Engineering Equation Solver (EES) Tutorial

In this tutorial, we will use a thermodynamics problem (courtesy of ES2310 taught by Dr. Paul Dellenback in the fall semester of 2014) to better understand how the program EES can be used to help solve problems. The solution to the problem is shown below to help the reader better understand the problem before it is solved in EES.

Problem Solution

Given: A compressor takes in 1.2 kg/s of R-134 that is in a saturated vapor state at -24°C. The compressor outlet state is at 0.8 MPa and 100°C.

Find: The power input of R-134 by the compressor, the volumetric flow rate at the exit and how much power must be provided by an electric motor if the compressor's efficiency is 70%. Then, set up a parametric table that re-solves for both the power input and volumetric outflow rate for outlet temperatures: 180, 160, 100, and 80° C. No more than three sig figs for results computed for EES.

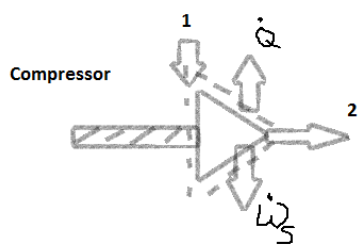


Fig. 1: Compressor described by this problem.

Solution: First let's solve the problem by hand so we can compare to the EES results.

Energy Equation for the compressor shown in Figure 1:

$$\dot{m}_1(h_1 + p_1e + k_1e) + \dot{W}_s = \dot{Q} + \dot{m}_2(h_2 + p_2e + k_2e) + \frac{dE}{dt}_{cv}$$

Where we can assume steady flow, the change in potential and kinetic energy is equal to zero, steady state and adiabatic, which will set $p_1e - p_2e = 0,\ k_1e - k_2e = 0,$ $\frac{dE}{dt}_{cv} = 0$, and $\dot{Q} = 0$, giving us a our simplified energy equation that we can use for this problem.

$$\dot{W}_s = m(h_2 - h_1)$$

From our thermodynamics property tables for R-134a as a saturated vapor at -24° C, the enthalpy can be found as $h_1 = 235.94\frac{kJ}{kg}$, and for state two where the pressure is 0.8 MPa and the temperature is 100° C, the enthalpy can be found as $h_2 = 337.32\frac{kJ}{kg}$ found from the superheated tables because $T_2 > T_{sat}$ for 0.8 MPa.

Hence, our energy equation can be now written as,

$$\dot{W}_s = 1.2\frac{kg}{s}\left(337.32\frac{kJ}{kg} - 235.94\frac{kJ}{kg}\right) = 121.7\ kW$$

Now, we need to find the volumetric flow rate at the exit and what the ideal power output is for the efficiency given.

We know an equation for the mass flow rate:

$$\dot{m} = \rho V A = \rho \dot{V}$$

Solving for $\dot{V}$ yields,

$$\dot{V}_2 = \frac{\dot{m}}{\rho_2}$$

From the same superheated table we used to find h_2 we can also find that $v_2 = 0.035193 \frac{m^3}{kg}$ which means that $\rho_2 = \frac{1}{v_2} = \frac{1}{0.035193 \frac{m^3}{kg}} = 28.415 \frac{kg}{m^3}$.

Hence,

$$\dot{V}_2 = \frac{1.2 \frac{kg}{s}}{28.415 \frac{kg}{m^3}} = 0.042 \frac{m^3}{s}$$

Lastly, we solve for the ideal work done by the system where

$$\dot{W}_{ideal} = \frac{\dot{W}_{actual}}{\eta_c} = \frac{121.7\ kW}{0.7} = 173.8\ kW$$

EES Solution

Now, let's solve using EES to see how the program can help speed up the process and also help solve for multiple variables.

Step 1: Enter the problem information as shown in Fig. 2.

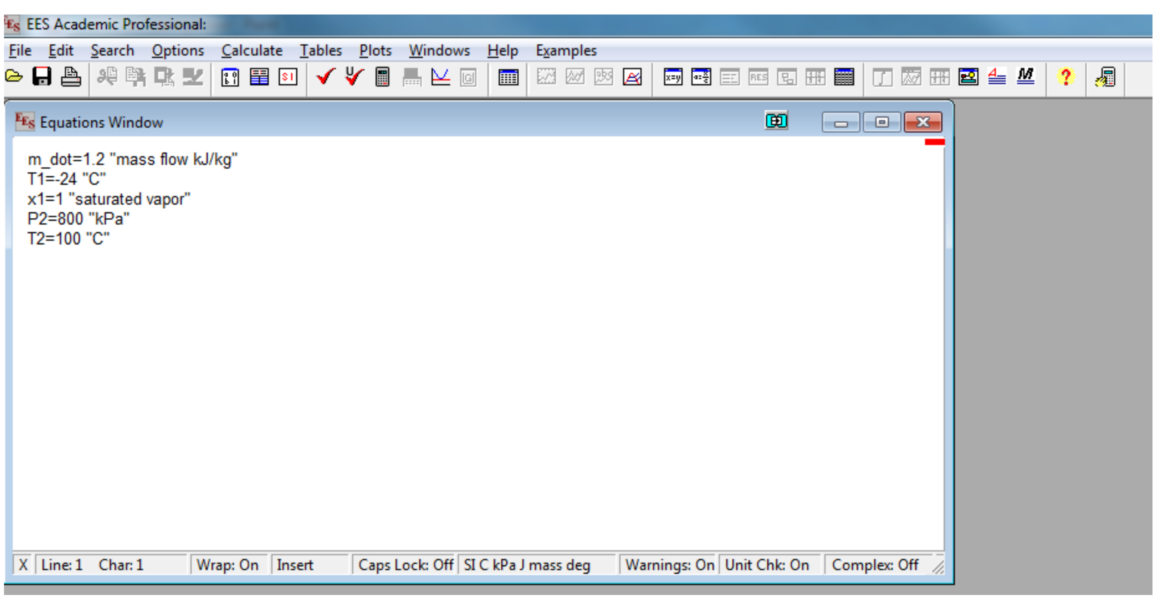


Fig. 2

You should notice there is an additional property given to us in the problem statement, the saturated vapor or the vapor quality of the fluid at state one, which can be represented as x1. EES has built in property tables that follow the thermodynamics rule that for saturated vapor the value of x is 1 and for saturated liquid the value is 0.

Now, we can call the properties we need from the EES database with these givens. These properties can be called with a function or they can be entered manually. The function opertates with a pre-built function name defined by EES and designated names for properties. For example, if we want EES to find the enthalpy of state one from its tables, the function name would be enthalpy. There are several properties including temperature, pressure, density, state, etc., we can use to call the correct value, but, in order for the function to work, we must enter two. You must also include the name of the substance you need the properties for, in this case, R-135a. The function methodology is shown below.

Step 2: Use EES to obtain the values of enthalpy and density at states one and two.

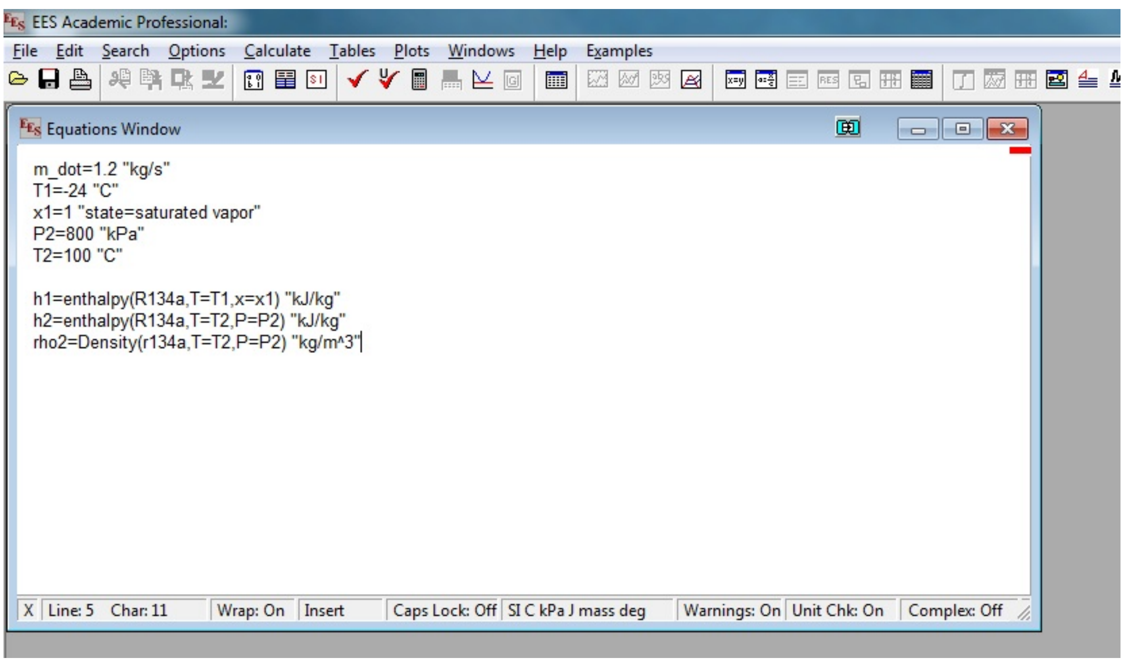


Fig. 3

Note that the function disregards capitalization in that even though the density function is capitalized, EES will still perform the correct function like it will for the enthalpy values.

The alternative way to obtain the properties needed for this problem starts with clicking the **Function Info** button on the **Diagram Window Toolbar** to open the Function Info Dialog Box shown in Fig. 5.

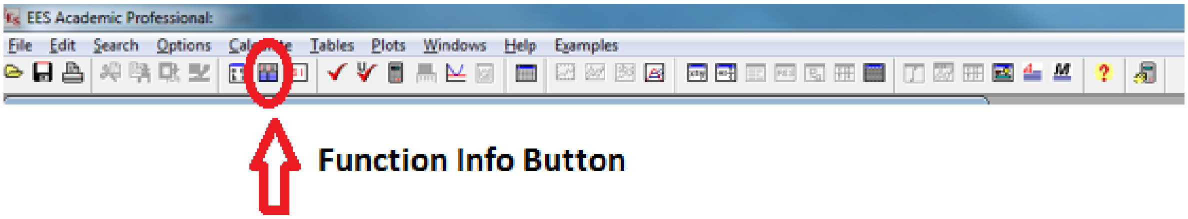


Fig. 4

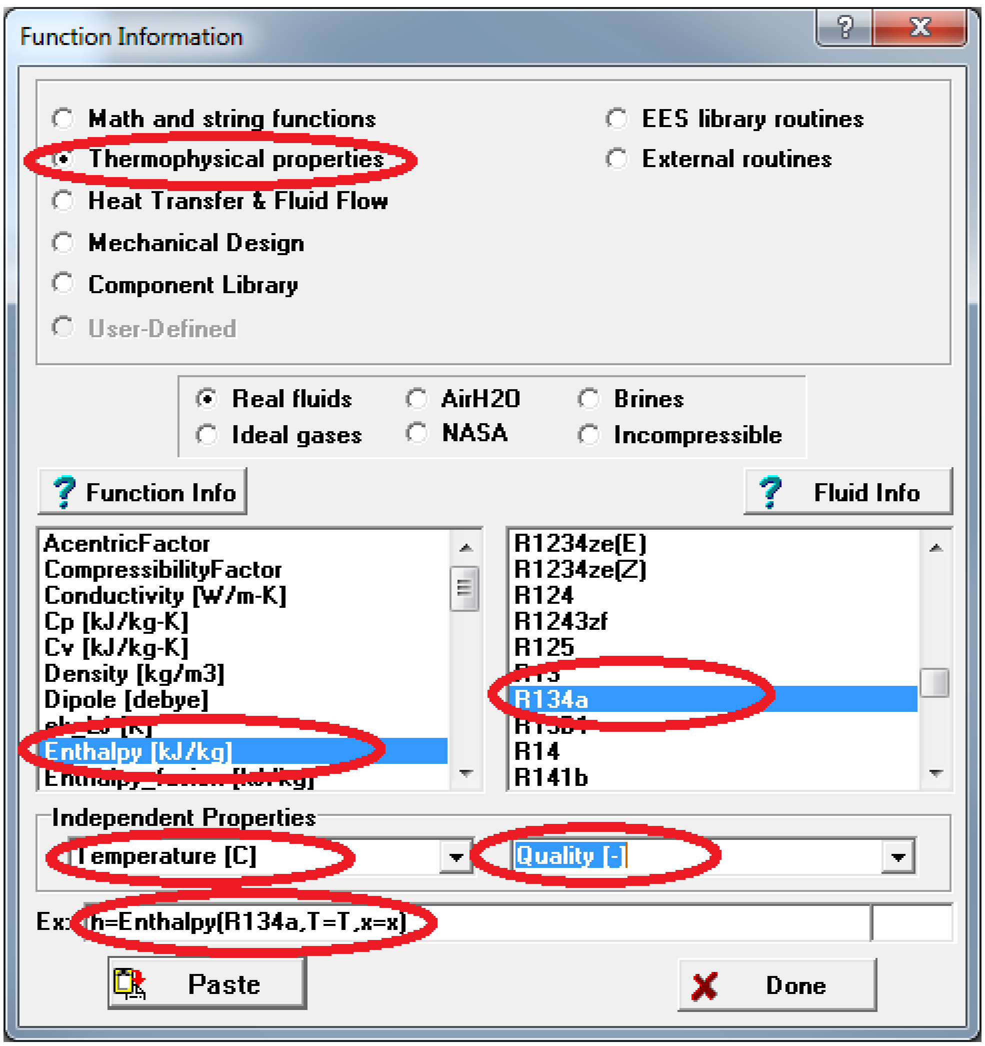


Fig. 5

For this problem we want Thermophysical properties so that option needs to be checked. The property we want is Enthalpy [kJ/kg], the fluid we want is R134a, and we want to solve using the properties of Temperature [C] and vapor Quality [-]. The independent properties can be changed to any of the options in the drop down box access by the drop down arrows on the right side of the property boxes. An example of what this function would look like if it were manually entered as is also provided so the user can understand how this function is EES works. When all the appropriate settings are in place, press Paste and the function shown appears in the EES window. The user needs to manually enter the variables assigned later. So, for state one, we need T=T1 and x=x1. We also need to assign this enthalpy as h1 for state one.

The dialog boxes for the other two properties are also shown below in Figs. 6 and 7.

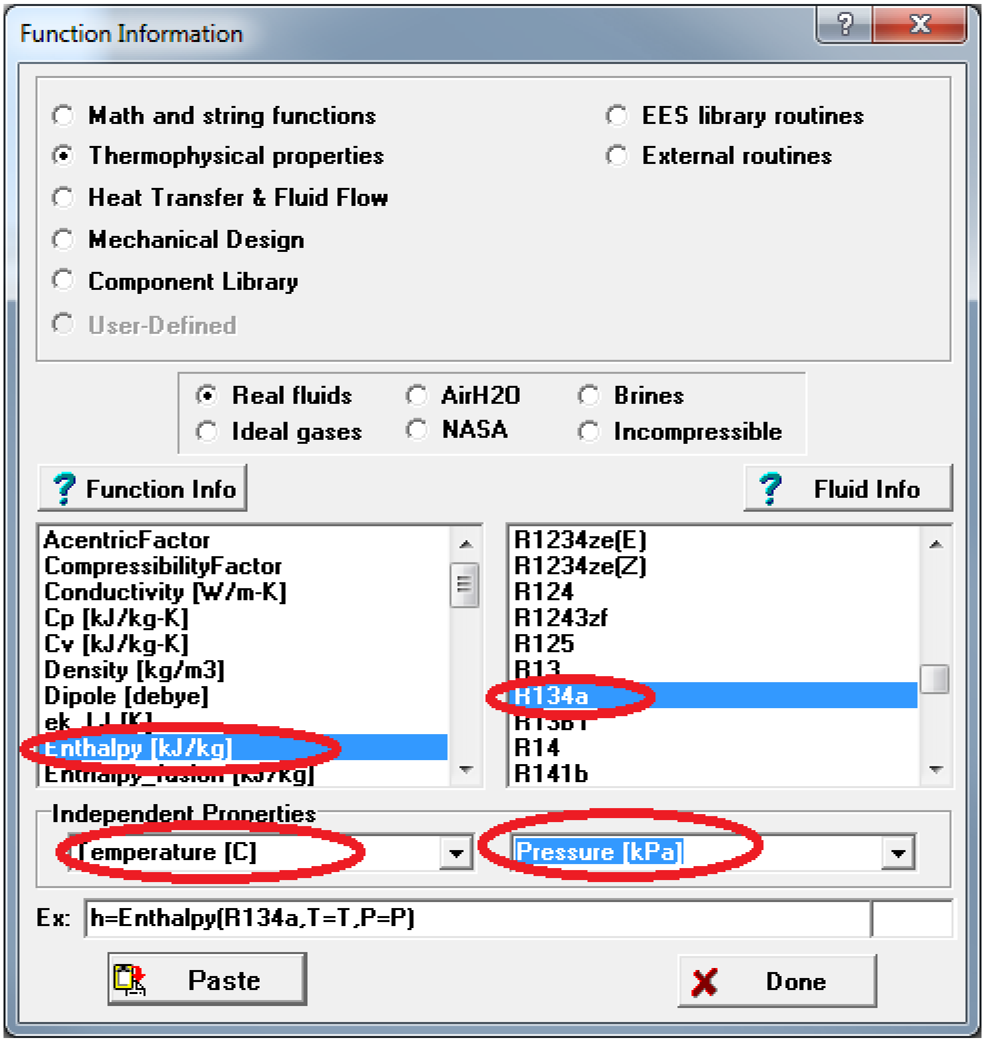


Fig. 6

The only change for enthalpy at state two is to change one of the independent properties to pressure by choosing one of the options from the drop down menu.

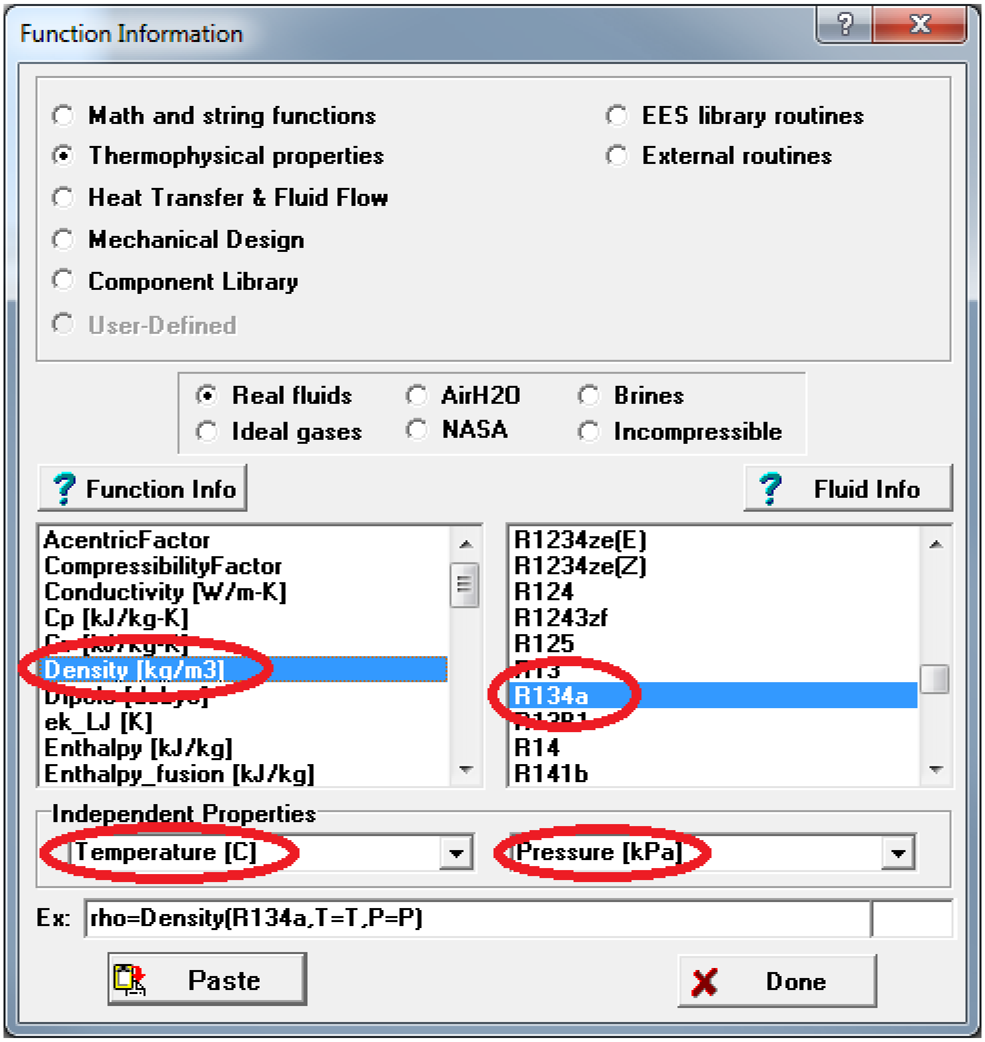


Fig. 7

Step 3: Enter the thermodynamics equations we want to solve for in EES (shown in Fig. 8)

Don't forget to include all the givens in the problem statement. In this case, we need to include the compressor efficiency of 70%. After you enter all the equations, we can have EES calculate the solution by pressing the **Calculator icon** in the Diagram Window Toolbar.

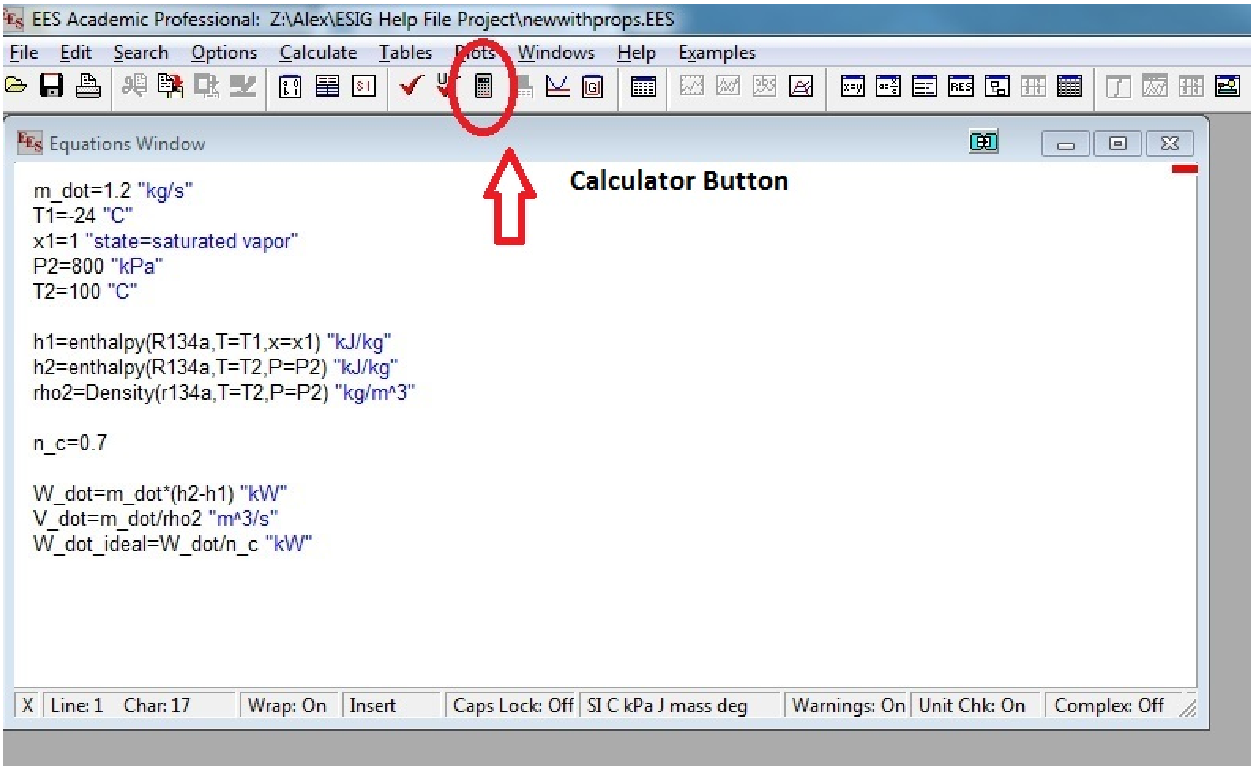


Fig. 8

Notice that after you calculate, all the text turns blue while the equations stay black. The calculation will open up a new Solutions Window, shown below in Fig 9.

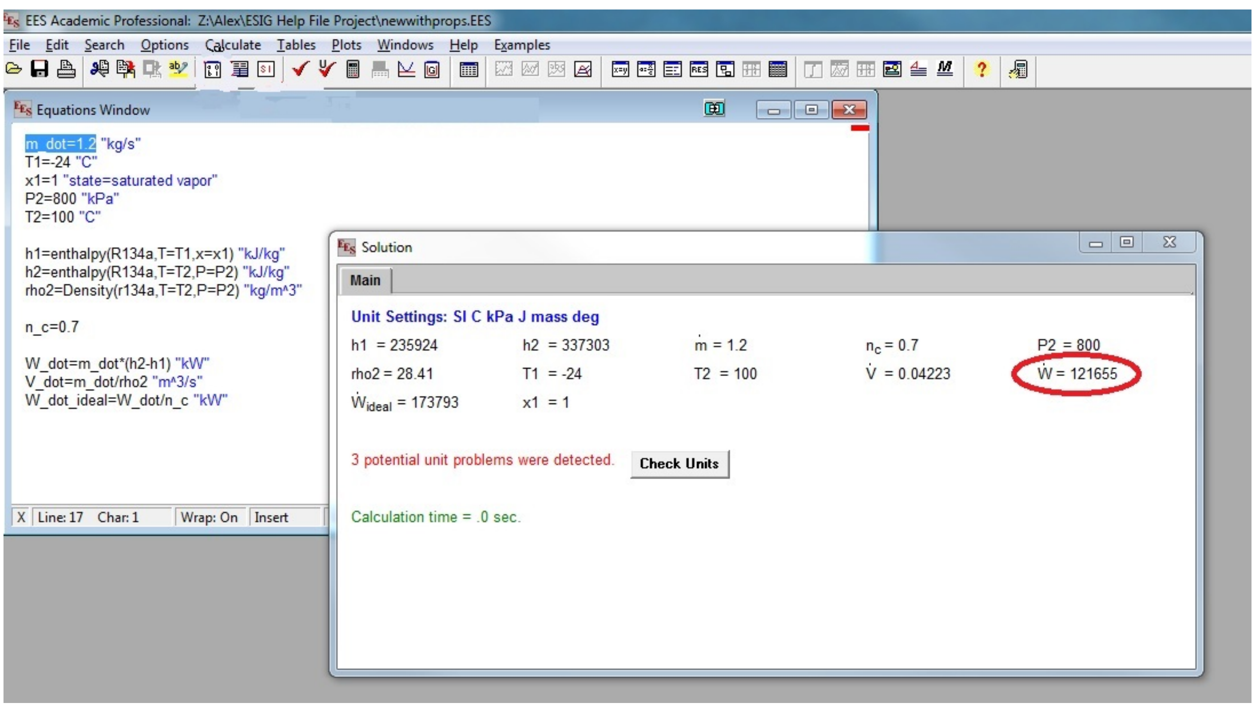


Fig. 9

You may notice there is a unit problem. Our final answer done by the work of the compressor should be 122 kW, not 121655 kW. The values on several other variables are also incorrect. This could be the result of one or two problems. The first could be that we entered the equations incorrectly. You can check the formatting of your equations by opening the Formatted Equation Window. This enables you to see if you made any addition, subtraction, multiplication, etc. mistakes in your formulas. It does not appear that we made any mistakes in entering the equations

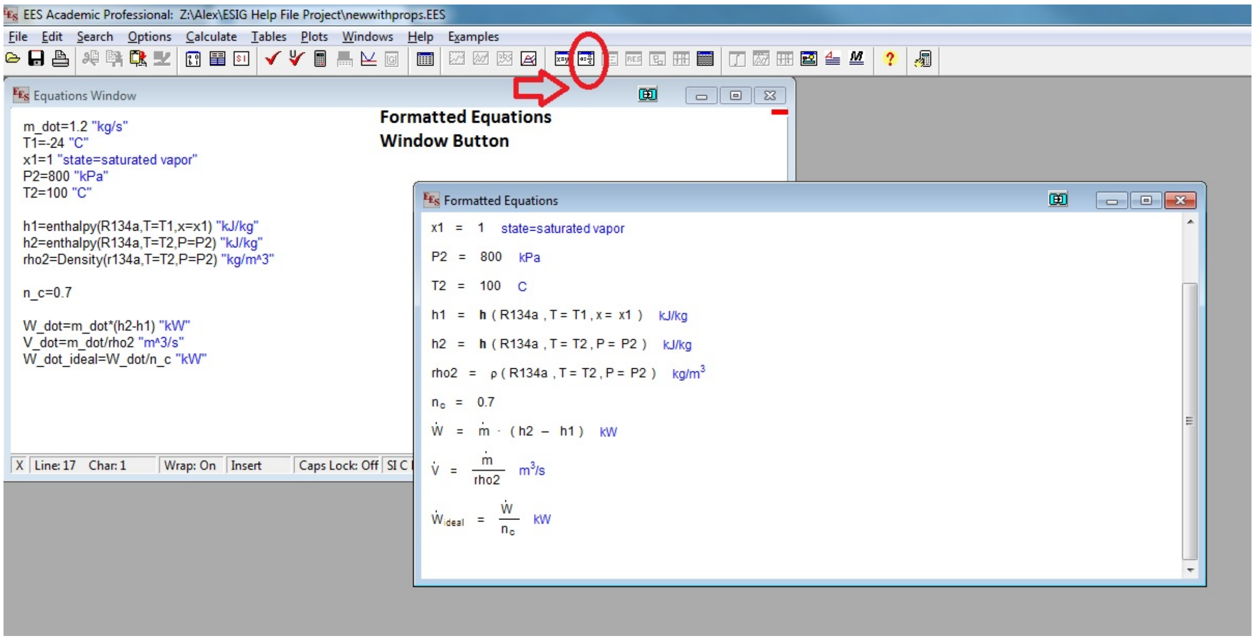


Fig. 10

The second problem could be that EES does not know the units of the variables we assigned for it. Even though we defined them in text, we did not define them in EES. EES allows us to assign properties by using the **Unit System Manager**, accessed through Diagram Window Toolbar, shown in Fig. 11. This opens up the **Variable Info Manager**. For this problem we want to use properties in terms of kPa, kJ/kg, etc. The correct options for this problem are also shown in Fig. 11.

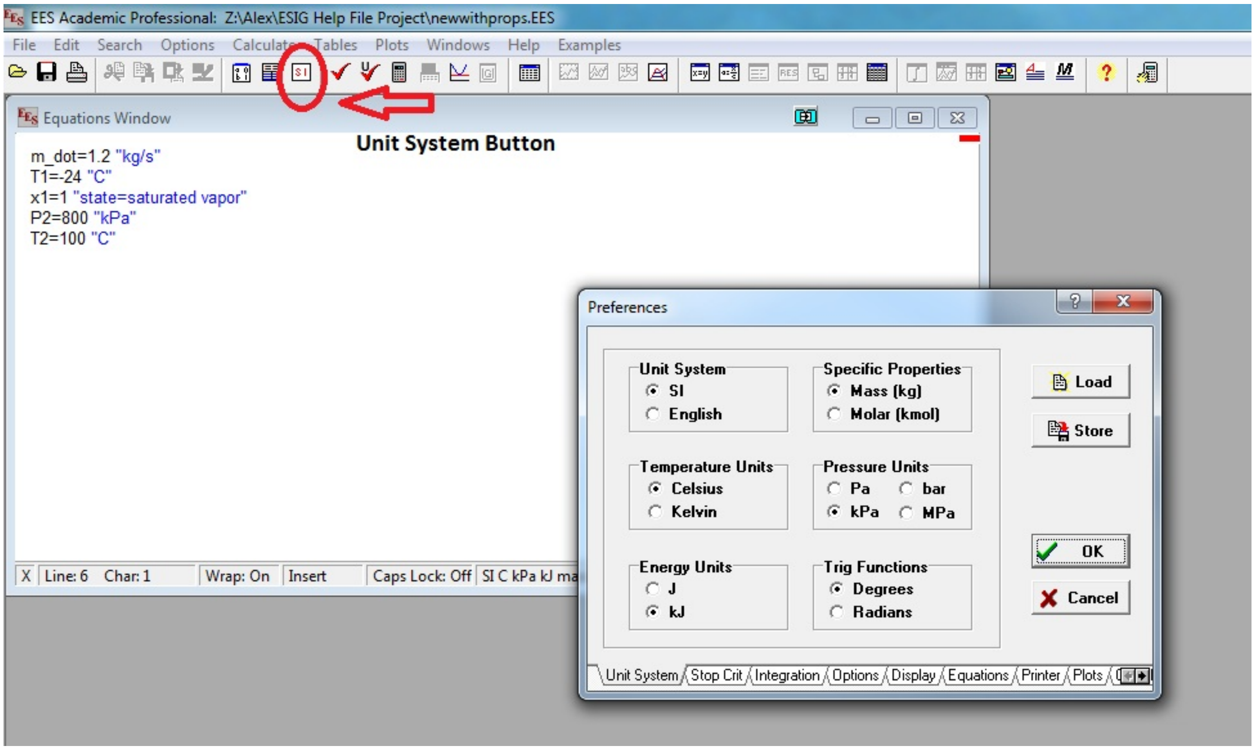


Fig. 11

Lastly, purely for formatting purposes, we can make the units appear in our Solutions Window by utilizing the Variable Information Manager, which can also be accessed via the Diagram Window Toolbar. This will make the reporting of your results more professional. When you first open the manager the Units column will be blank. Fig. 12 shows the units needed for the correct solution, which you also entered in text at the beginning of this tutorial.

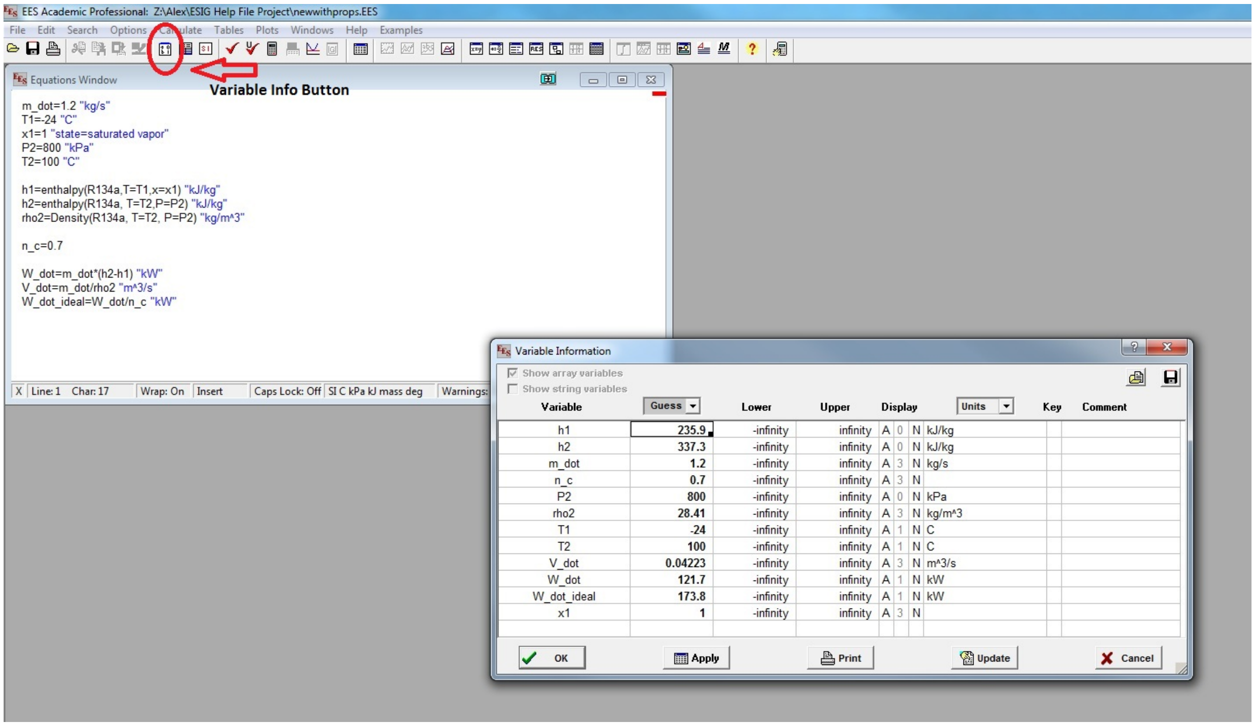


Fig. 12

Now, when EES solves the problem the results in the Solutions Window should be correct.

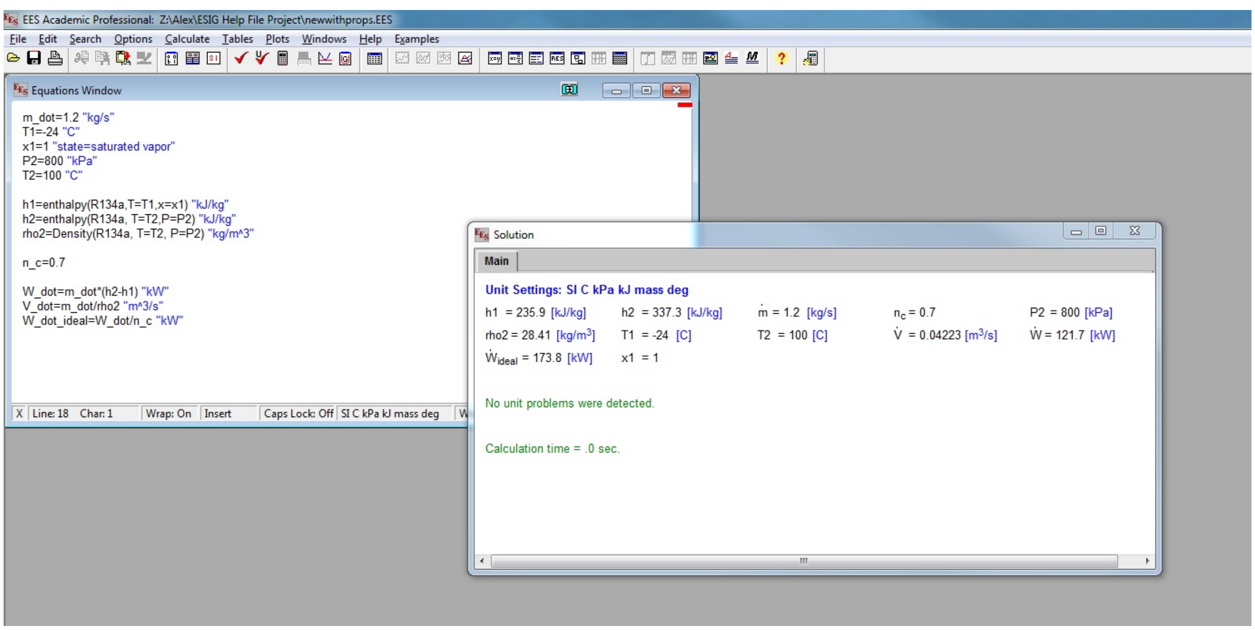


Fig. 13

Step 4: Build a Parametric Table for a range of temperatures at state two.

Lastly, we can use these equations to find solutions for multiple input of temperature, pressure, etc. For this problem we will find solutions for the temperatures mentioned previously (180, 160, 140, 120, 100, and 80 °C) First, you need to convert your T_2 to text, otherwise the table will not work because, to EES, this temperature has already been defined. Then, you can click the **New Parametric Table** button to open the table. Then click the variables in equations you want and add them to the table. For this table, we want to calculate the solutions for six temperatures, so we will have six runs.

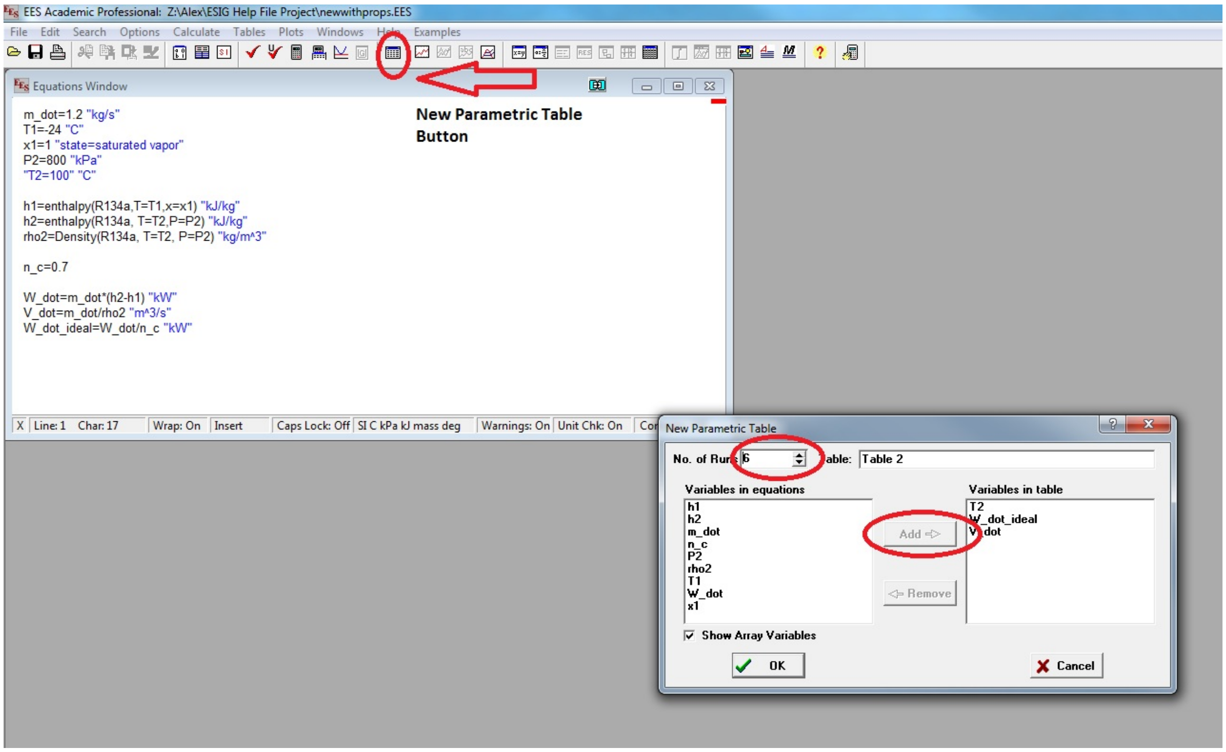
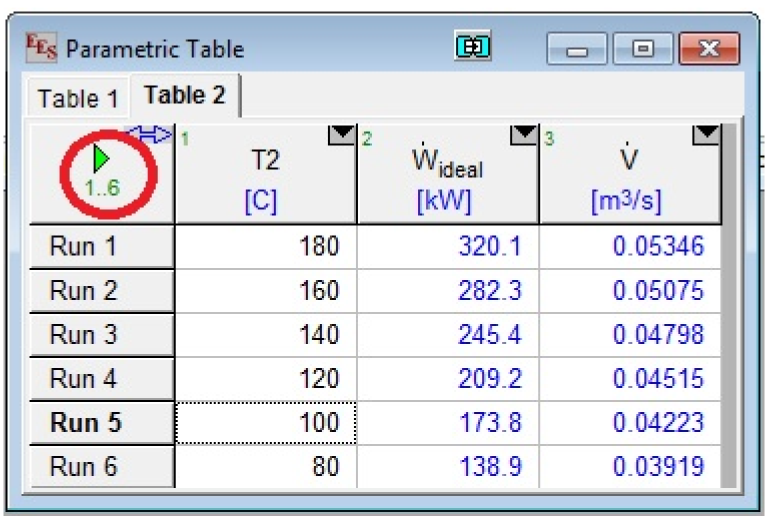


Fig. 14

Enter the temperatures into the table and click the **run** button to calculate the final results.



Parametric Table

Table 1 | Table 2

1..6	T2 [C]	$\dot{W}_{ideal}$ [kW]	$\dot{V}$ [m³/s]
Run 1	180	320.1	0.05346
Run 2	160	282.3	0.05075
Run 3	140	245.4	0.04798
Run 4	120	209.2	0.04515
Run 5	100	173.8	0.04223
Run 6	80	138.9	0.03919

***Note: In engineering, numbers are typically reported in three significant figures. We can change the significant figures reported by EES by returning to the Solutions Window and double-clicking on the blue units displayed there. This will bring up the **Specify Format and Units** dialog box for whichever unit you click on. Then change the Format to **N Signif. Figs** and change the amount to **3** significant figures. You can then do that for all the other units, too.

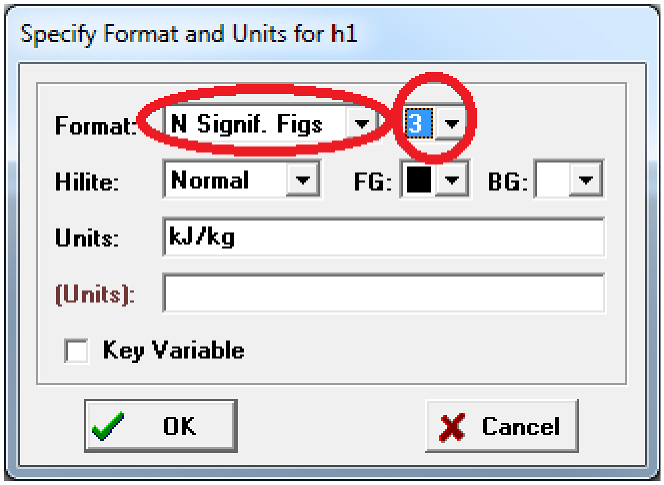


Fig. 15

***Changing the significant figures can also be accomplished by right clicking on the blue units in the Parametric Table and choosing the Properties option. This will bring up the Format Parametric Table dialog box. The number of significant digits can then be changed in the Format section of the dialog box.