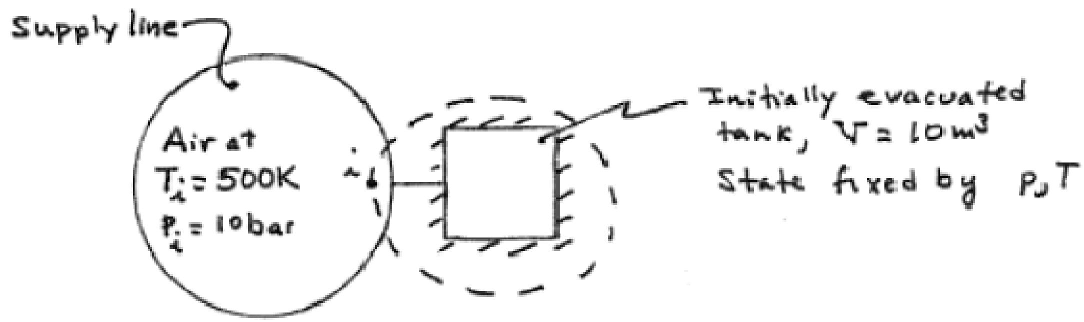
# Detailed EES solutions to selected problems

In this tutorial, a detailed step-by-step procedure is provided to solve thermodynamics problems using the EES software. The problems are selected such that, it demonstrates how to solve equations, retrieve thermodynamic data and make plots using EES.

## Question 1 (Problem 6.120 from the textbook)

A well-insulated rigid tank of volume 10 $m^3$ is connected by a valve to a large-diameter supply line carrying air at 227$^oC$ and 10 bar. The tank is initially evacuated. Air is allowed to flow into the tank until the tank pressure is p. Using the ideal gas model with constant specific heat ratio k, plot tank temperature, in K, the mass of air in the tank, in kg, and the amount of entropy produced, in kJ/K, versus p in bar.

**Schematic and Given Data:**




**Engineering Model**

(1) The control volume is shown in the above figure.
(2) For the control volume, $\dot{Q}_{CV}$=0, and kinetic and potential energy effects are negligible.
(3) The state of air within the supply line remains constant.
(4) Air is modeled as an ideal gas with constant specific heat ratio, k.

**EES solution**

EES can be used to solve a thermodynamic problem, once all the relevant variables and the governing equations are known. The equations are first derived below.

Paralleling the application of mass and energy balances in Example 4.12 but with $W_{CV}$=0, the result is $u(T)=h(T_i)$, where $T_i$ is the temperature within the supply line and T is the temperature inside the tank. For an ideal gas, $h(T_i)=u(T_i)+RT_i$, and so $u(T)= u(T_i)+RT_i$. Using ideal gas relations, $u(T)-u(T_i)=c_v(T-T_i)$, $R=c_p-c_v$. This gives

$T=kT_i$ (1)

where $k=c_p/c_v$, is the ratio of specific heats.

Using the ideal gas equation of state, the mass within the tank is,

m = pV/RT (2)

An entropy balance reads

$$\frac{dS_{CV}}{dt} = \dot{m}_i s_i + \dot{\sigma_{CV}}$$

Integrating, and using ideal gas relations,

$$\sigma_{CV} = m\left[c_p \ln\left(\frac{T}{T_i}\right) - R\ln\left(\frac{P}{P_i}\right)\right] \quad (3)$$

In EES, first select the desired Unit System located under the Options tab. Make sure the unit system selected for this problem is SI. Just like with any programming it is important to place appropriate comments throughout the code to aid in debugging. In EES separate comments from the code with quotation marks. Type in the following code:

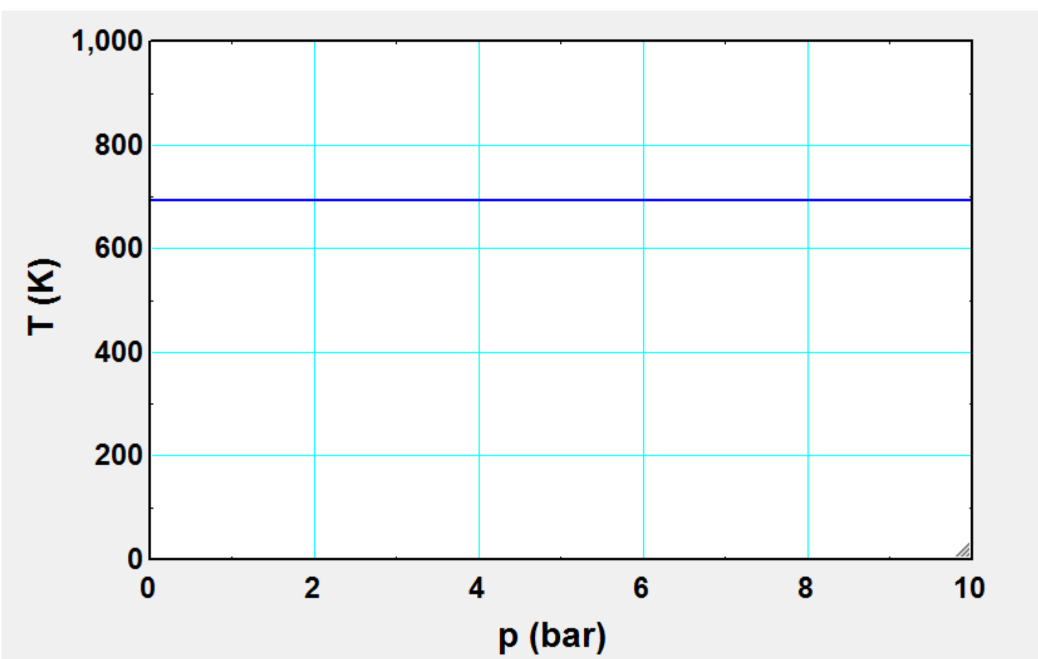
```
"Problem 6.120"
p_i=10    "[bar]"
T_i=500   "[K]"
V=10      "[m^3]"

CP=CP(AIR,T=T_i)
CV=CV(AIR,T=T_i)
k=CP/CV
T=k*T_i
p=5    "Comment this line to solve parametrically"
vol=VOLUME(AIR,T=T,P=p)
m=V/vol

sigma=m*(CP*LN(T/T_i)-R_gas*LN(p/p_i)
R_gas=8.314/28.97
```

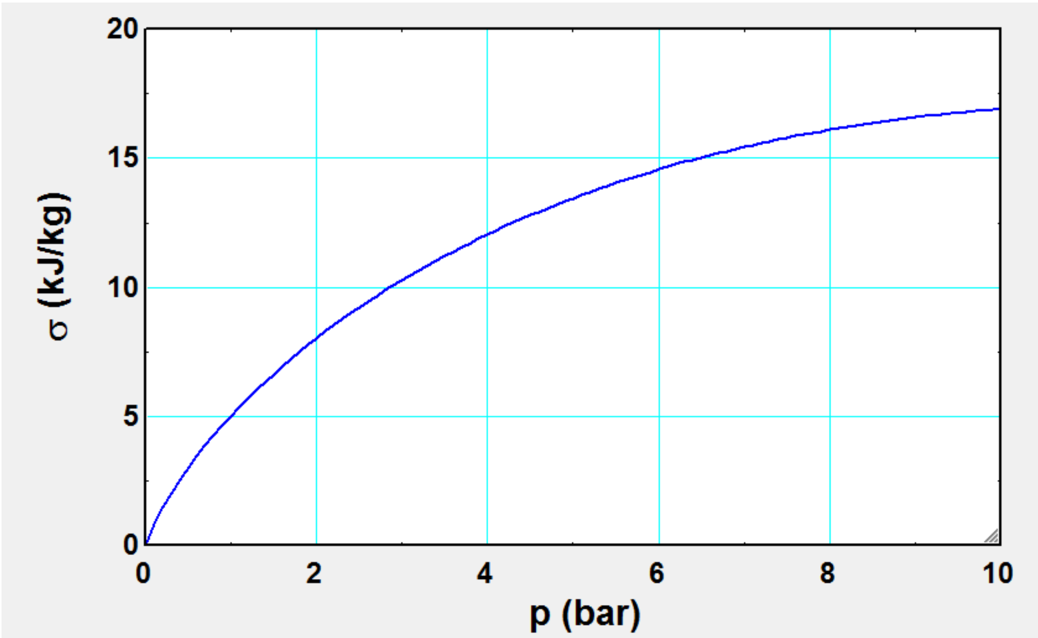
EES has the ability to check units for you but conversion factors must be used and all variables must be assigned a unit. Above, by placing the units for the variables in brackets ([bar]), you are assigning units to this variable. In the solution window, this unit will appear next to the variable. This type of assignment only works when a variable is assigned a numeric value like p_i.

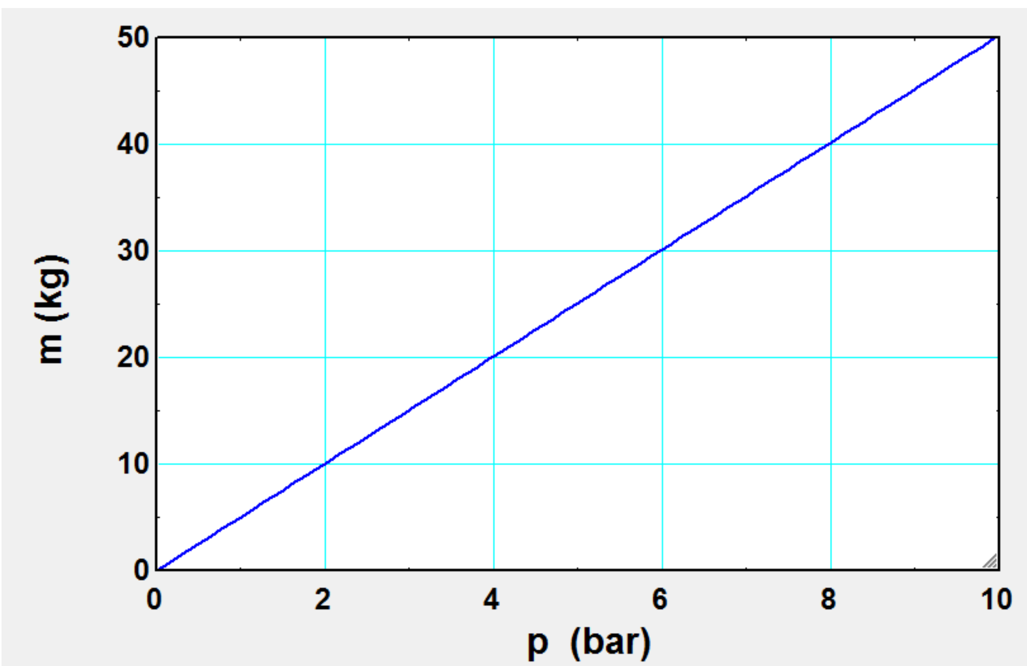
You do not have to remember the format for the property equations. Instead go to the Options tab and select Function Info. From here select Fluid Properties. The box on the left shows the property, while the box on the right shows the fluid. Instead of typing the equation, choose CP and air and then paste.

Now that the code has been entered, the system of equations can be solved. Before solving the equation, check for any syntax errors by clicking on Check/Format under the Calculate tab (or by pushing the red check button). If no errors are found, this check will inform you of the number of equations and the number of unknowns. If the number of equations and number of unknowns are not equal, no solution can be found. If the format is correct, then click on Solve also under the Calculate tab (or by clicking the calculator button). The solution window will appear showing the values for all the variables. EES will also perform a units check. Click Check Units under the Calculate tab. You will notice that the properties have units automatically added.

Another powerful feature of EES is the Parametric Table. This feature allows you to vary parameters and see the result on the system. In this problem, pressure, p, is the parameter. Comment this line. Click on New Parametric Table under the Tables tab. The left box shows all the variables in the program. Choose all variables and click Ok. A spreadsheet looking table now appears. On the column for p, click on the black arrow at the top. Set the first value to 1 and the last value to 10 and click OK. EES will now fill in the column of p with the test values. To solve the table either click the green arrow in the upper left or click Solve Table under the Calculate Tab. The plots can be created by clicking New Plot Window (X-Y Plot) under the Plots tab. The plots obtained for this problem are listed below.



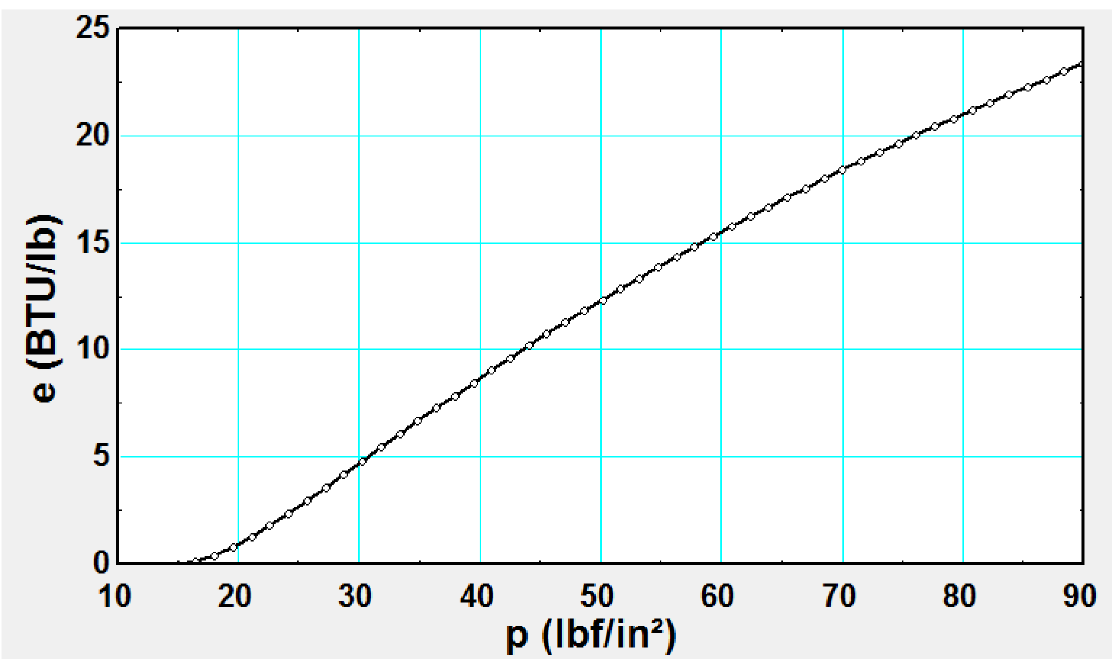

σ (kJ/kg)
20
15
10
5
0
0
2
4
6
8
10
p (bar)

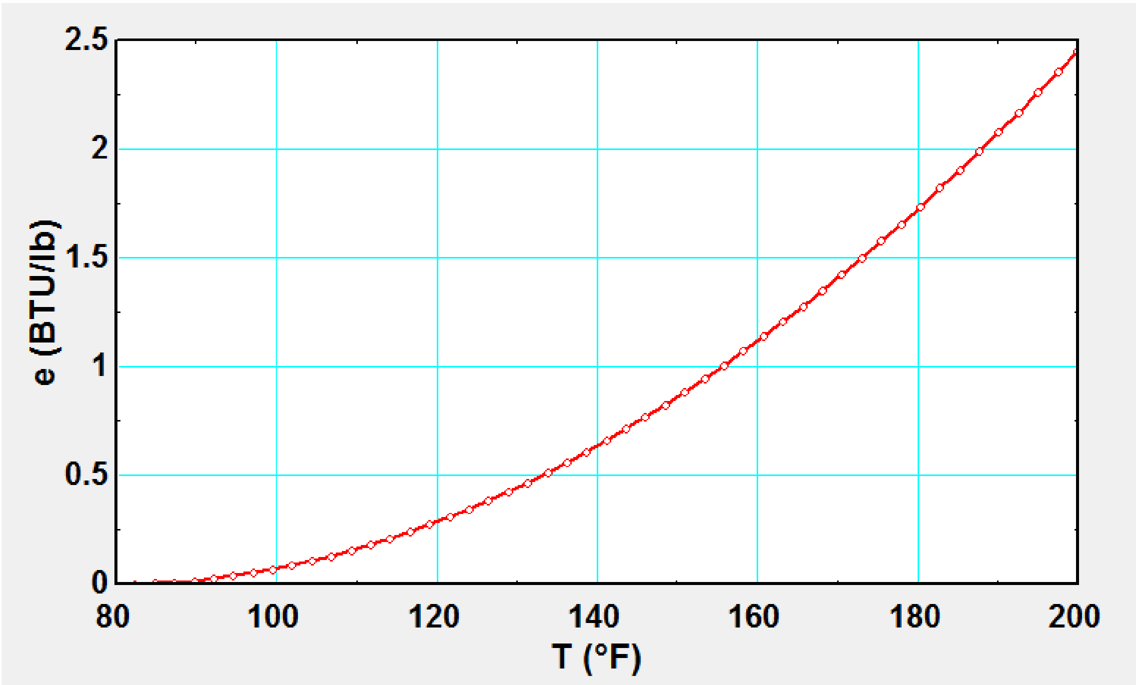

m (kg)
50
40
30
20
10
0
0
2
4
6
8
10
p (bar)

## Question 2 (Problem 7.16)

The procedure is very similar to that explained above. The only difference is that the units selected should be the English units. The solution is given below, along with the plots.

```
"!Problem 7.16"
T = 80                "[°F]"                    "Comment this to solve parametric table 1"
p = 15                "[lbf/in²]"               "Comment this to solve parametric table 1"
To = 80        "[°F]"
po = 15        "[lbf/in²]"

e = (u - uo) + (po * (144 / 778)) * (v - vo) - (To + 460) * (s - so)
u = INTENERGY(CO2,T=T)
uo = INTENERGY(CO2,T=To)
v = VOLUME(CO2,T=T,p=p)
vo = VOLUME(CO2,T=To,P=po)
s = ENTROpY(CO2,T=T,P=P)
so = ENTROPY(CO2,T=To,P=po)
```




2.5
2
1.5
1
0.5
0
e (BTU/lb)
80
100
120
140
160
180
200
T (°F)