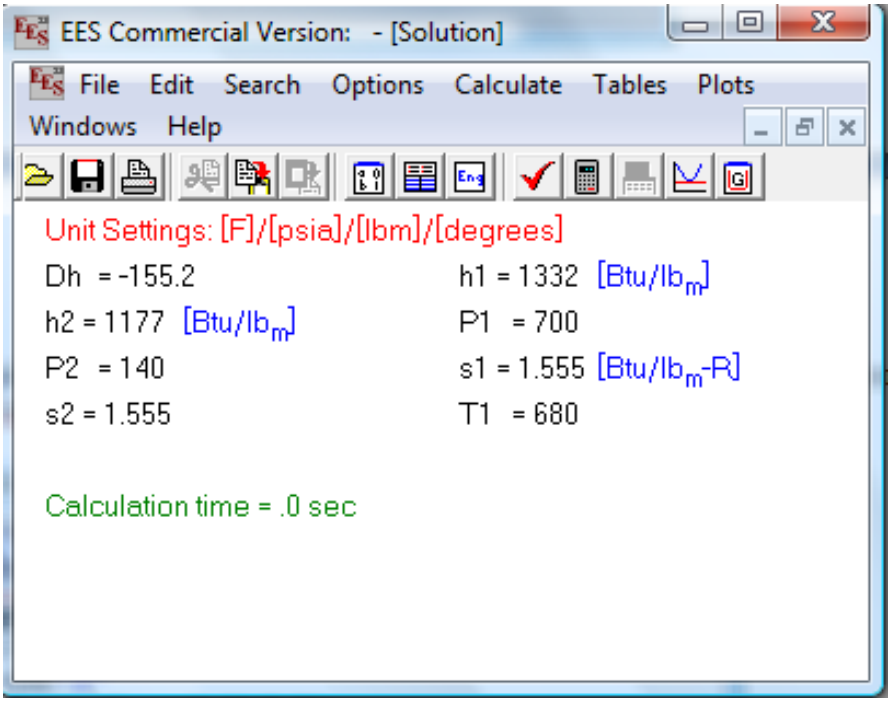
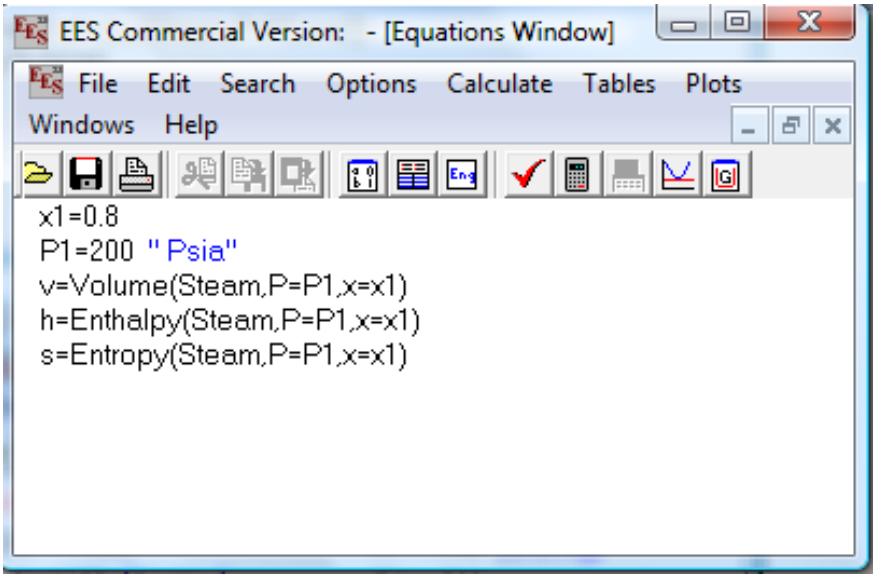



Example (8): What are the specific volume, enthalpy, and entropy of steam having a quality of 80% at 200 psia?

***The solution:***



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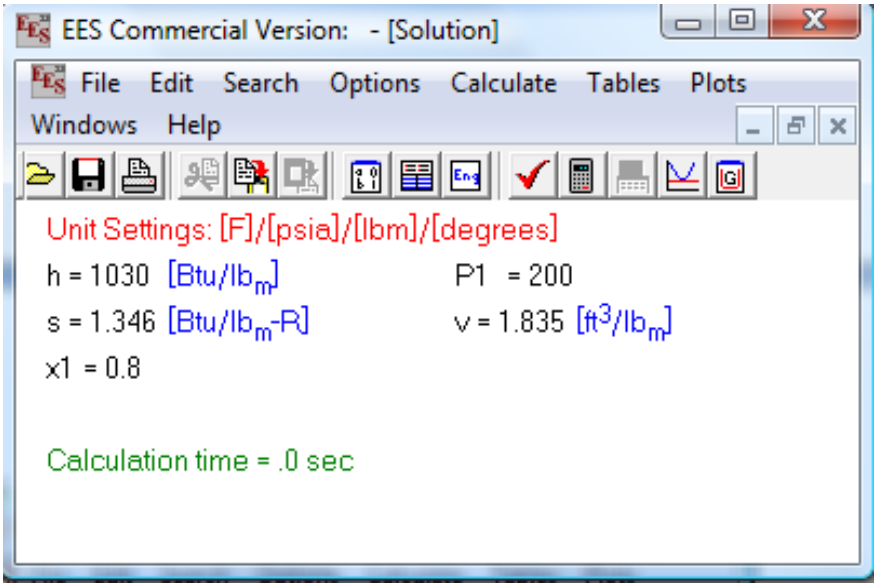
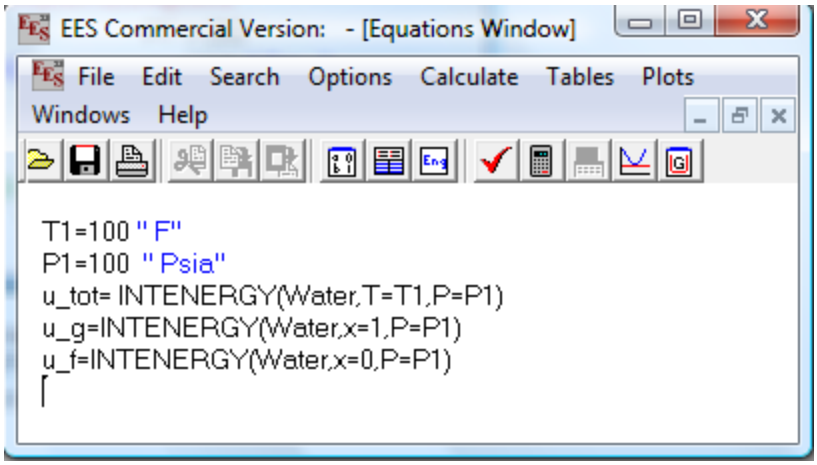



Example (9): Water is used in a particular process in which the pressure is 100 psia and the temperature is 100°F. What is the total internal, saturated vapor and saturated liquid internal energies value of the water at the given pressure?

Ans.



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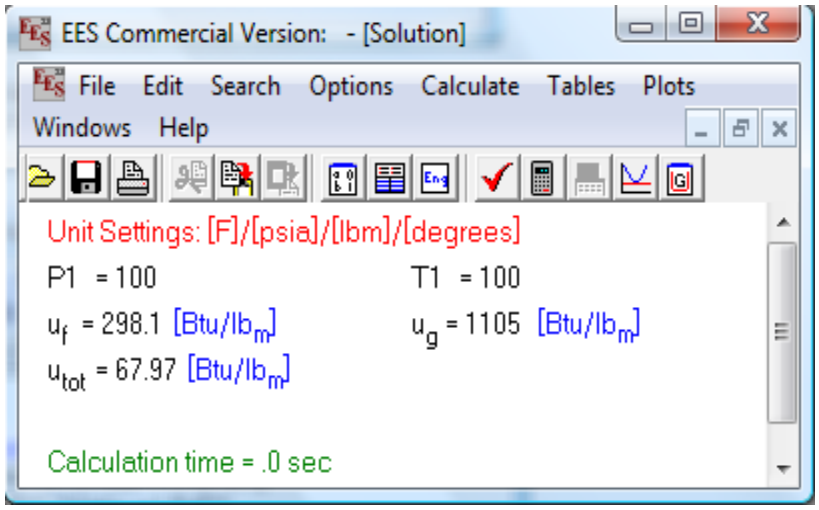
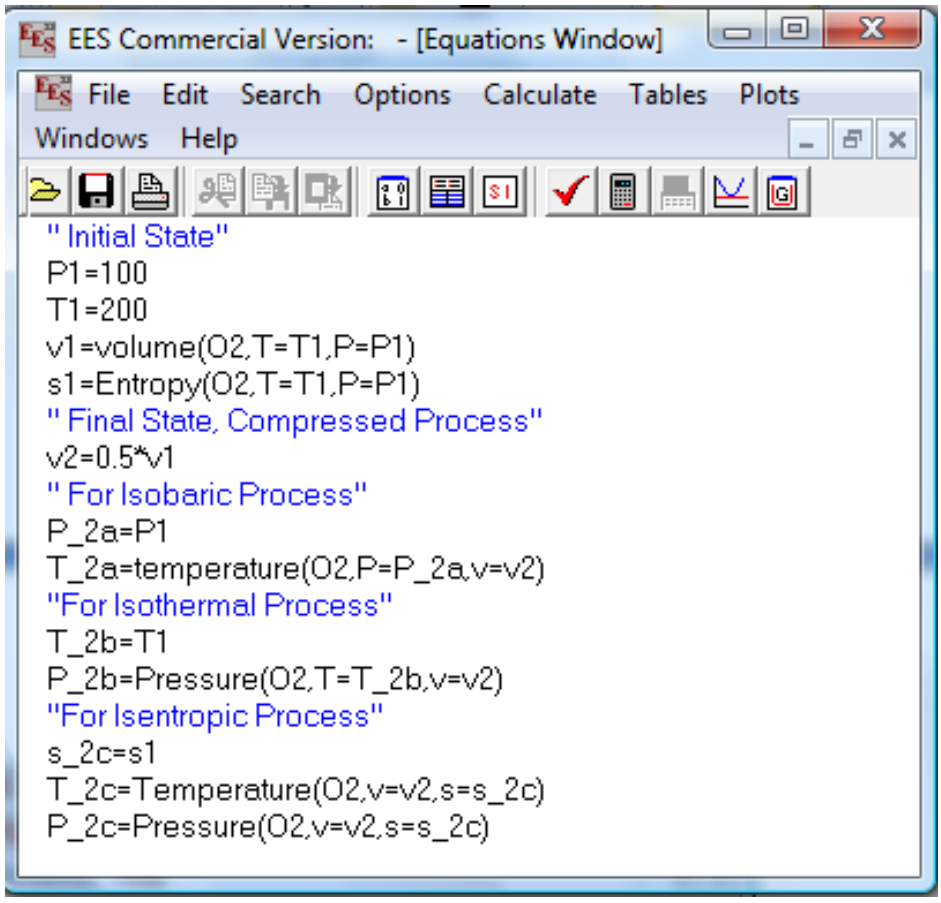



Example (10): Oxygen is trapped inside a piston cylinder at 100 kPa and 200°C is compressed to half its initial volume. Determine the final state in terms of pressure and temperature if the compression is carried out in an (a) isobaric (b) isothermal and (c) isentropic Process.

Ans.



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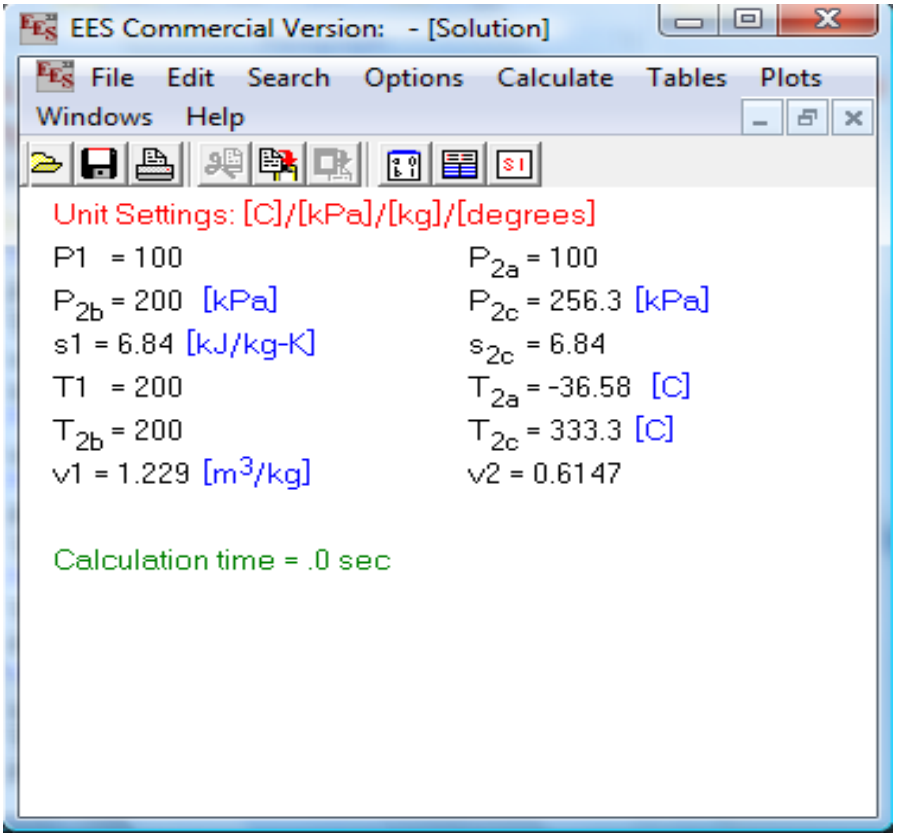
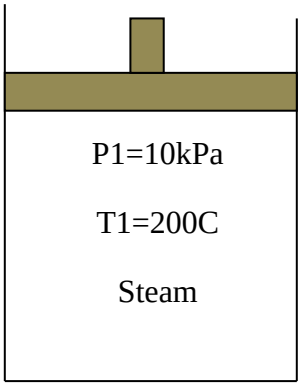



Example (11): Superheated steam is trapped inside the piston cylinder at a pressure of 10 kPa and temperature 200$^{o}$C and it expands to a final pressure of 50 kPa and temperature 300$^{o}$C. Determine (a) $\Delta u$ (b) $\Delta h$ and (c) $\Delta s$.

***The solution:***



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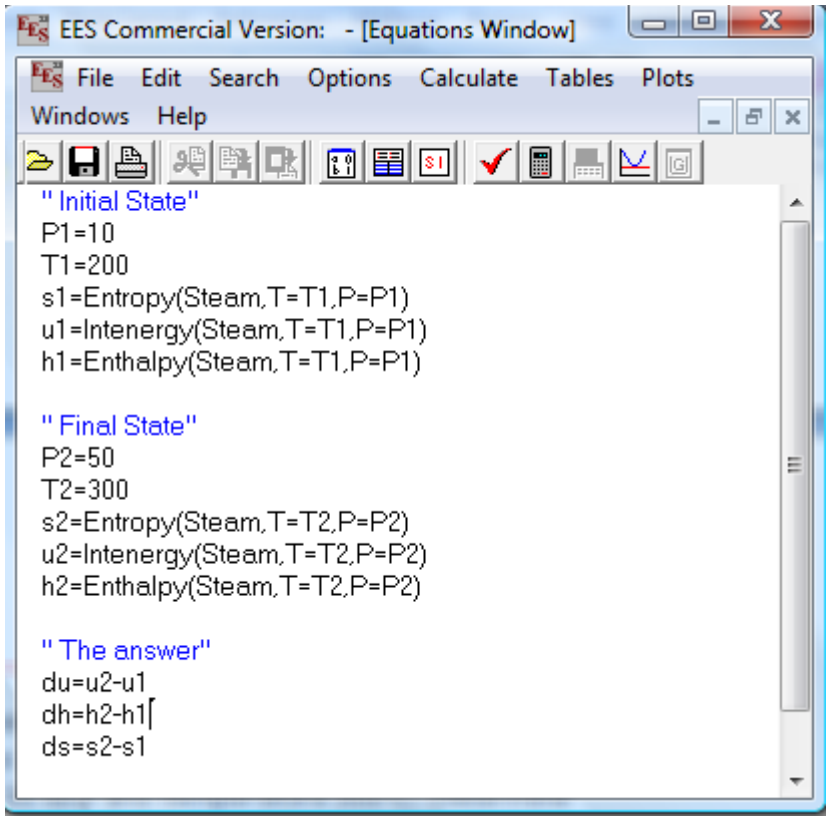


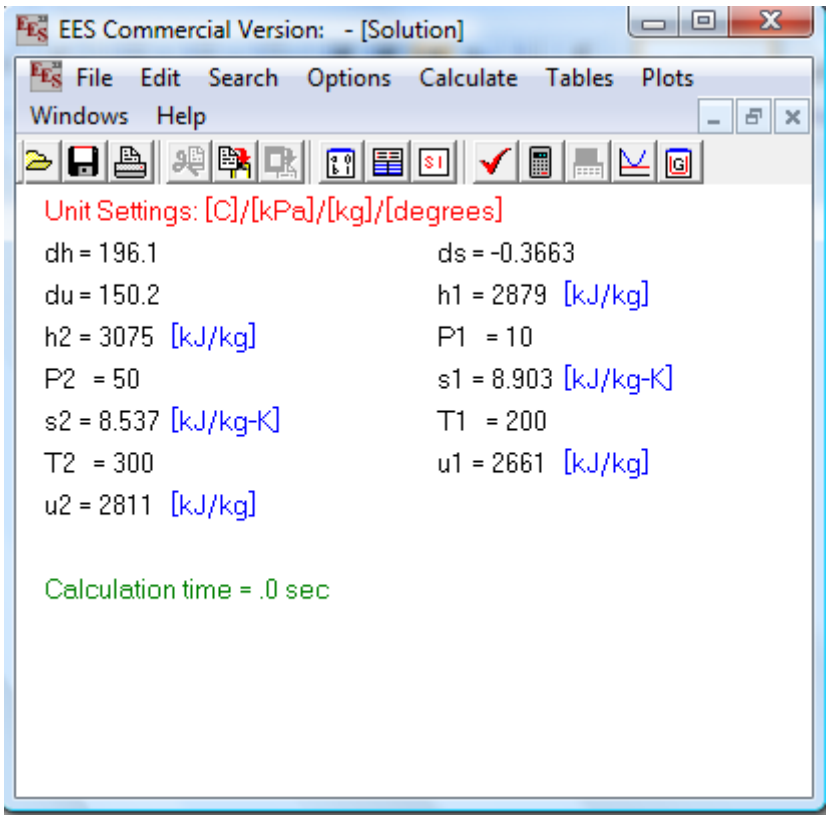




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# *Chapter#4: A Plotting and a Parametric Table*

Creating a plot is easy by using EES. The programmer should create a table of an array by using square parentheses for each elements such as P[1], h[1]…..etc . If a user creates an array table, he/she can add the type of a plot.

### *4.1. P-v and T-v diagrams*

Property Plot icon is used to show the P-v and T-v diagrams or others plot in y-x direction.

***Example (12):*** Water is inside a piston-cylinder undergoes two processes. The initial state is 1000kPa, 400 C. From state 1 and state 2, at isobaric process the state1 is cooling to saturated vapor. From state 2 to state 3 at a isochoric process the state is cooling to 150 C (state 3). On T-v and P-v diagrams, show these two processes

***The solution:***



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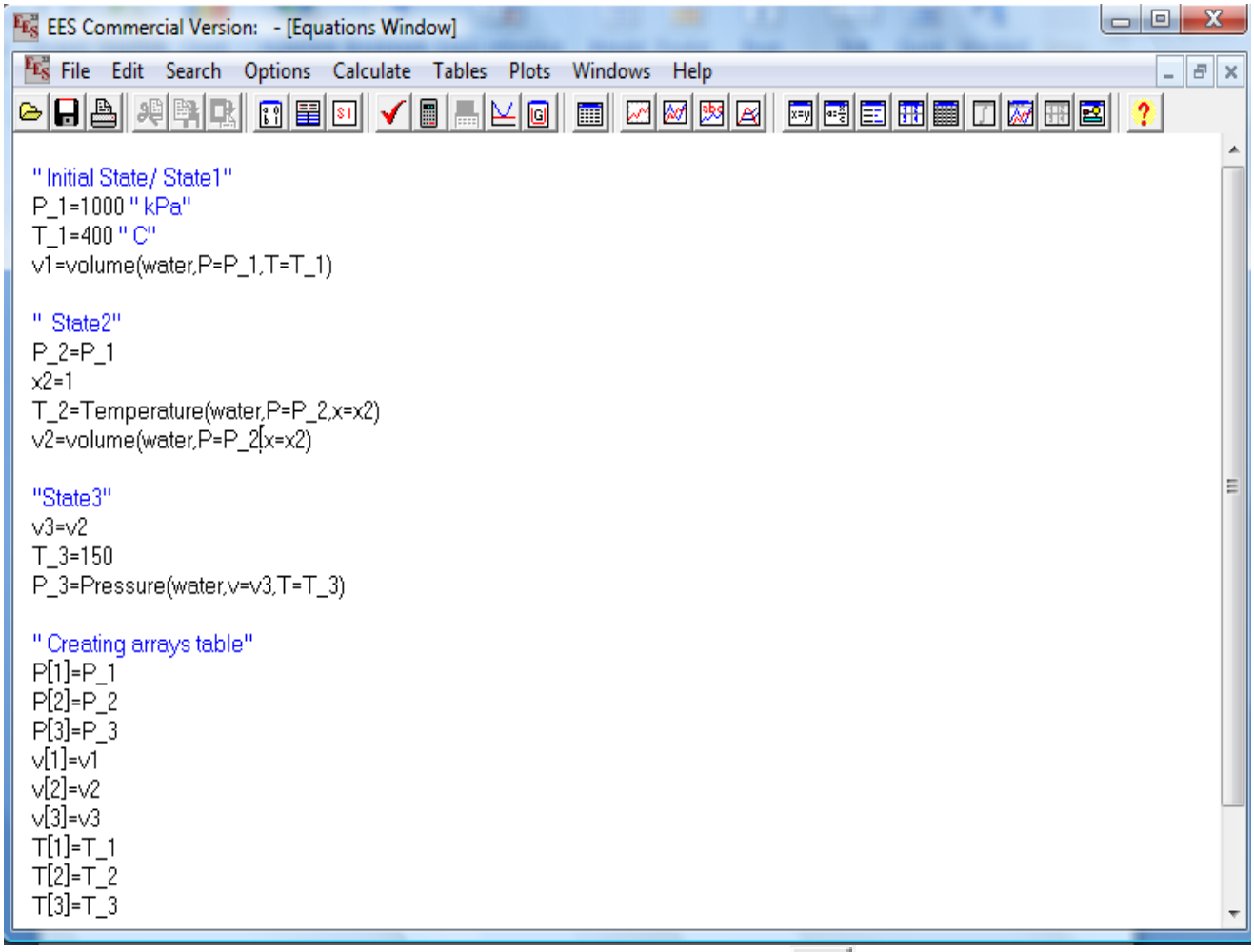
Step#1 Create a program




Step#2: Select the T-v diagram by clicking in Property plot icon 



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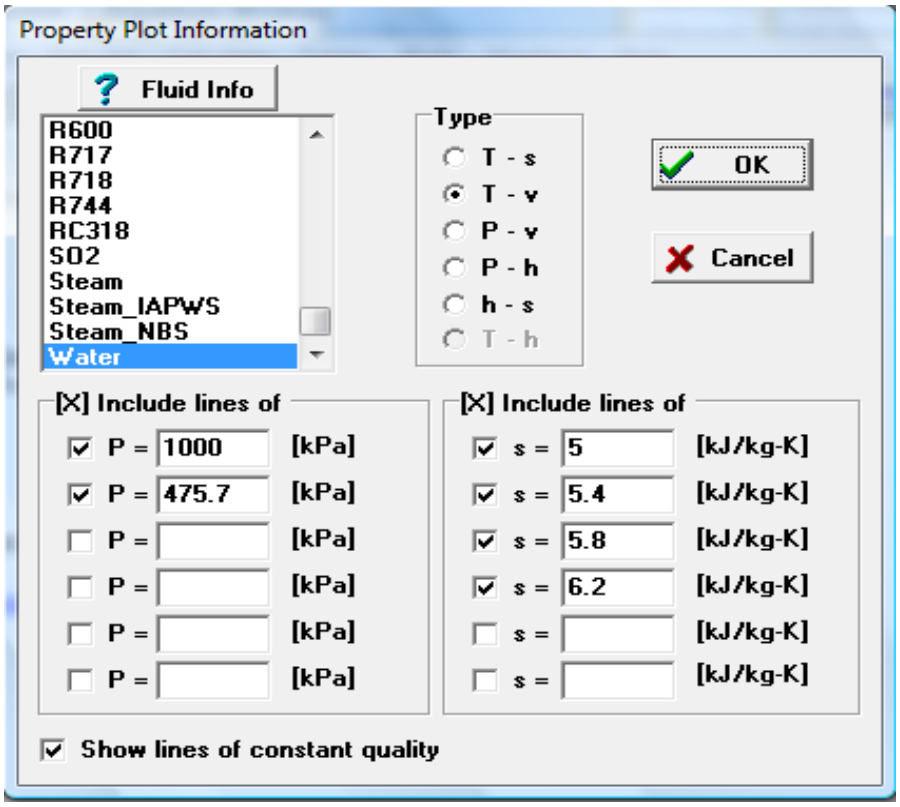
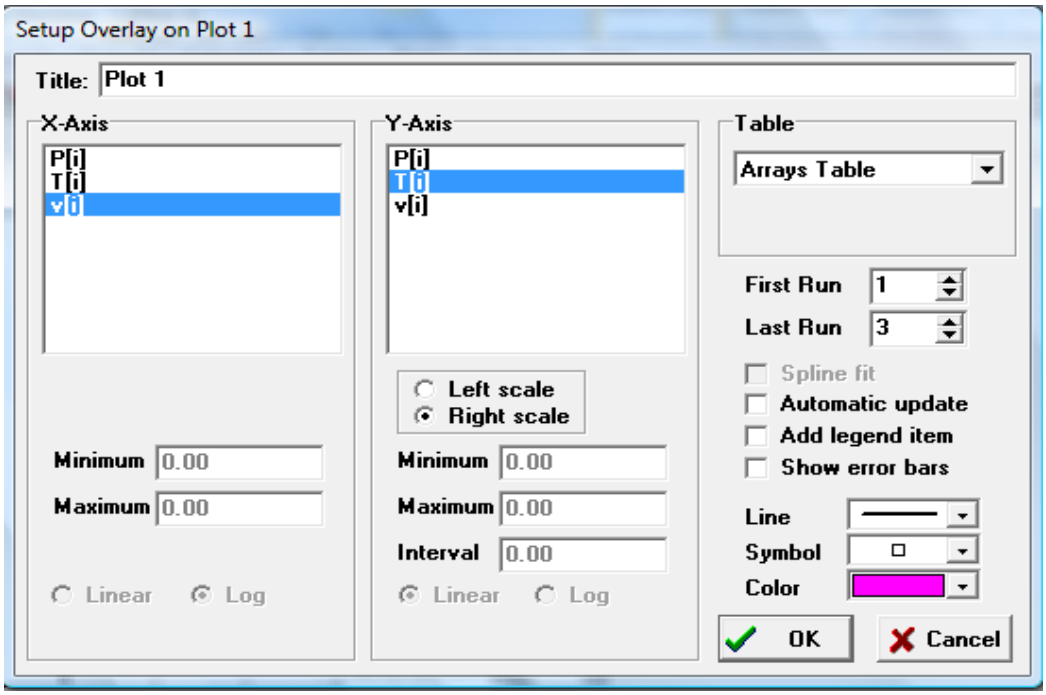



Step#3: To add the process you have to select Overlap Plot icon



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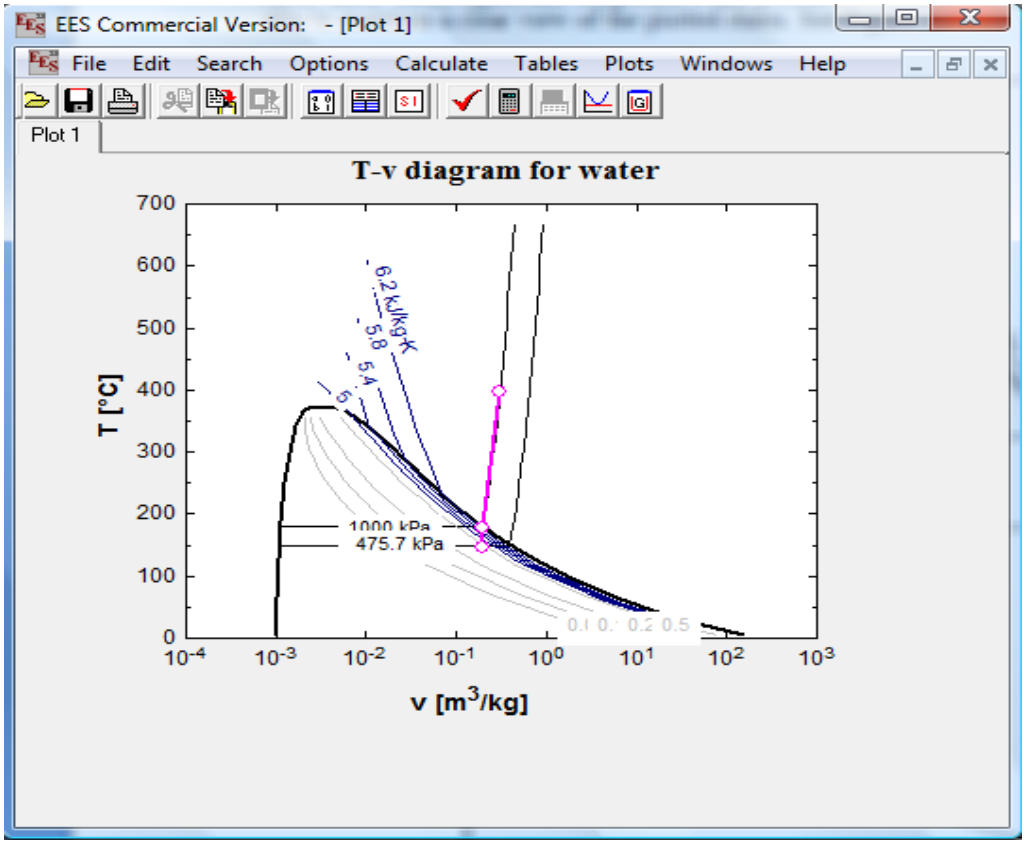


Also, follow same procedure to sketch P-v diagram.



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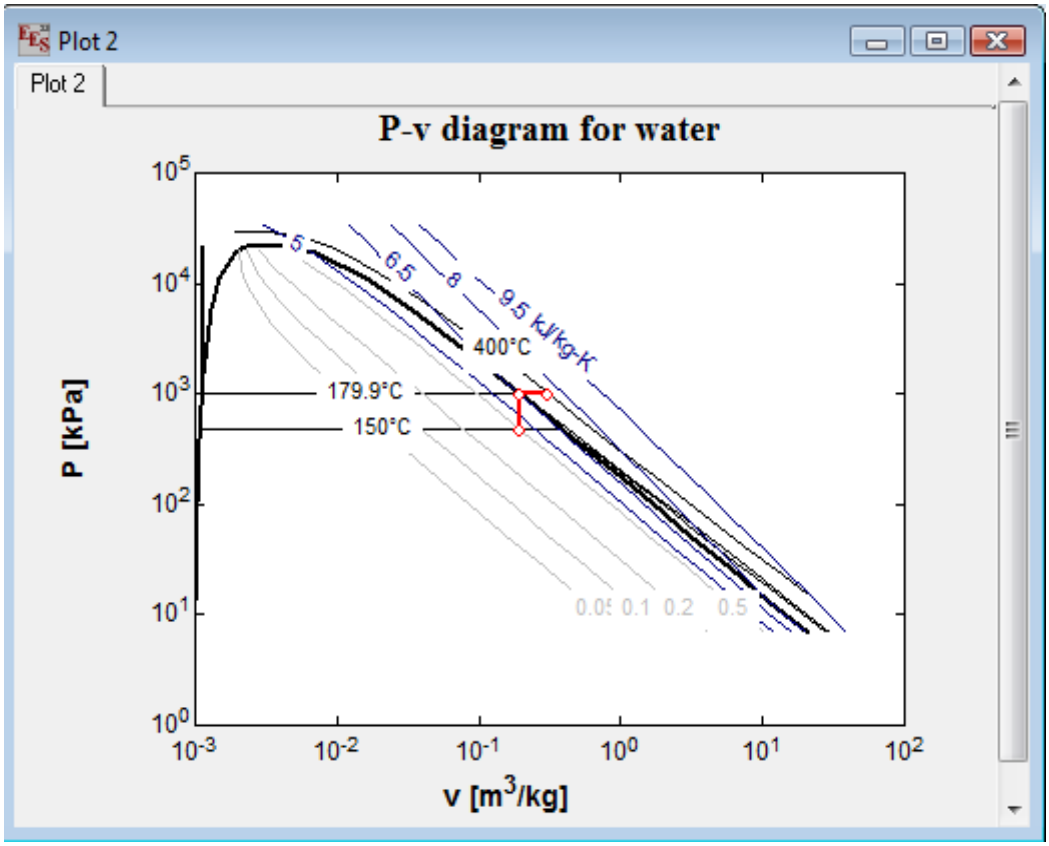


### *4.2. T-s and P-h diagrams*

Example (13): Thermodynamic An Engineering Approach, 5th edition "Consider a steam power plant that operates on a reheat Rankine cycle and has a net power output of 80 MW. Steam enters the high-pressure turbine at 10 MPa and 500°C and the low-pressure turbine at 1 MPa and 500°C. Steam leaves the condenser as a saturated liquid at a pressure of 10 kPa. The isentropic efficiency of the turbine is 80 percent, and that of the pump is 95 percent. Show the cycle on a *T-s* diagram with respect to saturation lines, and determine

(*a*) The quality (or temperature, if superheated) of the steam at the turbine exit,

(*b*) The thermal efficiency of the cycle, and



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(*c*) The mass flow rate of the steam.''

## ***Ans.***

Equations Window

```
" Reheat Actual Rankine Cycle: Efficiencey ="

" State 1: Steam Enters HPT"
P1=10000 " kPa"
T1=500 " C"
s1=Entropy(Water,P=P1,T=T1)
h1=Enthalpy(Water,P=P1,T=T1)
effT=0.80
effP=0.95
W_net=80000 " kW"

" State2: Steam reheats"
s2=s1
P2=P3
h2s=Enthalpy(water,P=P2,s=s2)
h2a=h1-effT*(h1-h2s)
s2a=Entropy(water,P=P2,h=h2a)
T2a=temperature(water,P=P2,h=h2a)
"State3: Working Fluid enters LPT"
P3=1000 "kPa"
T3=T1
h3=enthalpy(water,P=P3,T=T3)
s3=Entropy(Water,P=P3,T=T3)
" State4: Working Fluid enters the condenser"
P4=10 " kPa"
s4=s3
h4s=Enthalpy(Water,P=P4,s=s4)
h4a=h3-effT*(h3-h4s)
s4a=entropy(water,P=P4,h=h4a)
T4a=temperature(water,P=P4,h=h4a)
"State5: Working Fluid enters the Pump"
P5=P4
x5=0  " Sat. Liquid"
h5=Enthalpy(Water,P=P5,x=x5)
T5=temperature(water,P=P5,x=x5)
s5=entropy(water,P=P5,x=x5)
v5=volume(Water,P=P5,x=x5)
```

Arrays Table

| | 1 $s_i$ | 2 $T_i$ |
|---|---|---|
| [1] | 6.598 | 500 |
| [2] | 6.845 | 231.6 |
| [3] | 7.758 | 500 |
| [4] | 8.383 | 87.09 |
| [5] | 0.6491 | 45.85 |
| [6] | 0.6508 | 45.98 |
| [7] | 0.6508 | 45.98 |



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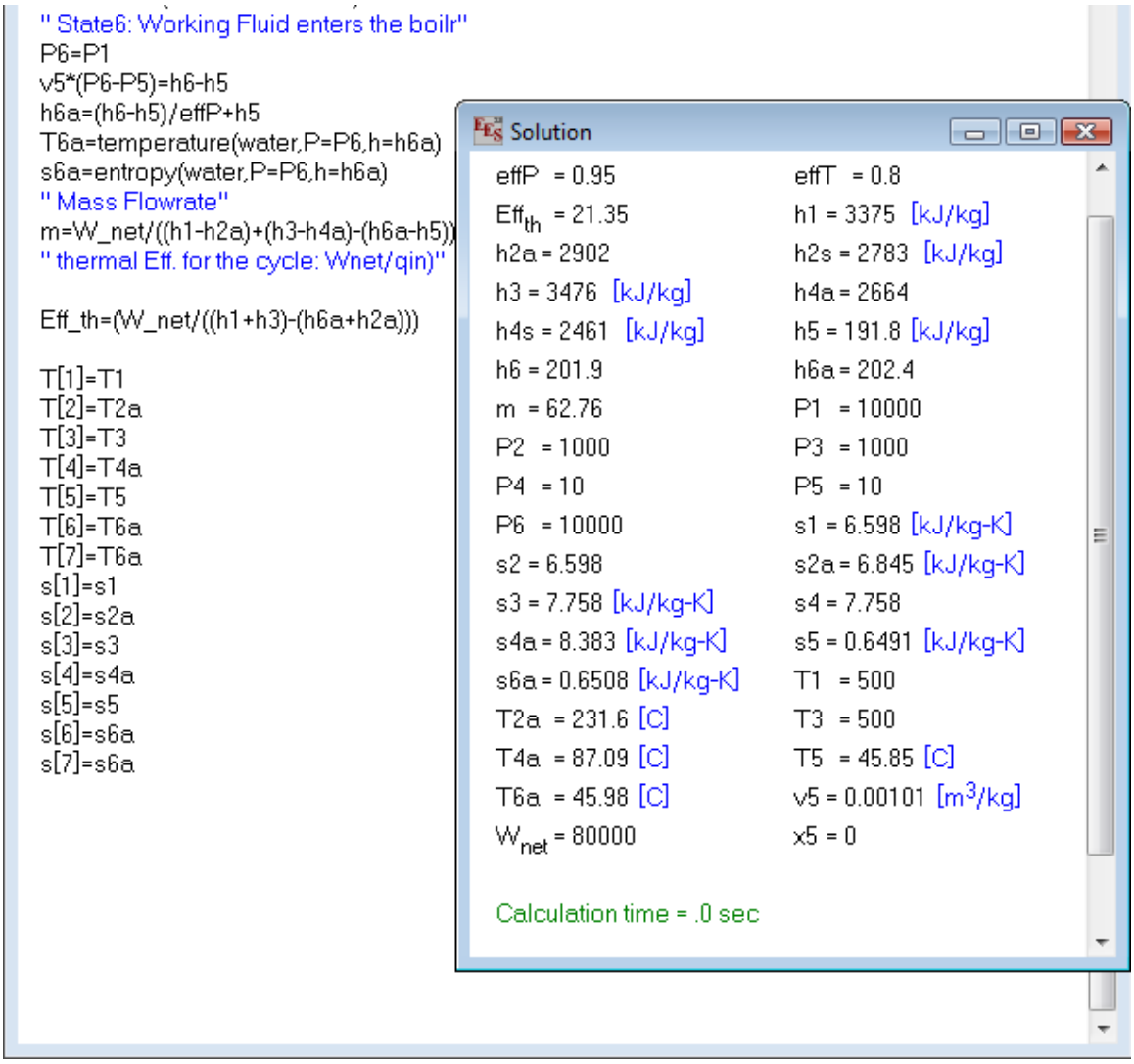


a. Superheated State, so T4a=87.09 C
b. Thermal eff. = 21.35 %
c. m= 62.76 kg/sec


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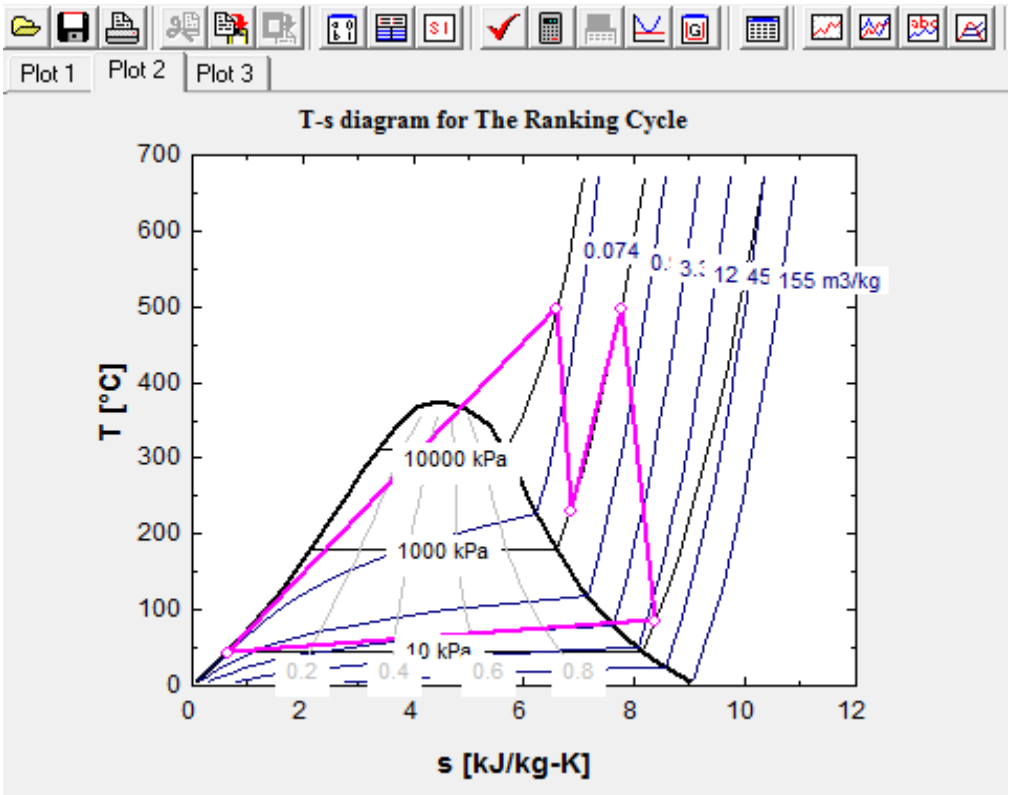


P-h diagram

We should add P-h array table is similar to T-s array table

| | 1 $P_i$ | 2 $h_i$ |
|---|---|---|
| [1] | 10000 | 3375 |
| [2] | 1000 | 2902 |
| [3] | 1000 | 3476 |
| [4] | 10 | 2664 |
| [5] | 10 | 191.8 |
| [6] | 10000 | 202.4 |
| [7] | 10000 | 3375 |



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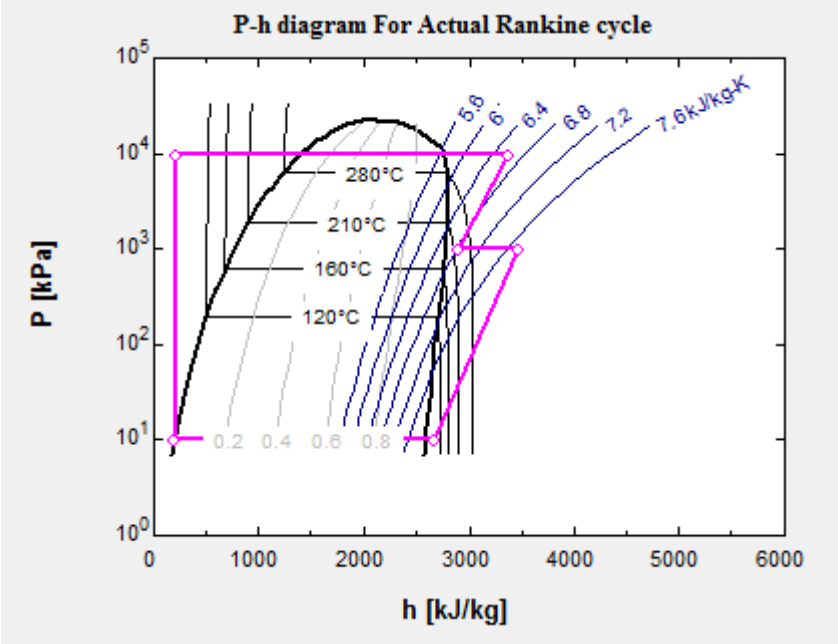


### *4.3. Creating a Parametric Table*

Creating a parametric table is a crucial part when a user needs to run more than one data. Therefore, we should learn how we create a new parametric table. A parametric table helps us to plot any type of functions

Example (14): A well - insulated V/V is used to drop steam pressure from 8 MPa, and 500C to different exist pressures. Using EES program to investigate the effect of exist pressure of steam on the exit temperature after throttling if the exits pressure varies from 6MPa to 1MPa. Plot the exit temperature of steam against exist pressure?

Ans.

Note: For exist pressure and temperature, we should set an initial value and then we delete them to reset them inside a parametric table.

Step#1: writing a program



```
T_i=500 " C"
P_i=8000 " KPa"
hi=Enthalpy(steam,P=P_i,T=T_i)
he=hi
Pe=6000 " kPa"
Te=temperature(steam,P=Pe,h=he)
```



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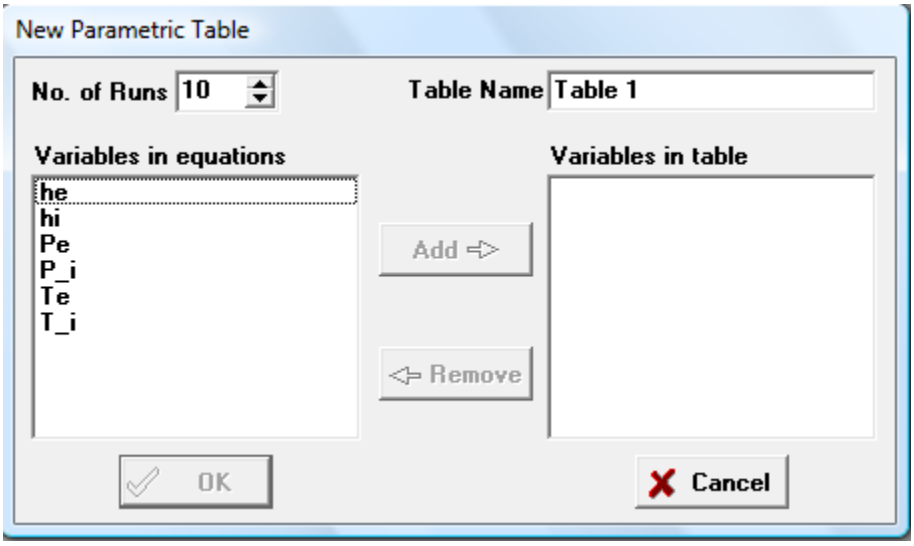
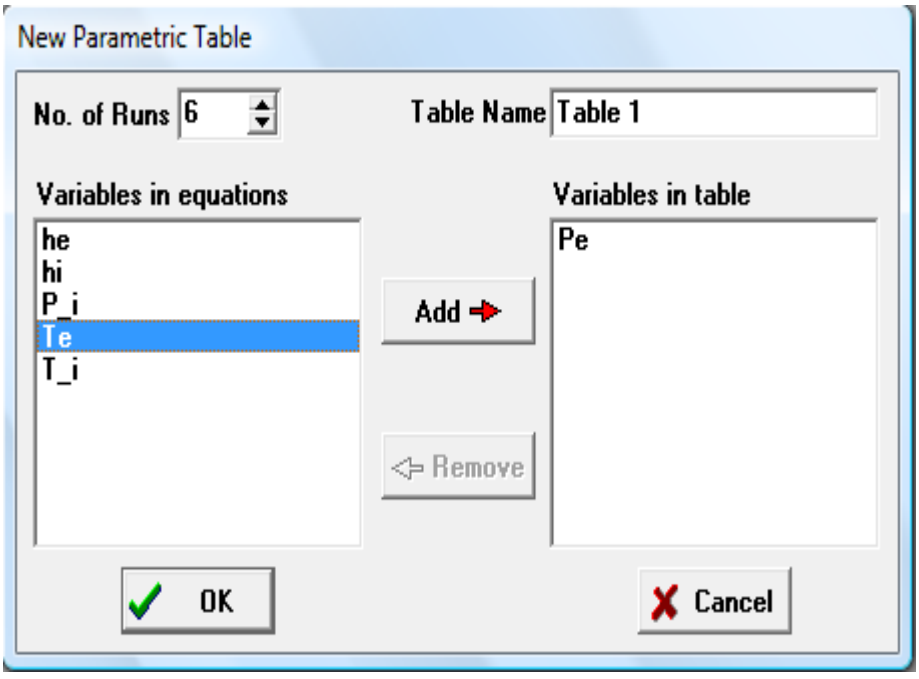
Step#2: creating a parametric table, so we should select the parametric table icon. Then we will see this window.




Step#3: add the two parameters that you need to compare or plot and select how many runs you want to do in the parametric table.




After adding all parameters, press on OK. Then the parametric table will appear as shown below.



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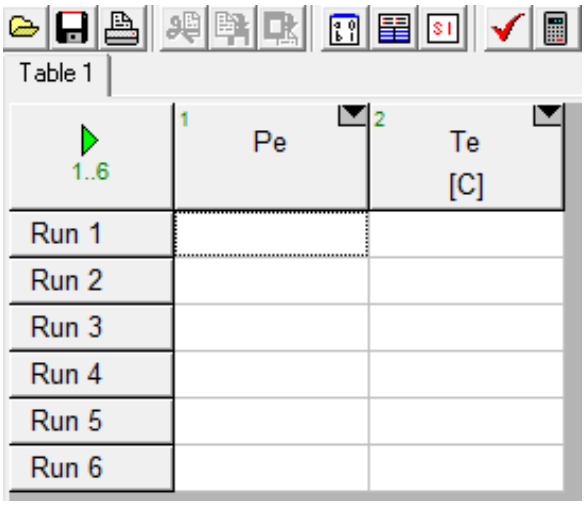
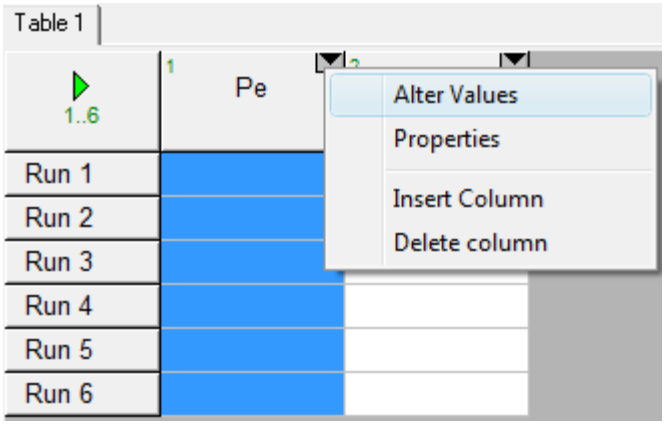
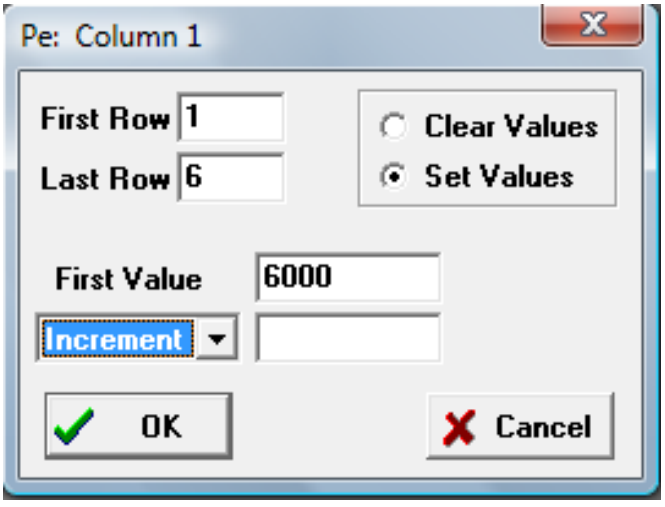



Step#4: Run the table to see the data.

Before running the data, we should select the increment value




The increment value + or – based on a given question.



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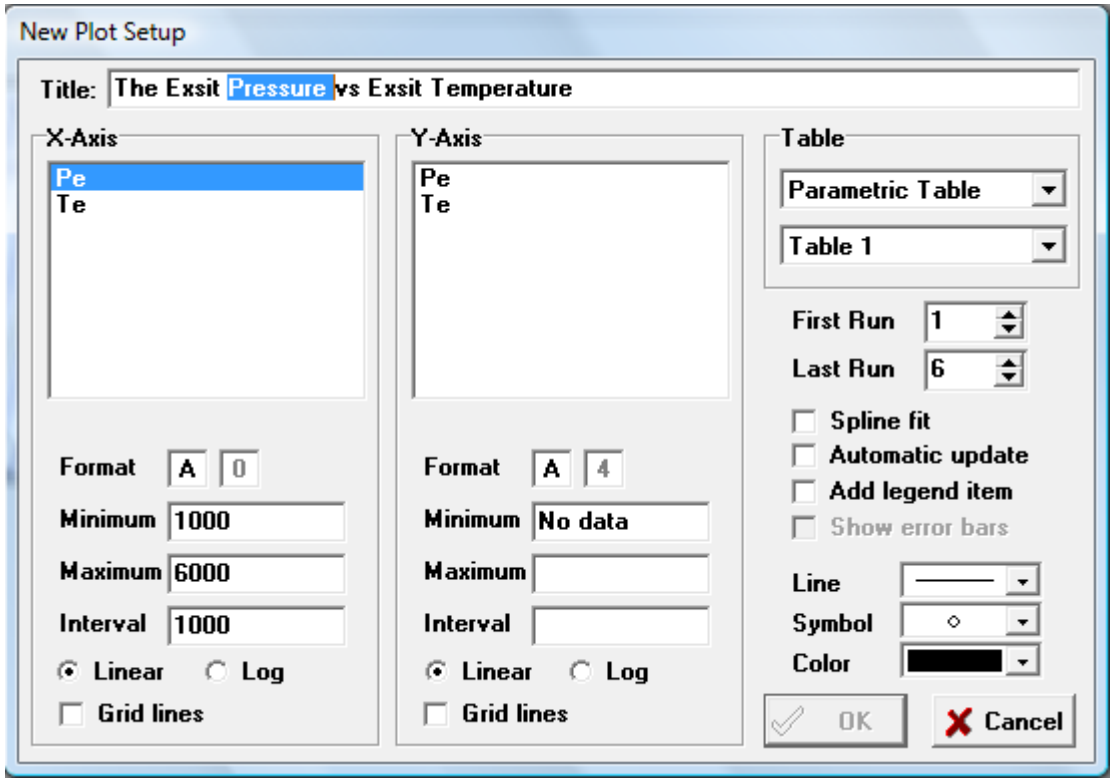
Then, we should reset the value of pressure Pe from the original program to set all its values in the parametric table.

Table 1

| 1..6 | Pe | Te [C] |
|---|---|---|
| Run 1 | 6000 | 490 |
| Run 2 | 5000 | 484.9 |
| Run 3 | 4000 | 479.6 |
| Run 4 | 3000 | 474.2 |
| Run 5 | 2000 | 468.6 |
| Run 6 | 1000 | 463 |

To plot this data, we select New Plot Plot Window Icon



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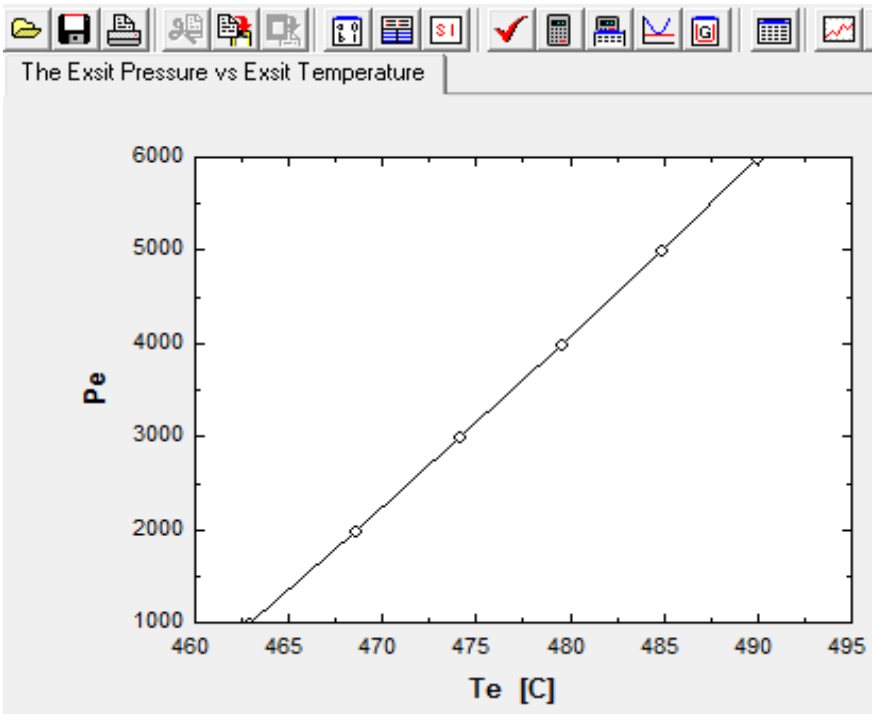


### *4.4. Plotting Mathematical Functions (x-y plot)*

By using EES program, we are able to plot any mathematical Functions. Therefore, we will use a parametric table to do that.

Example (15): Plot this function$y = x^4 + 2x^2 + 4x + 3$, when x=0 to 60 step 5?

Follow all the parametric table procedure in pervious section.



```
x=0
y=x^4+2*x^3+4*x+3
```

Then, reset the value of x by delete it when you add it in the parametric table



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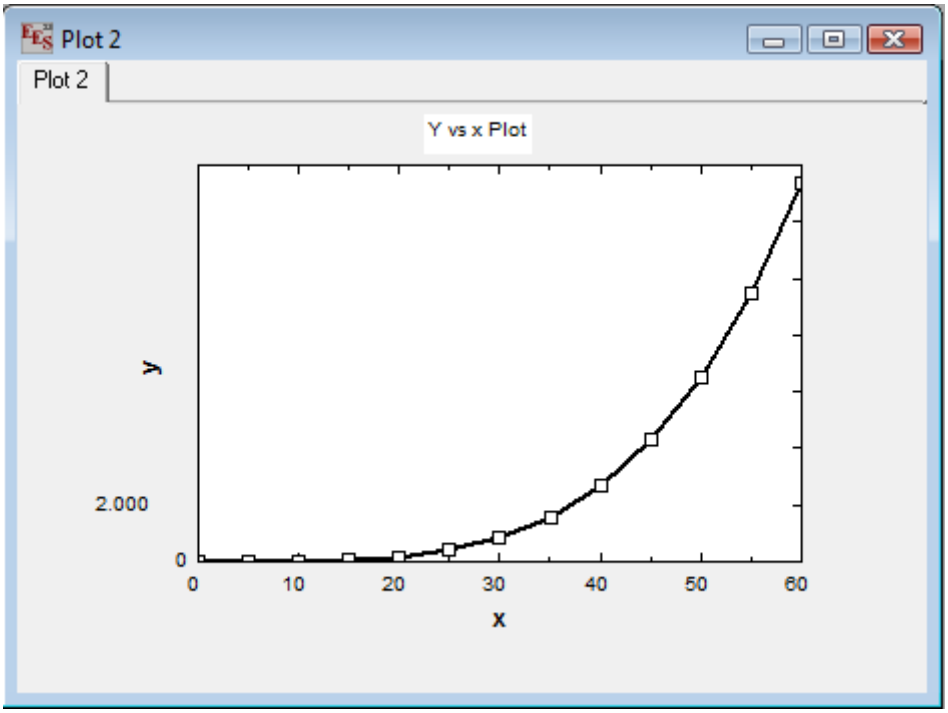
Table 1

| 1..13 | 1 x | 2 y |
|---|---|---|
| Run 1 | 0 | 3 |
| Run 2 | 5 | 898 |
| Run 3 | 10 | 12043 |
| Run 4 | 15 | 57438 |
| Run 5 | 20 | 176083 |
| Run 6 | 25 | 421978 |
| Run 7 | 30 | 864123 |
| Run 8 | 35 | 1.587E+06 |
| Run 9 | 40 | 2.688E+06 |
| Run 10 | 45 | 4.283E+06 |
| Run 11 | 50 | 6.500E+06 |
| Run 12 | 55 | 9.484E+06 |
| Run 13 | 60 | 1.339E+07 |

The plotting x-y plot





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Example (16): Plot the two functions

$y1 = x^7 + 4x^5 + 3x^3 + 8, and\ y2 = x^7 + 7x^6 + 8x + 6.$

The values of x are from 0 to 34 and increment is 2.

Ans.

Table 1

| 1..18 | 1 x | 2 y1 | 3 y2 |
|---|---|---|---|
| Run 1 | 0 | 8 | 6 |
| Run 2 | 2 | 104 | 598 |
| Run 3 | 4 | 4312 | 45094 |
| Run 4 | 6 | 47336 | 606582 |
| Run 5 | 8 | 263720 | 3.932E+06 |
| Run 6 | 10 | 1.003E+06 | 1.700E+07 |
| Run 7 | 12 | 2.991E+06 | 5.673E+07 |
| Run 8 | 14 | 7.538E+06 | 1.581E+08 |
| Run 9 | 16 | 1.679E+07 | 3.859E+08 |
| Run 10 | 18 | 3.403E+07 | 8.503E+08 |
| Run 11 | 20 | 6.402E+07 | 1.728E+09 |
| Run 12 | 22 | 1.134E+08 | 3.288E+09 |
| Run 13 | 24 | 1.911E+08 | 5.924E+09 |
| Run 14 | 26 | 3.090E+08 | 1.019E+10 |
| Run 15 | 28 | 4.820E+08 | 1.687E+10 |
| Run 16 | 30 | 7.291E+08 | 2.697E+10 |
| Run 17 | 32 | 1.074E+09 | 4.188E+10 |
| Run 18 | 34 | 1.545E+09 | 6.334E+10 |

Using New Plot window icon and then Overlap Plot icon is to plot two functions.

Refer to commands Icon Table to see the symbol of overlap plot and new window plot icons.



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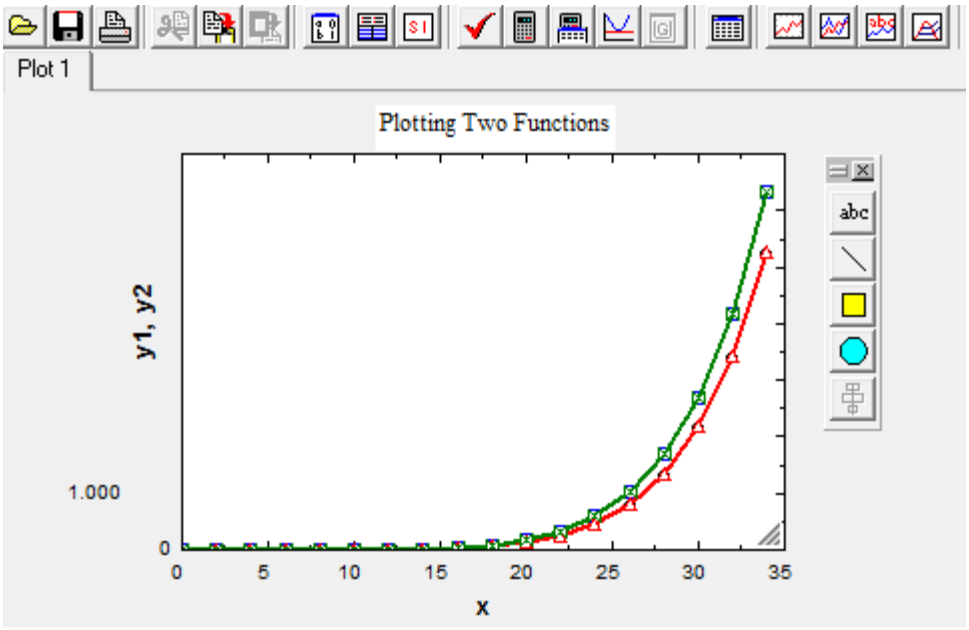
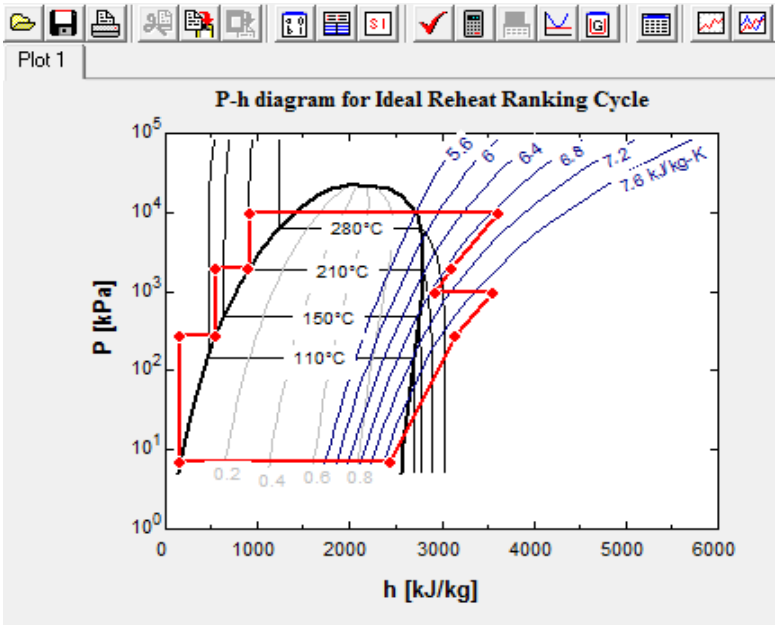



Example (17): A steam power plant operates on an ideal reheat-regenerative Rankine with one reheat and two open feed water heaters. Steam enters the high pressure turbine at 10 MPa, 600$^{o}$C and leaves the low pressure turbine at 7 kPa. The steam is extracted from the turbine at 2 MPa and 275 kPa, and it is reheated to 540$^{o}$C at a pressure of 1 MPa. Water leaves both feedwater heaters as a saturated liquid. Heat is transferred to the steam in the boiler at a rate of 6 MW. Draw a P-h diagram and determine (a) the mass flow rate of steam through the boiler, (b) the net power output and (c) the thermal efficiency of the cycle

***The solution:***



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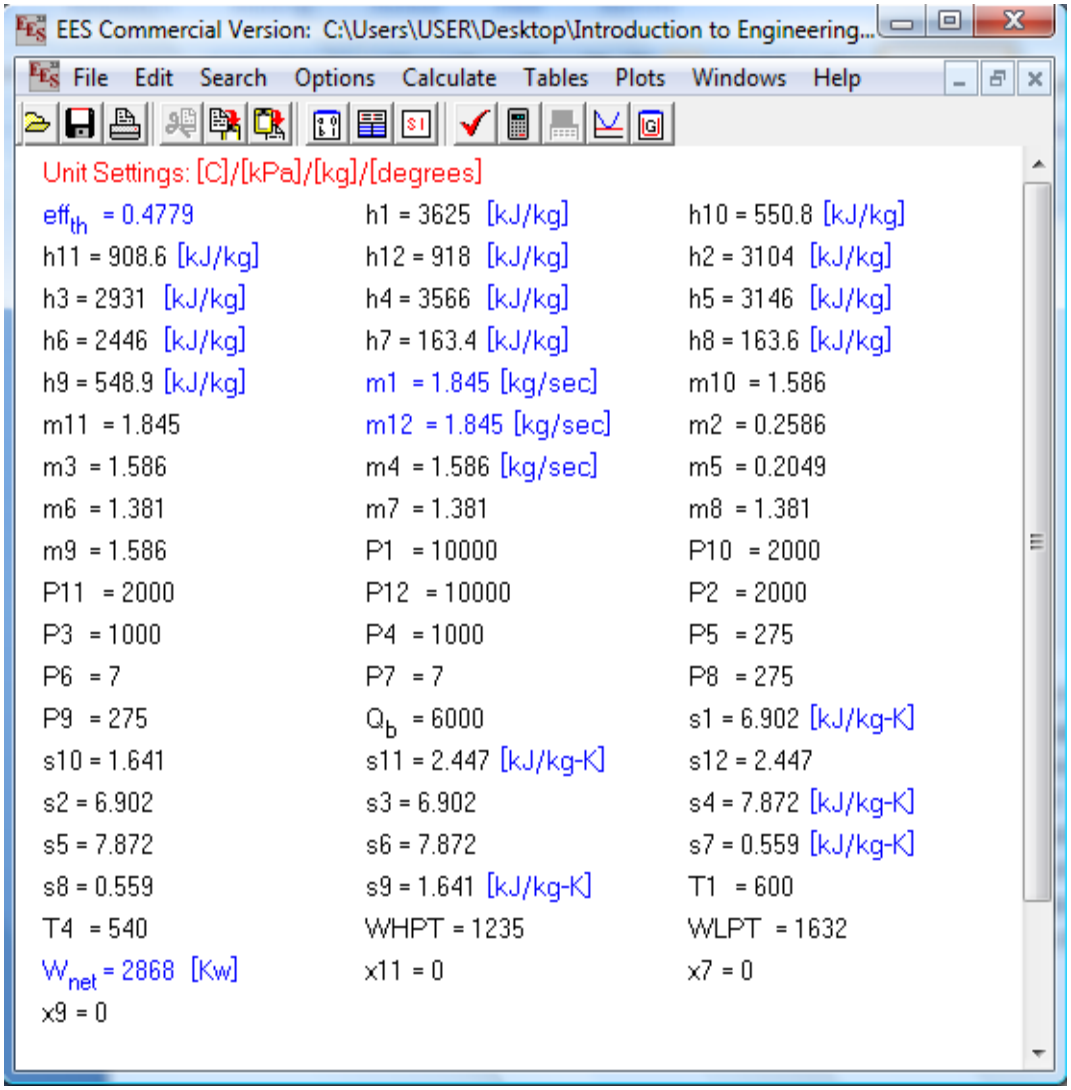
a. Thermal efficiency is 0.4779
b. The mass flow rate is 1.855 kg/sec
c. The newt output power is 2868 kW.

The program is





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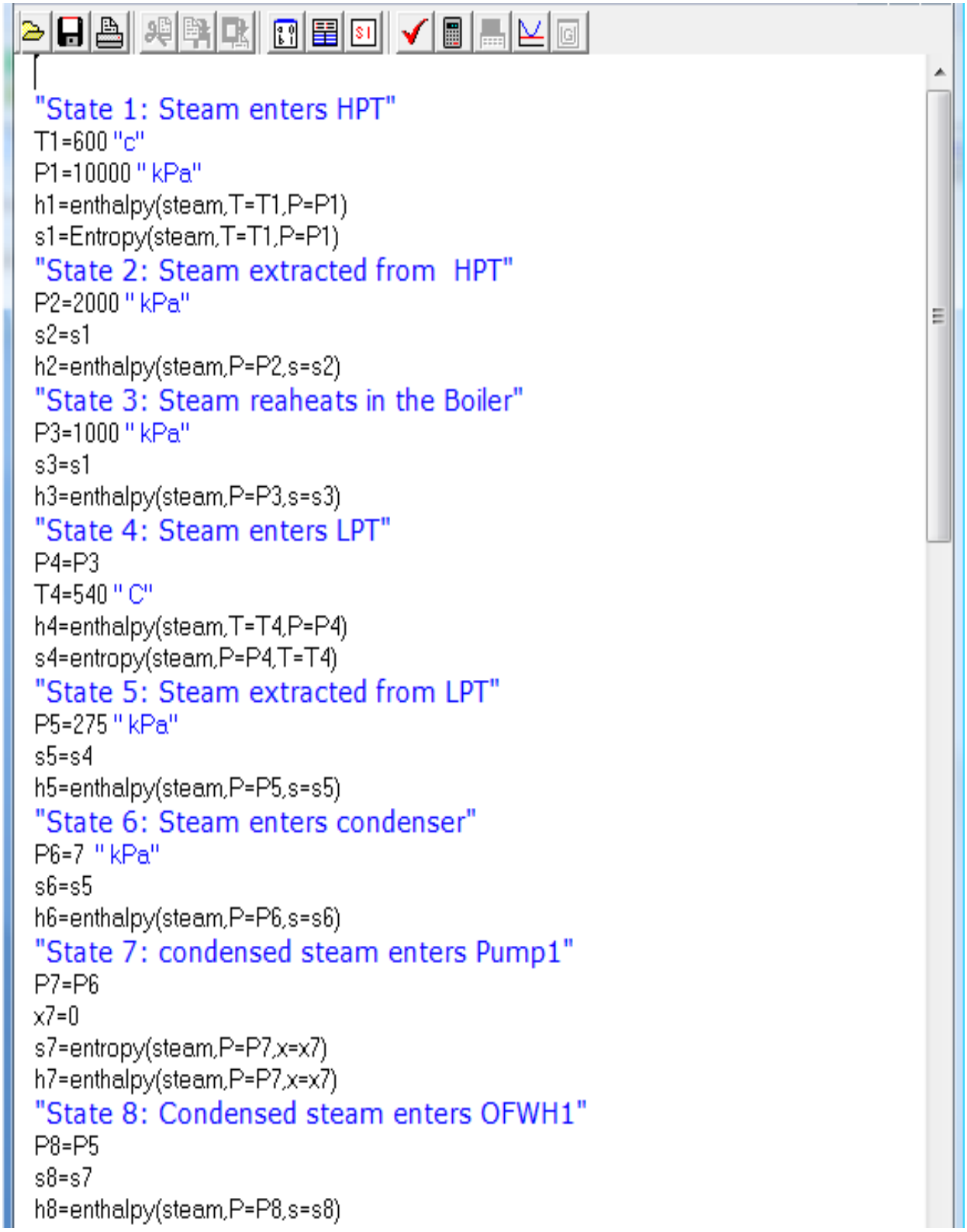

```
"State 1: Steam enters HPT"
T1=600 "c"
P1=10000 " kPa"
h1=enthalpy(steam,T=T1,P=P1)
s1=Entropy(steam,T=T1,P=P1)
"State 2: Steam extracted from  HPT"
P2=2000 " kPa"
s2=s1
h2=enthalpy(steam,P=P2,s=s2)
"State 3: Steam reaheats in the Boiler"
P3=1000 " kPa"
s3=s1
h3=enthalpy(steam,P=P3,s=s3)
"State 4: Steam enters LPT"
P4=P3
T4=540 " C"
h4=enthalpy(steam,T=T4,P=P4)
s4=entropy(steam,P=P4,T=T4)
"State 5: Steam extracted from LPT"
P5=275 " kPa"
s5=s4
h5=enthalpy(steam,P=P5,s=s5)
"State 6: Steam enters condenser"
P6=7  " kPa"
s6=s5
h6=enthalpy(steam,P=P6,s=s6)
"State 7: condensed steam enters Pump1"
P7=P6
x7=0
s7=entropy(steam,P=P7,x=x7)
h7=enthalpy(steam,P=P7,x=x7)
"State 8: Condensed steam enters OFWH1"
P8=P5
s8=s7
h8=enthalpy(steam,P=P8,s=s8)
```



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```
"State 9: Condensed steam enters Pump2"
x9=0
P9=P5
s9=entropy(steam,P=P9,x=x9)
h9=enthalpy(steam,P=P9,x=x9)
"State 10: condensed steam enters OFWH2"
s10=s9
P10=P2
h10=enthalpy(steam,P=P10,s=s10)
"State 11: condensed steam enters Pump3"
x11=0
P11=P2
h11=enthalpy(steam,P=P11,x=x11)
s11=entropy(steam,P=P11,x=x11)
"State 12: condensed steam enters boiler"
s12=s11
P12=P1
h12=enthalpy(steam,P=P12,s=s12)
" Mass Flowrate"
"Mass and Energy Balance on the bolier"
Q_b=6000 " kW"
m4=m3
m1*h12+Q_b+m3*h3=m1*h1+m4*h4
" Mass Balance and Energy Balance on OFWH2"
m2=m1-m3
m10=m9
m9=m8+m5
m4=m5+m6
m8=m7
m11=m2+m10
m12=m11
m1=m12
m10*h10+h2*m2=m11*h11
"Energy and Mass balance on OFWH#1"
m5*h5+m8*h8=m9*h9
" The net Output Power"
WHPT+m2*h2+m3*h3=m1*h1
```



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```
WLPT+m5*h5+m6*h6=m4*h4
W_net=WHPT+WLPT
"The thermal efficiency of the cycle"
eff_th=W_net/Q_b

P[1]=P1
P[2]=P2
P[3]=P3
P[4]=P4
P[5]=P5
P[6]=P6
P[7]=P7
P[8]=P8
P[9]=P9
P[10]=P10
P[11]=P11
P[12]=P12
P[13]=P1
h[1]=h1
h[2]=h2
h[3]=h3
h[4]=h4
h[5]=h5
h[6]=h6
h[7]=h7
h[8]=h8
h[9]=h9
h[10]=h10
h[11]=h11
h[12]=h12
h[13]=h1
```

| | 1 $h_i$ | 2 $P_i$ |
|---|---|---|
| [1] | 3625 | 10000 |
| [2] | 3104 | 2000 |
| [3] | 2931 | 1000 |
| [4] | 3566 | 1000 |
| [5] | 3146 | 275 |
| [6] | 2446 | 7 |
| [7] | 163.4 | 7 |
| [8] | 163.6 | 275 |
| [9] | 548.9 | 275 |
| [10] | 550.8 | 2000 |
| [11] | 908.6 | 2000 |
| [12] | 918 | 10000 |
| [13] | 3625 | 10000 |


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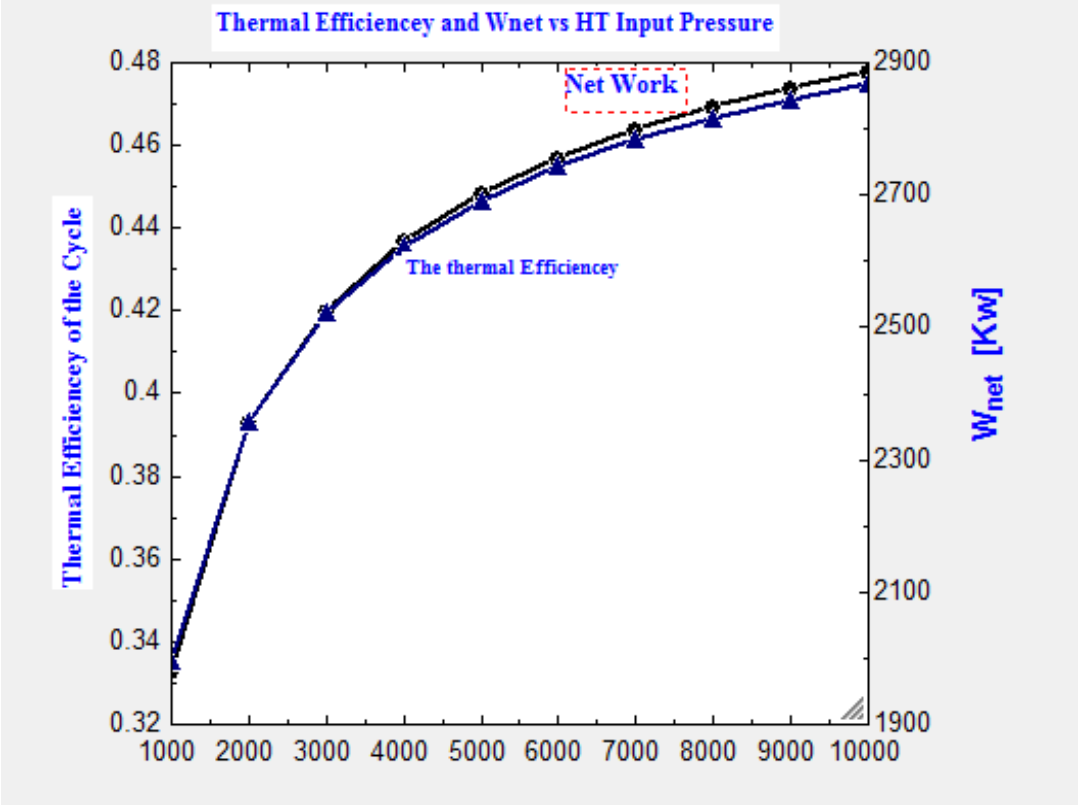


Plotting two functions or more and showed in y-left and right axes are important method if the two quantities have different scale. By using EES, it is easy if you follow these steps.

Step#1: Create a parametric table for two or more parameters.

Step#2: Select the New plot and then the overlap plot for the others.

Step#4: Select the right or left y-axis

Step#5: Press Ok for each plotting individually.

Example (18): A steam power plant operates on the reheat-regenerative Rankine cycle with a closed feed water heater. Steam enters the turbine at 12 MPa, 500oC at a rate of 25 kg/s and is condensed in the condenser at a pressure of 20 kPa. Steam is reheated at 5 MPa to 500$^{o}$C. Steam at a rate of 5 kg/s is extracted from the low pressure turbine at 1.2 MPa, and is completely condensed in the closed feed water heater, and pumped to 12 MPa before it mixes with the feed water at the same pressure. Assuming an isentropic efficiency of 88% for both the turbine and the pump, Plot the newt power, power of low pump and high pump, thermal efficiency of the cycle vs the inlet pressure of the high turbine, determine (a) the temperature at the inlet of the closed feed water heater, (b) the thermal efficiency of the cycle and (c) the net power output.



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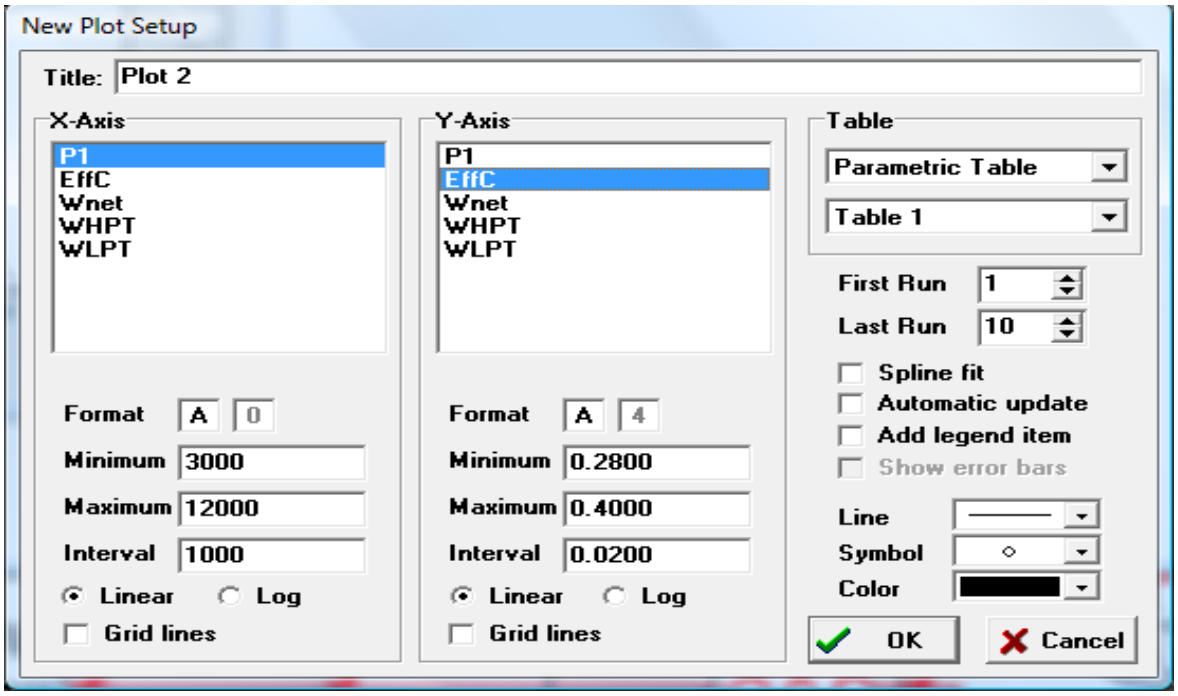
***The solution:***

Parametric Table

Table 1

| 1..10 | P1 | EffC | Wnet | WHPT | WLPT |
|---|---|---|---|---|---|
| Run 1 | 12000 | 0.3831 | 27119 | 5636 | 21828 |
| Run 2 | 11000 | 0.3793 | 26685 | 5173 | 21828 |
| Run 3 | 10000 | 0.3748 | 26180 | 4639 | 21828 |
| Run 4 | 9000 | 0.3694 | 25586 | 4016 | 21828 |
| Run 5 | 8000 | 0.363 | 24882 | 3282 | 21828 |
| Run 6 | 7000 | 0.355 | 24035 | 2405 | 21828 |
| Run 7 | 6000 | 0.3449 | 22996 | 1337 | 21828 |
| Run 8 | 5000 | 0.3318 | 21689 | 2.776E-15 | 21828 |
| Run 9 | 4000 | 0.3139 | 19980 | -1739 | 21828 |
| Run 10 | 3000 | 0.2873 | 17608 | -4140 | 21828 |

For efficiency



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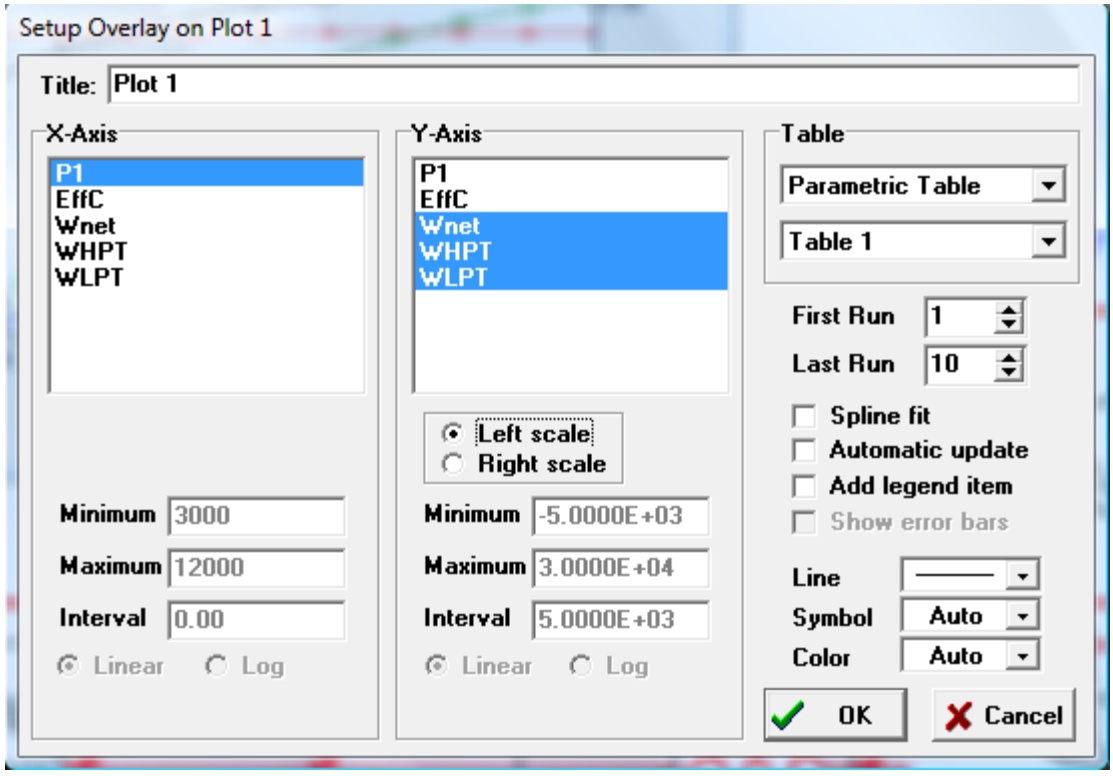
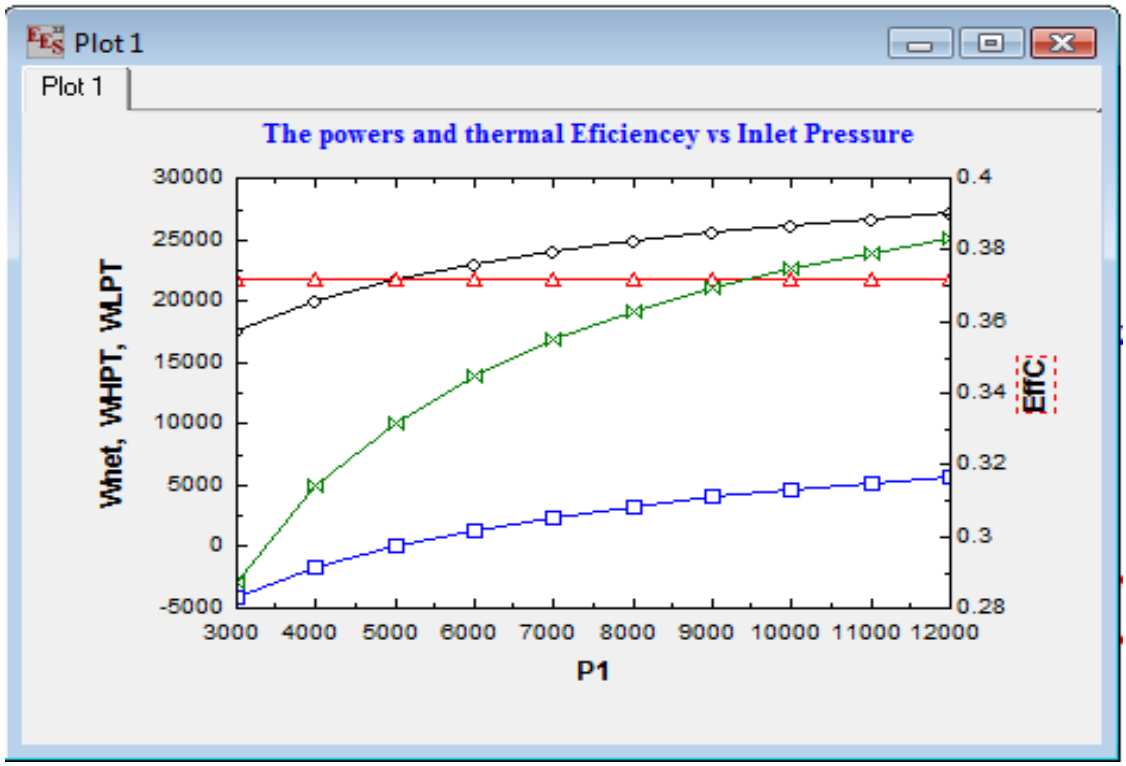
, and then overlap plot for each individually and each time press ok. Select the  Y-axis scale.



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```
" Condesner "
P7=20 " KPa"
S7=S4
h7=Enthalpy(R$,P=P7,S=S7)
h8=h4-(h4-h7)*effT
P9=P7
m9=m8
" Pump I"
x9=0
h9=enthalpy(R$,P=P9,x=x9)
s9=entropy(R$,P=P9,x=x9)
s10=s9
" EffP=(h10-h9)/(h11-h9)"
P10=P1
P11=P1
h10=Enthalpy(R$,P=P10,S=S10)
EffP=0.88
h11=((h10-h9)/EffP)+h9
m10=m9
m11=m9
m12=m11
"Closed FWH"
P13=P5
X13=0
h13=Enthalpy(R$,P=P13,X=X13)
S13=Entropy(R$,P=P13,X=X13)
S14=S13
P14=P1
" Pump II"
h14=Enthalpy(R$,P=P14,S=S14)
h15=((h14-h13)/effP)+h13
m13=m5
m14=m13
```



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```
m15=m13
m16=m12+m14
" Energy Blance on PumpI&II"
WPI=m9*(h11-h9)
WPII=m13*(h15-h13)
" Energy Balance on Condenser"
Qc=m8*(h8-h9)
" Energy Balance on CFWH"
m6*h6+m11*h11=m13*h13+m12*h12
"Energy Balance on Mixing"
m12*h12+m15*h15=m16*h16
" Energy Balance on Boiler"
m3*h3+m16*h16+QB=m1*h1+m4*h4
" Energy Balance on Turbine  HPT and LPT"
m1*h1=m3*h3+WHPT
WLPT+m8*h8+m6*h6=m4*h4
" Thermal Efficiencey of cycle"
Wnet=(WHPT+WLPT)-(WPI+WPII)
EffC=Wnet/QB
T6= Temperature(R$,h=h6,P=P6)
```



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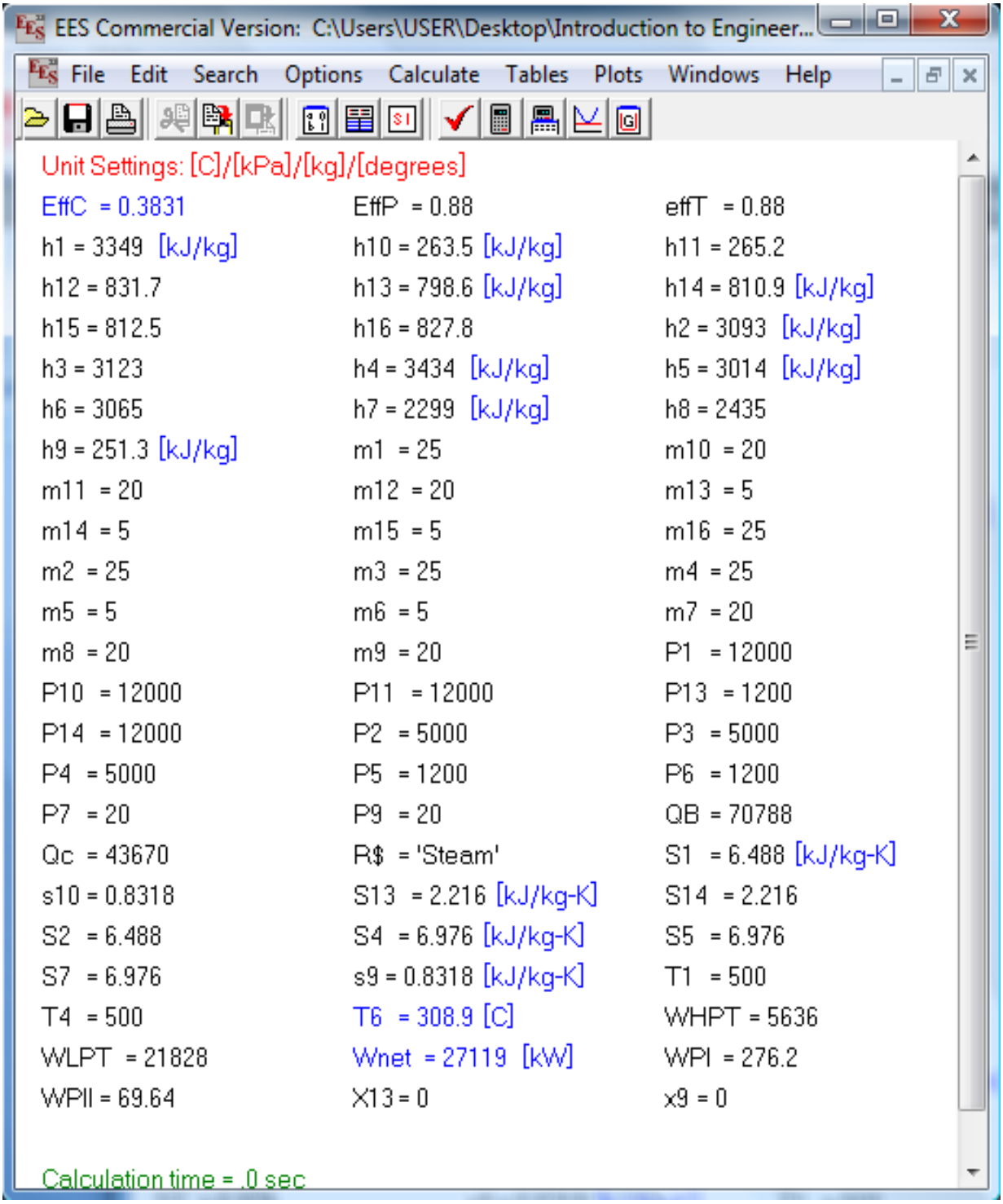




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***Example (19): [Otto Cycle]*** Using EES to evaluate the effects of the compression ratios on the net work output and the thermal efficiency of the Otto cycle for a max. cycle temperature of 2000 K. Take the working fluid to be air that 100 kPa and 300 K at the beginning of the compression process and assume variables specific heat for r varies from 6 to 15 with an increment of 1. Plot your results against the compression ratios.

Ans.

Equations Window

```
" Inlet Conditions"
T1=300  " K"
P1=100 " kPa"
K=1.4 " Specific Heat Ratio for air"
Cp= SPECHEAT(Air,T=T1)
Cv=Cp/k
T2=T1*(r)^(k-1)  " K"
T3= 2000 " Max. Tmperature in K"
T_avr=(T3+T2)/2
Cp_avr=SPECHEAT(AIR,T=T_avr)
Cv_avr=Cp_avr/k
q_in=Cv_avr*(T3-T2)
eff_otto=1-(1/(r^(k-1)))  " Otto Cycle Efficiencey"
W_net=q_in*eff_otto    " Output Work"
```

Parametric Table

Table 1

| 1..10 | 1 r | 2 $eff_{otto}$ | 3 $W_{net}$ |
|---|---|---|---|
| Run 1 | 6 | 0.5116 | 601.6 |
| Run 2 | 7 | 0.5408 | 619.3 |
| Run 3 | 8 | 0.5647 | 630.6 |
| Run 4 | 9 | 0.5848 | 637.5 |
| Run 5 | 10 | 0.6019 | 641.2 |
| Run 6 | 11 | 0.6168 | 642.5 |
| Run 7 | 12 | 0.6299 | 642.1 |
| Run 8 | 13 | 0.6416 | 640.3 |
| Run 9 | 14 | 0.652 | 637.4 |
| Run 10 | 15 | 0.6615 | 633.6 |



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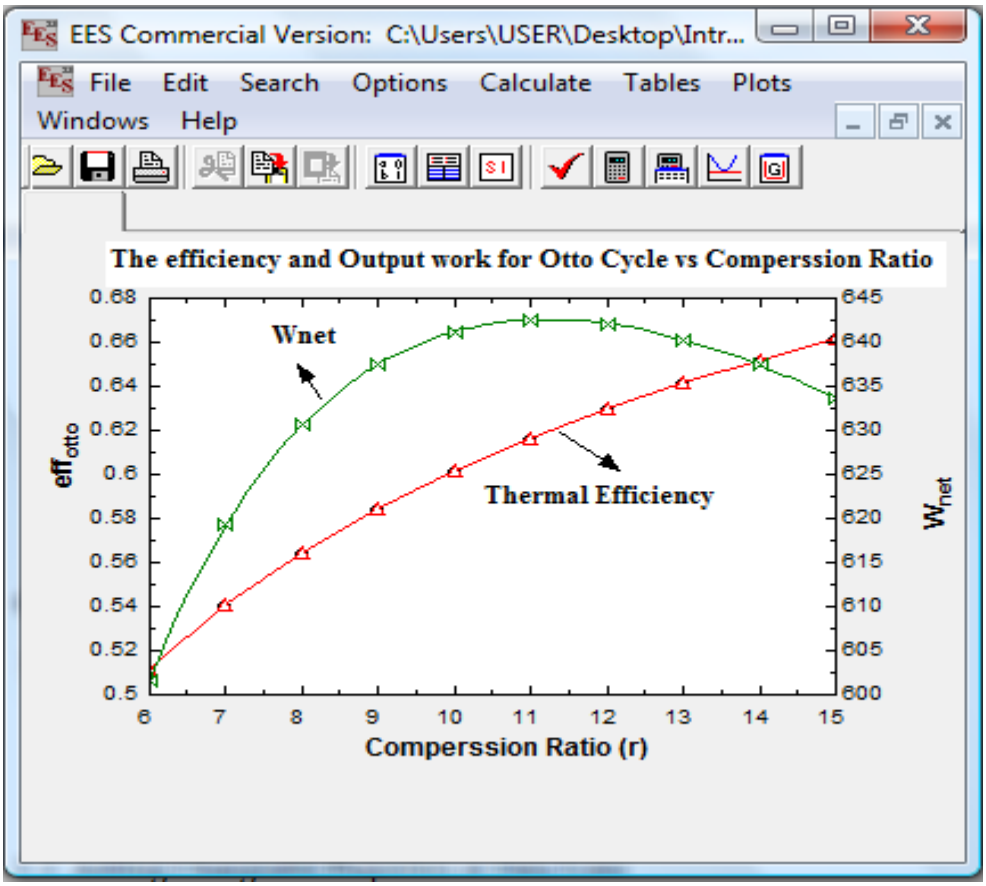


***Chapter#5: Drawing of Layouts and Adding Properties***

Sketch out a diagram is easy by using EES program. By diagram window command will be able to do that.



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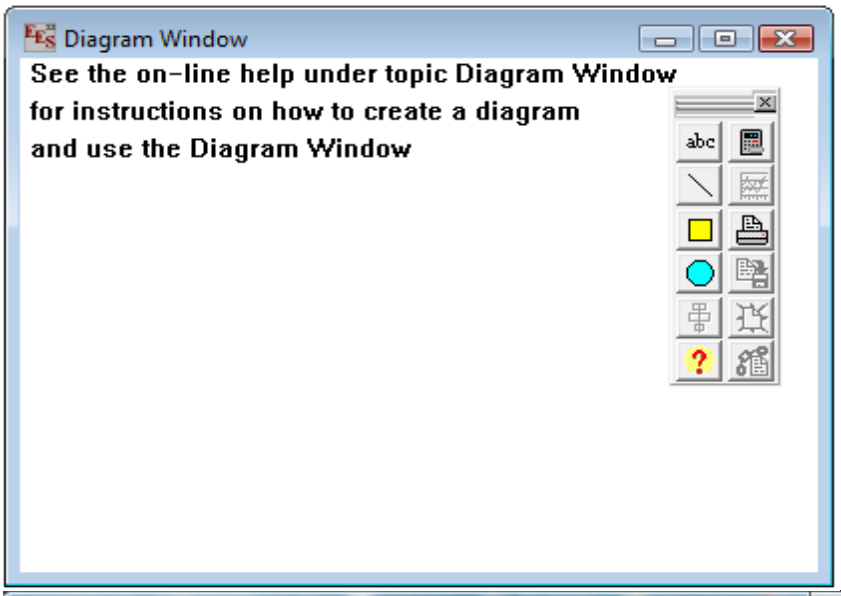
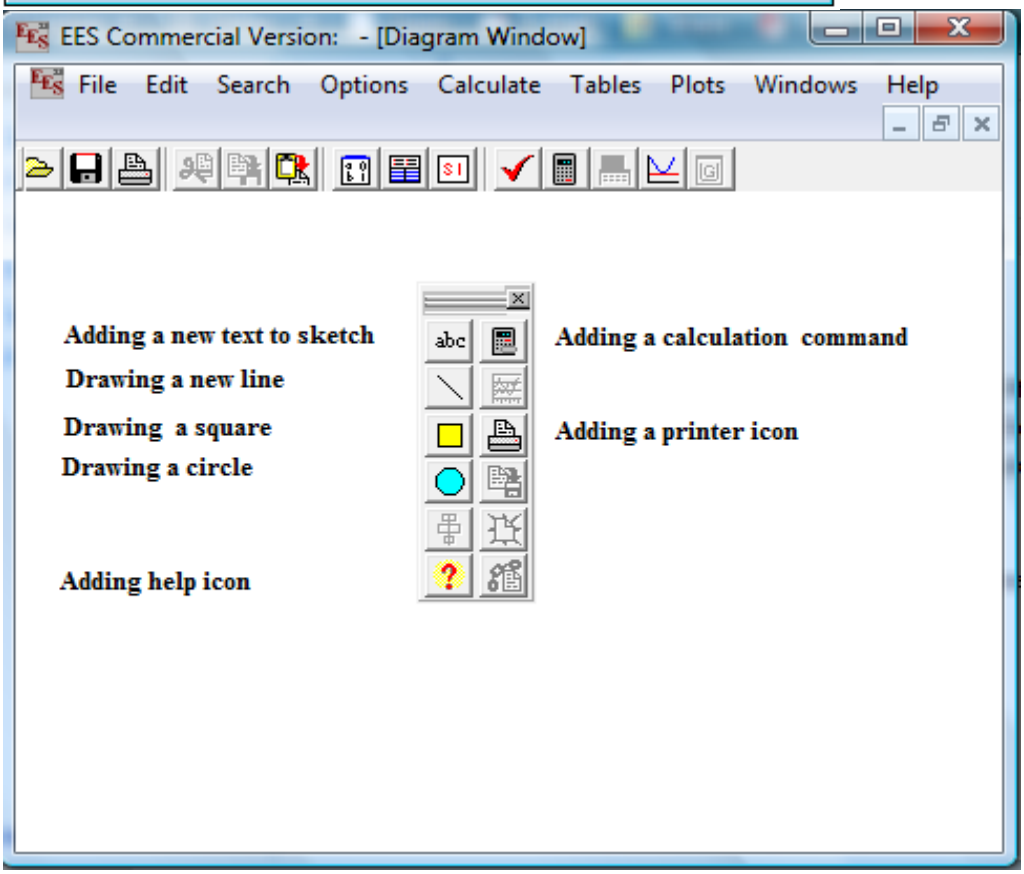
### *5.1. Using Diagram Window Tools*



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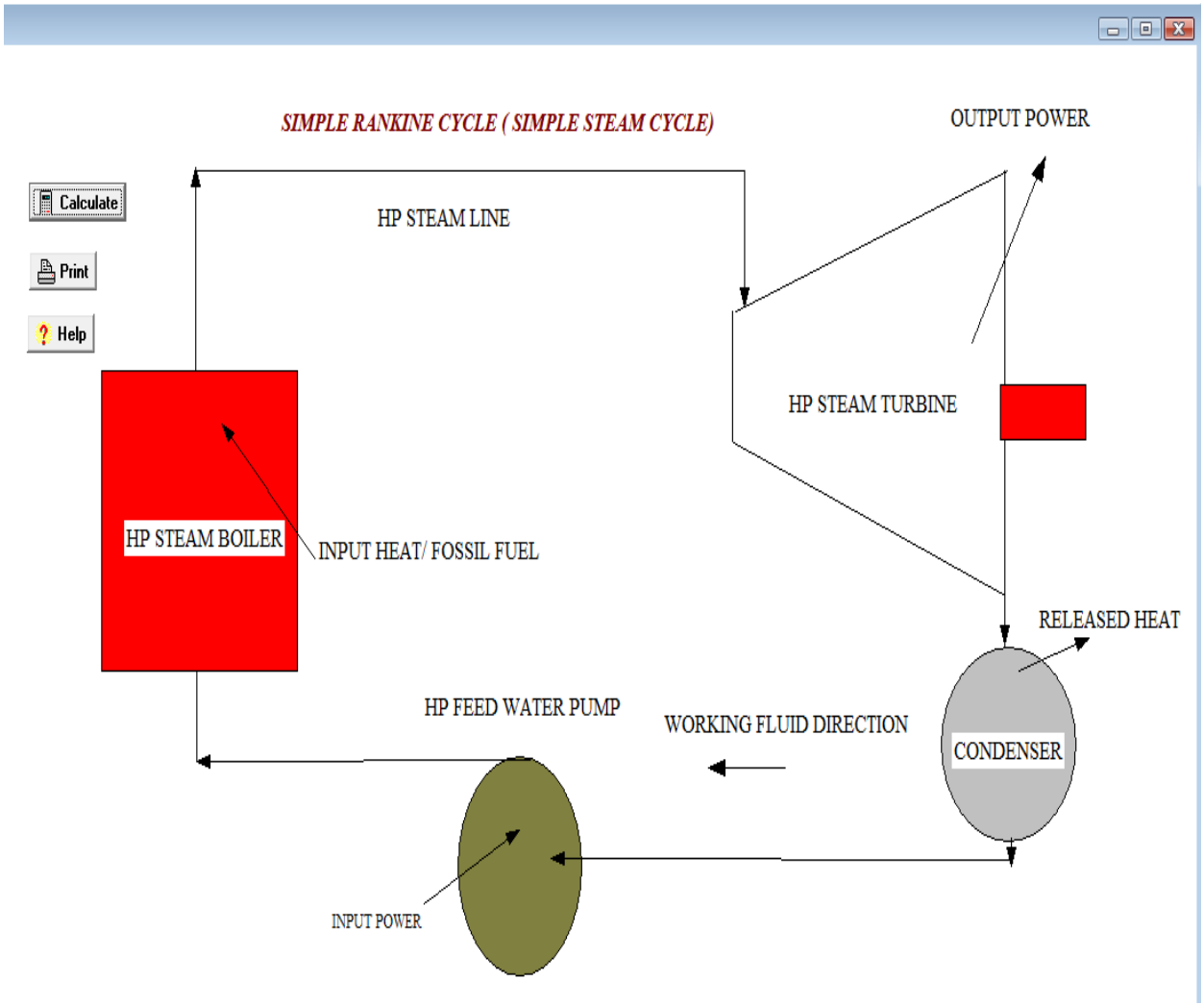
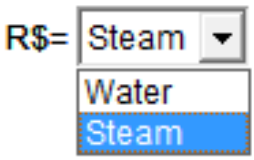
Example (20): Draw by using a free hand sketch window a simple Rankine Cycle?

***The solution***:




### *5.2. Adding Changeable Properties or Data Icons*

This sign (R$) is used to add changeable properties or different working fluid. For example h=enthalpy(R$, T=T1,P=P1)



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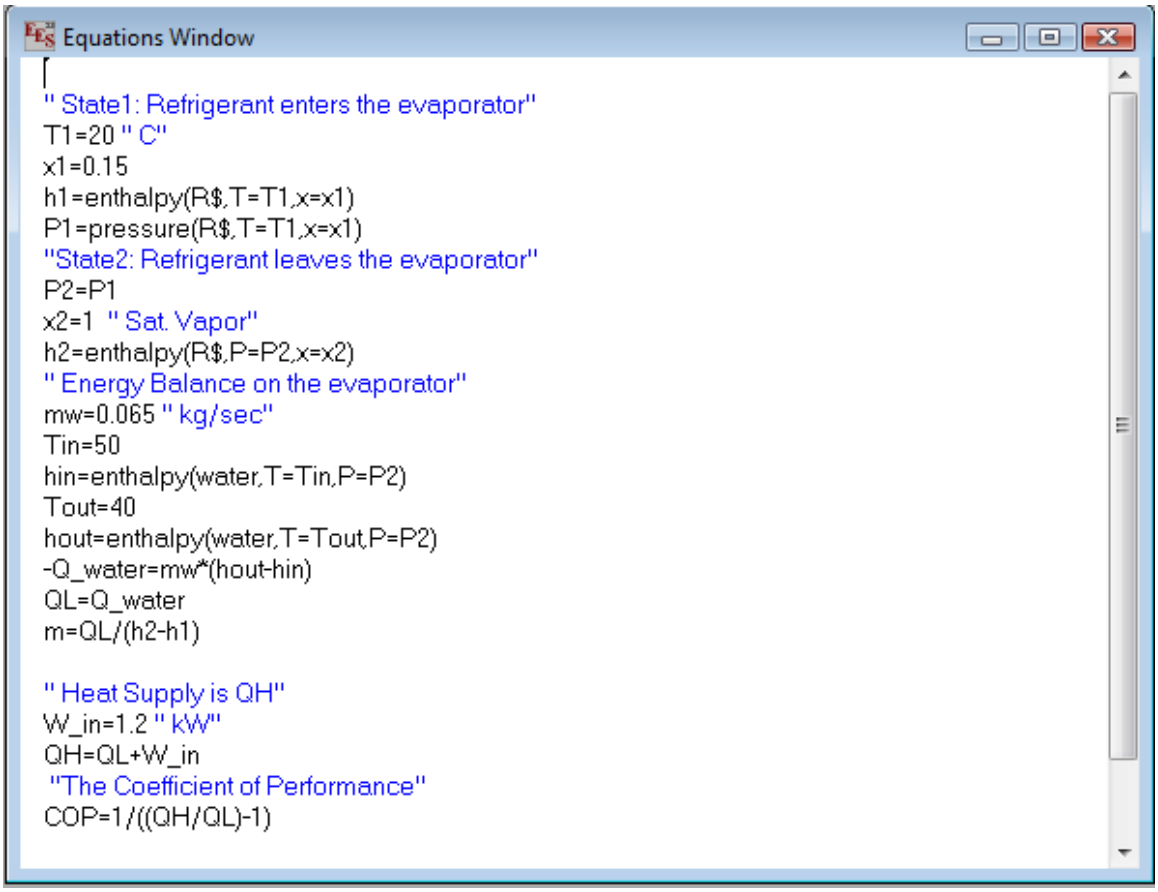
Example(21): A heat pump with refrigerant-134a, R22, R12, R11,R32,R152a as the working fluid which is used to keep a space at 25°C by absorbing heat from geothermal water that enters the evaporator at 50°C at a rate of 0.065 kg/s and leaves at 40°C. Refrigerant enters the evaporator at 20°C with a quality of 15 percent and leaves at the same pressure as saturated vapor. If the compressor consumes1.2 kW of power, determine (*a*) the mass flow rate of the refrigerant, (*b*) the rate of heat supply, (*c*) the COP

***The solution:***



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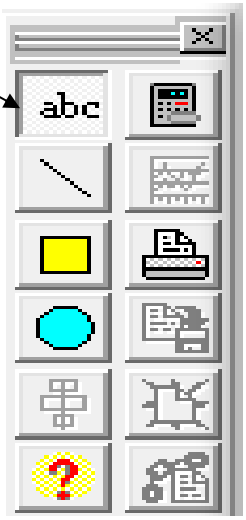
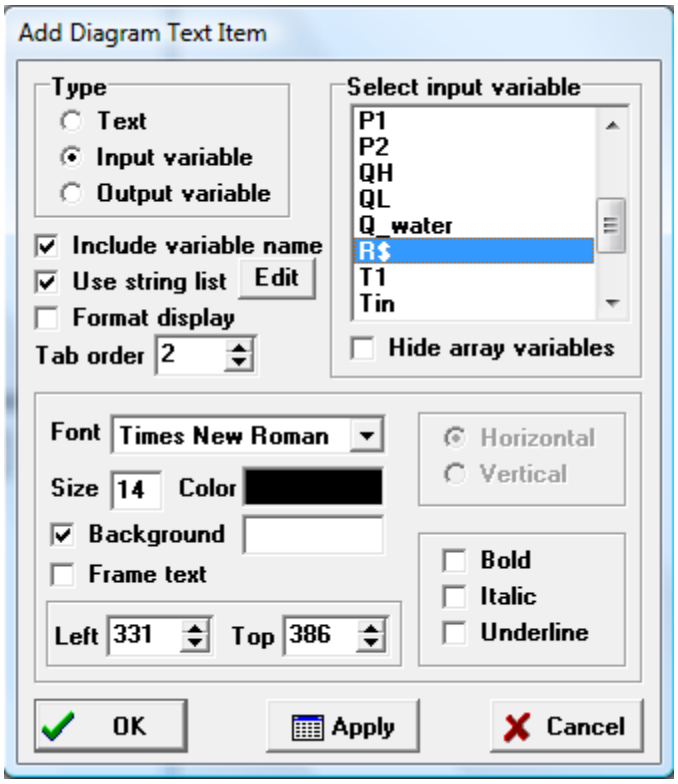
***To add the changeable variables***

***Step#1: Press on adding text***

***Text icon***




***Step#2: Select Input variable and R$***



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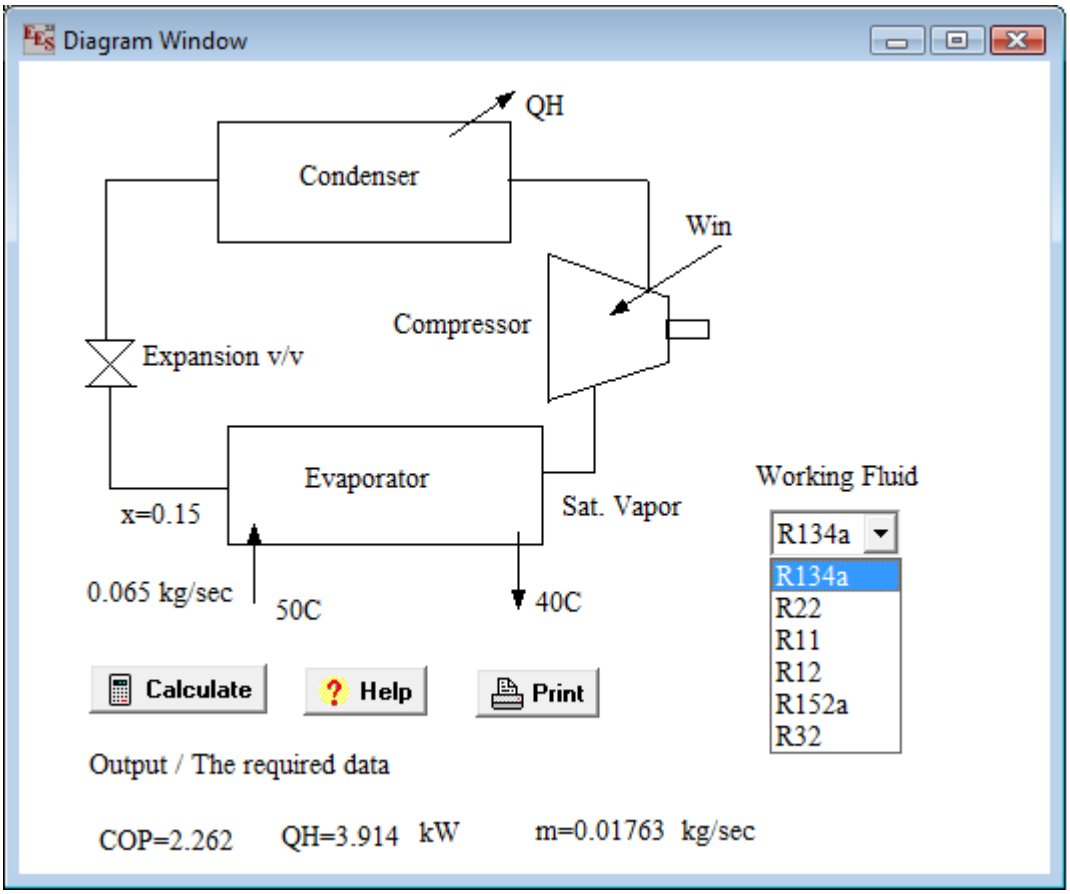


### *5.3. Solving linear and non-linear Equations with one, two, and three unknowns*

Mathematical functions have different degree with one or more unknowns, 1st degree, 2nd degree, 3rd degree…….nth degree. Therefore, EES program will help us to solve all mathematical functions types.

Example (22): Evaluate the following functions for these unknowns x,T, and V

1. $If\ y1 = 0,\ y1 = x^3 + 5x + 6$
2. $if\ P = 101\ ,\ P = T^3 + 3T^2 + 2T + 8$
3. If Q=3.45 $\ , Q = 3.4V^3 + 2V^2 + 3$



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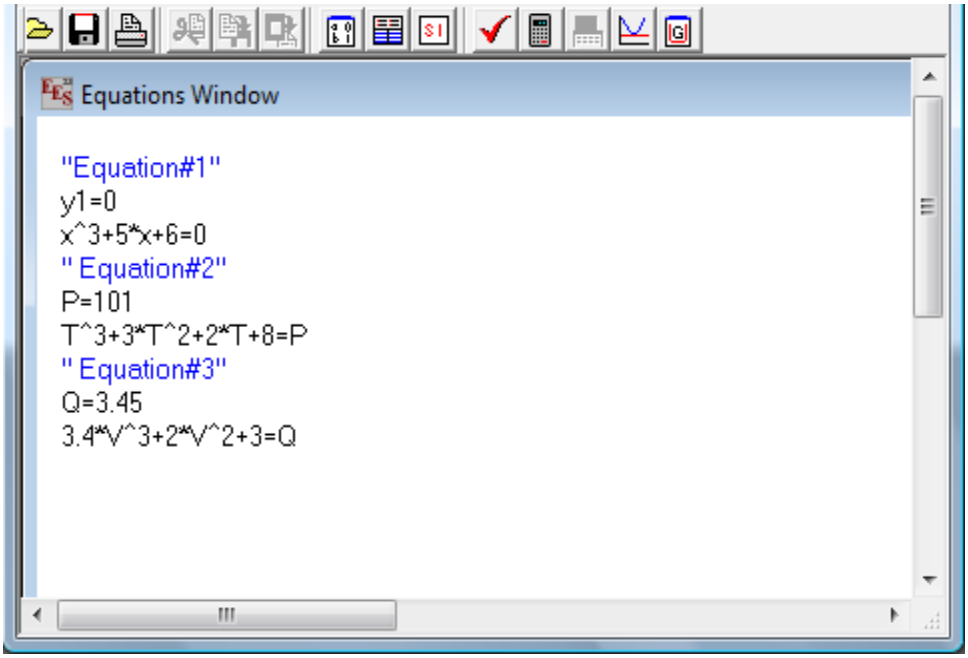
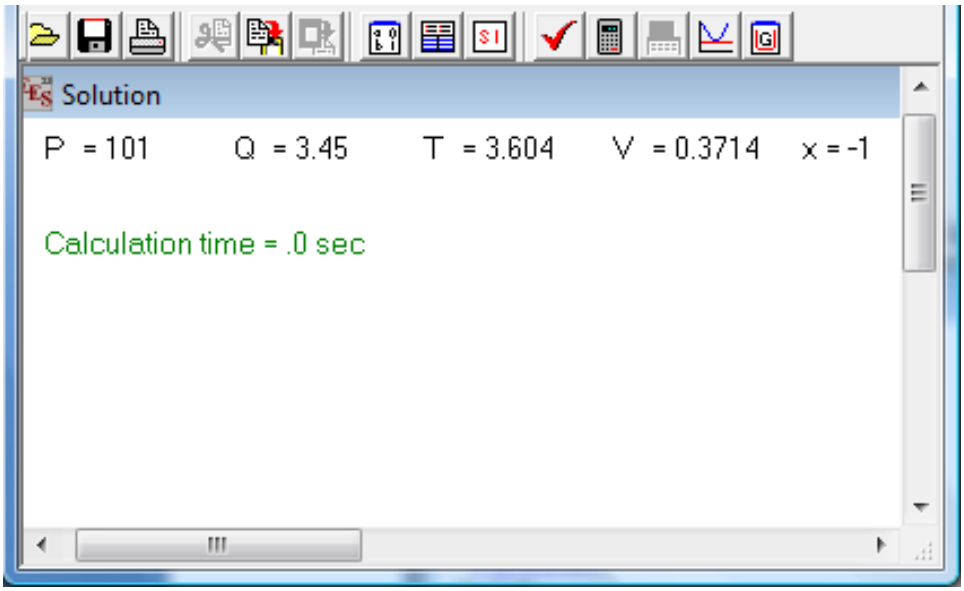
***The solution.***




Example (23) Determine the solution for the following equations

x+y+z=23

5x+4y+3z=10

2x+6y=5



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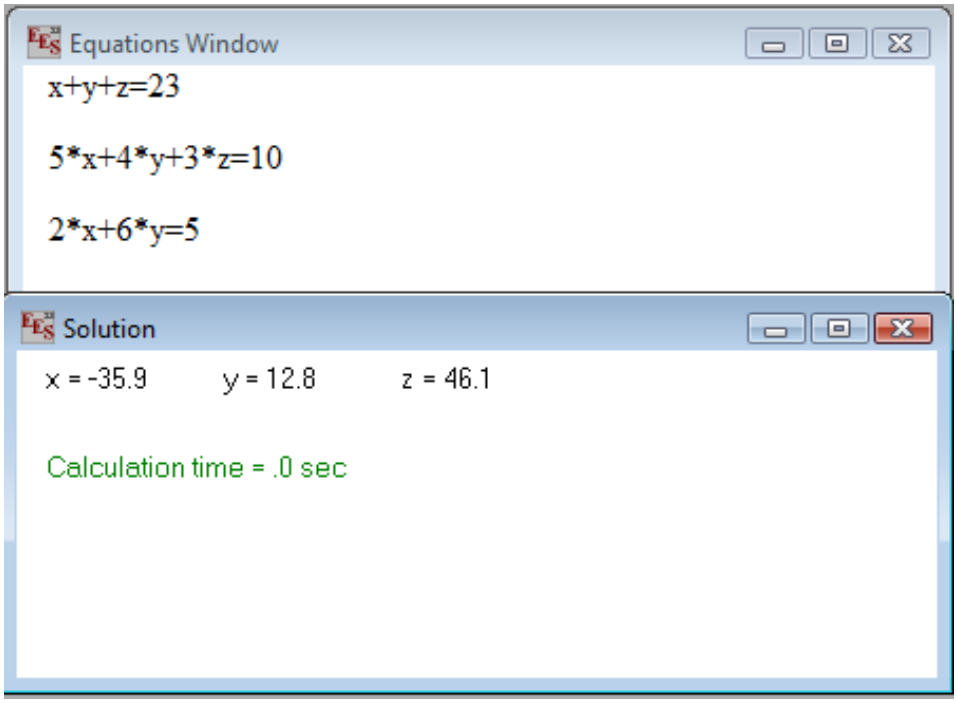
***The solution.***



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