Introduction to EES

Overview

EES (pronounced 'ease') is an acronym for Engineering Equation Solver. The basic function provided by EES is the numerical solution of non-linear algebraic and differential equations. In addition, EES provides built-in thermodynamic and transport property functions for many fluids, including water, dry and moist air, refrigerants, combustion gases, and others. Additional property data can be added by the user. The combination of equation solving capability and engineering property data makes EES a very powerful tool.

A license for EES is provided to departments of educational institutions that adopt this McGraw-Hill text. If you need more information contact your local McGraw-Hill representative, call 1-800-338-3987, or visit the McGraw-Hill website at http://www.mhhe.com. A commercial or professional version of EES can be obtained from:

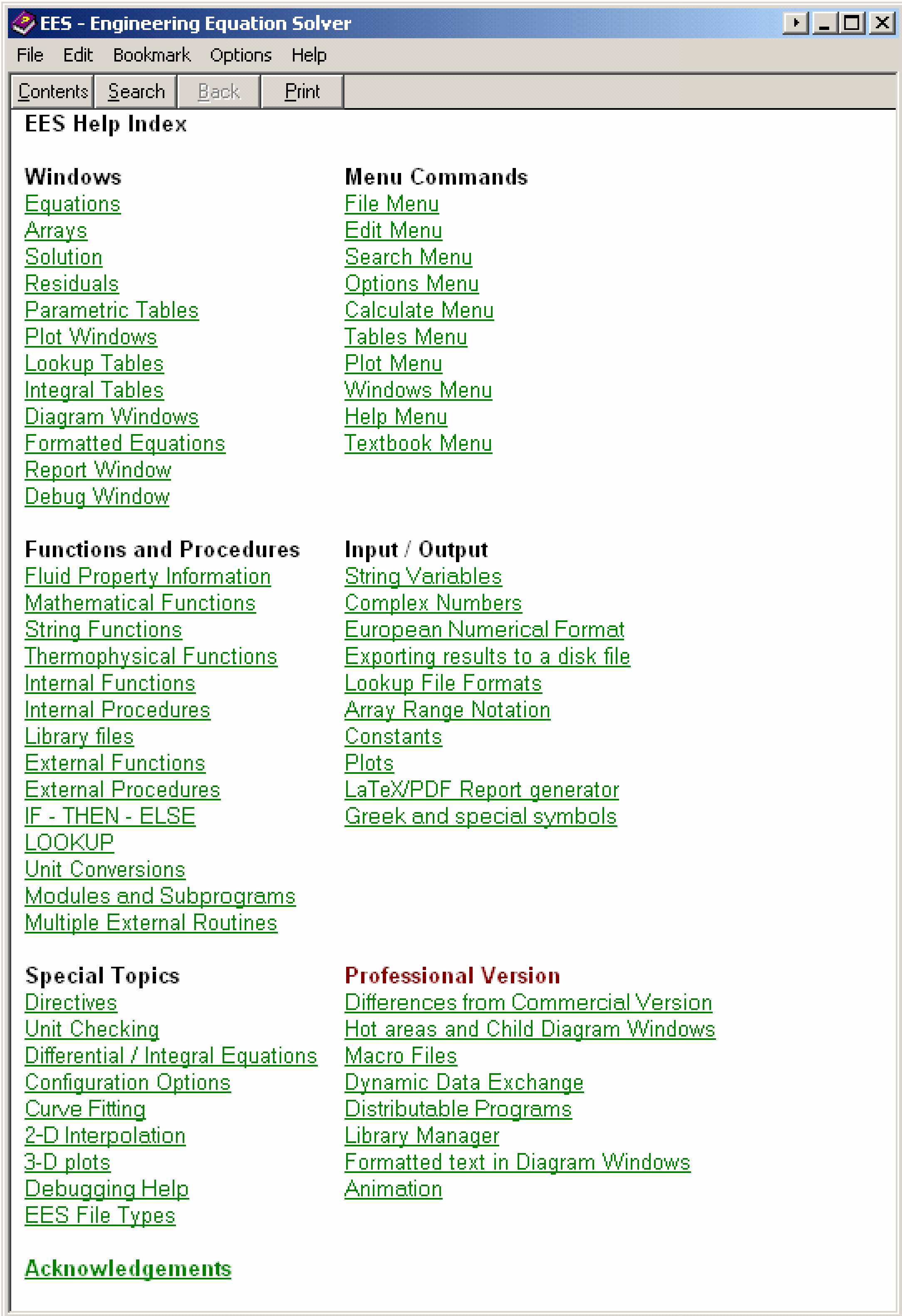
F-Chart Software, LLC
Box 44042
Madison, WI 53744
http://fchart.com email: info@fchart.com

Background Information

The EES program is probably installed on your departmental computer. In addition, the license agreement for use of EES allows students and faculty in a participating educational department to copy the program for educational use onto their personal computer systems. Ask your instructor for details.

To start EES, double-click on the EES program icon shown above or on any file created by EES having the .EES filename extension. You can also start EES from the Windows Run command in the Start menu by entering EES clicking the OK button. EES begins by displaying a dialog window, which shows registration information, the version number and other information. Click the OK button to dismiss the dialog window.

Detailed help is available at any point in EES. Pressing the F1 key will bring up a Help window relating to the foremost window. Clicking the Contents button will present the Help index shown below. Clicking on an underlined word (shown in green on color monitors) will provide help relating to that subject.



EES commands are distributed among ten pull-down menus. A brief summary of their functions follows.

The System menu is accessible by clicking on the EES icon above the file menu. The System menu is not part of EES, but rather a feature of the Windows Operating System. It holds commands which allow window moving, resizing, and switching to other applications.

The File menu provides commands for loading, merging and saving work files and libraries, and printing. The Load Textbook command in this menu reads the problem disk developed for this text and creates a new menu to the right of the Help menu for easy access to EES problems accompanying this text.

The Edit menu provides the editing commands to cut, copy, and paste information.

The Search menu provides Find and Replace commands for use in the Equations window.

The Options menu provides commands for setting the guess values and bounds of variables, the unit system, default information, and program preferences. A command is also provided for displaying information on built-in and user-supplied functions.

The Calculate menu contains the commands to check, format and solve the equation set. A command to check the units of the equations is also provided.

The Tables menu contains commands to set up and alter the contents of the Parametric and Lookup Tables and to do linear regression on the data in these tables. The Parametric Table, which is similar to a spreadsheet, allows the equation set to be solved repeatedly while varying the values of one or more variables. The Lookup table holds user-supplied data which can be interpolated and used in the solution of the equation set.

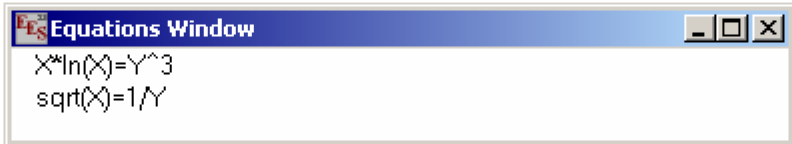
The Plot menu provides commands to prepare a new plot of data in the Parametric, Lookup, Array or Integral tables or to modify an existing plot. Curve-fitting capability and thermodynamic property plots are also provided.

The Windows menu provides a convenient method of bringing any of the EES windows to the front or to organize the windows.

The Help menu provides commands for accessing the online help documentation.

The Thermodynamics menu provides access to EES solutions to problems in this text.

A basic capability provided by EES is the solution of a set of non-linear algebraic equations. To demonstrate this capability, start EES and enter this simple example problem in the Equations window.

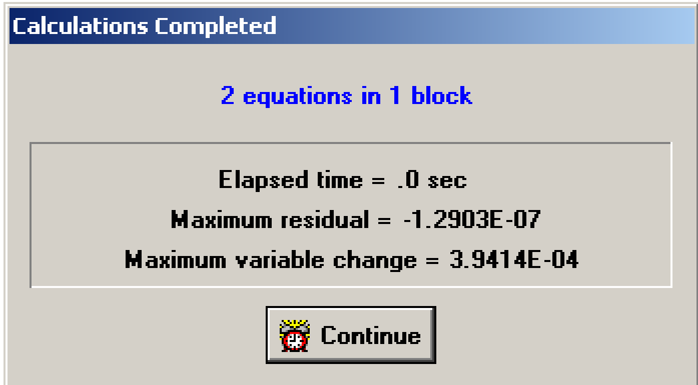


Text is entered in the same manner as for any word processor. Formatting rules are as follows:

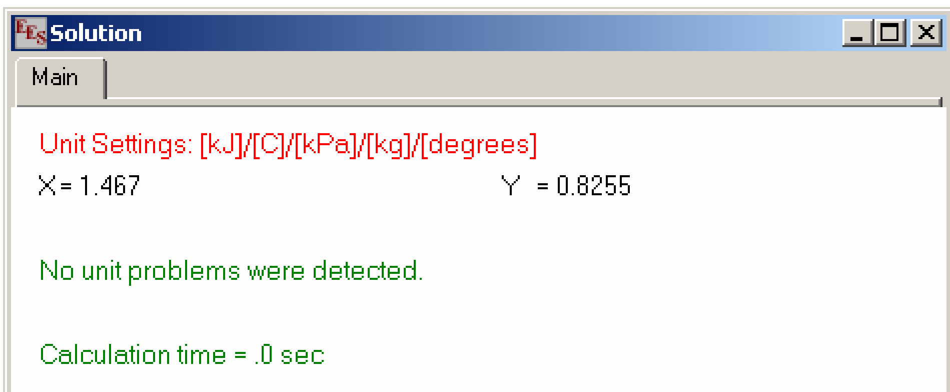
1. Upper and lower case letters are not distinguished. EES will (optionally) change the case of all variables to match the manner in which they first appear.
2. Blank lines and spaces may be entered as desired since they are ignored.
3. Comments must enclosed within braces { } or within quote marks " ". Comments may span as many lines as needed. Comments within braces may be nested in which case only the outermost set of { } are recognized. Comments within quotes will also be displayed in the Formatted Equations window.
4. Variable names must start with a letter and consist of any keyboard characters except ( ) ' | * / + - ^ { } : " or ;. Array variables are identified with square braces around the array index or indices, e.g., X[5,3]. The maximum variable length is 30 characters.
5. Multiple equations may be entered on one line if they are separated by a semi-colon (;).
6. The caret symbol (^) or ** is used to indicate raising to a power.
7. The order in which the equations are entered does not matter.
8. The position of known and unknown variables in the equation does not matter.

If you wish, you may view the equations in mathematical notation by selecting the Formatted Equations command from the Windows menu or from the Formatted Equations speed button located below the menu bar or by pressing ctrl-F.

Select the Solve command from the Calculate menu or press F2. A dialog window will appear indicating the progress of the solution. When the calculations are completed, the button will change from Abort to Continue.



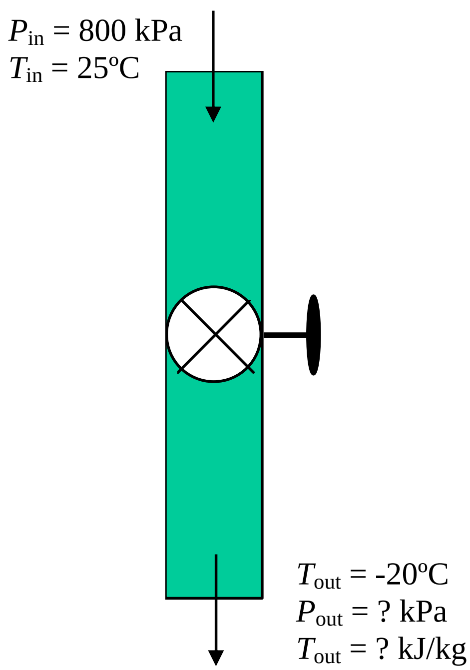
Click the Continue button. The solution to this equation set will then be displayed.



AN EXAMPLE PROBLEM

In this section, Problem 5-70 from the text is worked from start to finish illustrating the built-in fluid property routines and some other capabilities of the EES program. EES is particularly appropriate for this problem since it requires property data information that would have to be interpolated from property tables if the problem were done by hand. The problem to be solved is this.

> Refrigerant-134a at 800 kPa and 25°C is throttled to a temperature of -20°C. Determine the pressure and internal energy of the refrigerant at the final state.



This problem requires mass and energy balances on the steady-flow system shown in the figure. To solve this problem, it is necessary to select a system and set up appropriate mass and energy balances. The logical system choice is the throttle. The mass flow is steady and there is only one inlet and one outlet. No indication of the mass flow rate is provided in the problem statement so the analysis will be done on a per unit mass basis by assuming both $\dot{m}_{in}$ and $\dot{m}_{out}$ to be 1 kg/s.

An energy balance on the throttle neglecting kinetic and potential energy contributions and considering steady-state operation is

$$\dot{m}_{in} h_{in} - \dot{m}_{out} h_{out} + \dot{Q} - \dot{W} = 0$$

where h is the enthalpy [kJ/kg], $\dot{Q}$ is the rate of net heat transfer input [kW], and $\dot{W}$ is the net power output [kW]. The valve is assumed to be well-insulated with no moving parts so that both $\dot{Q}$ and $\dot{W}$ are zero.

From relationships between the properties of R-134a:

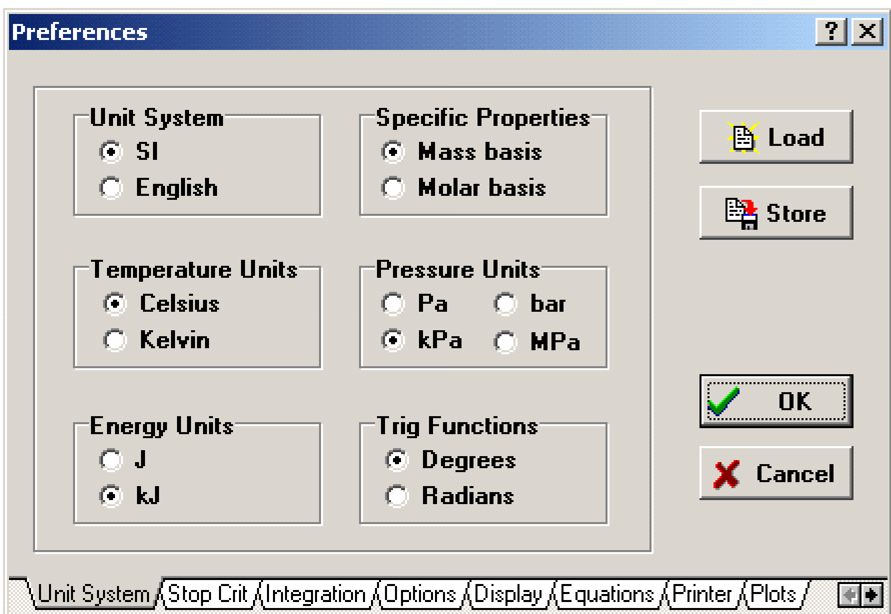
$$h_{in} = h(T_{in}, P_{in})$$

Solving the above equations shows that $h_{in} = h_{out}$. All that is needed to complete the problem is to determine the pressure and internal energy that results in a temperature of -20°C at this value of enthalpy.

$$P_{out} = P(T_{out}, h_{out})$$
$$u_{out} = u(T_{out}, h_{out})$$

The values of $\dot{m}_{in}$, $\dot{m}_{out}$, $\dot{Q}$, $\dot{W}$, T_{in}, P_{in}, and T_{out} are all known. There are four unknowns: P_{out}, h_{in}, h_{out}, and u_{out}. Since there are four equations, the solution to the problem is defined. It is now only necessary to solve the equations. This is where EES can help.

Start EES or select the New command from the File menu if you have already been using the program. A blank Equations window will appear. Before entering the equations, however, set the unit system for the built-in thermophysical properties functions. To view or change the unit system, select Unit System command in the Options menu.



The equations can now be entered into the Equations window. Formatting rules were discussed earlier in this appendix. After entering the equations for this problem and (optionally) checking the syntax using the Check/Format command in the Calculate menu, the Equations window will appear as shown. Comments (within quotes) are normally displayed in blue on a color monitor. Other formatting options are set with the Preferences command in the Options menu. Note that the $TabStops directive has been used here to set tabs so that the comments are lined up.

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Equations Window

"!Problem 5-70  from Thermodynamics: An Engineering Approach, 6th ed by Y.A. Çengel and M.A. Boles"

"Refrigerant-134a at 800 kPa and 25 C is throttled to a temperature of -20 C.  Determine the pressure and
internal energy of the refrigerant at the final state."

"Given:"
Refrig$='R134a'
P_in=800 [kPa]
T_in=25 [C]
T_out=-20 [C]

"Analysis"
m_dot_in=m_dot_out                              "steady-state mass balance"
m_dot_in=1                                      "mass flow rate is arbitrary"
m_dot_in*h_in-m_dot_out*h_out+Q_dot-W_dot=0     "steady-state energy balance"
Q_dot=0                                         "assume the throttle to operate adiabatically"
W_dot=0                                         "throttles do not have any means of producing power"
h_in=enthalpy(Refrig$,T=T_in,P=P_in)            "property  evaluation"
P_out=pressure(Refrig$,T=T_out,h=h_out) "       property evaluation"
u_out=intEnergy(Refrig$,T=T_out,h=h_out)        "property  evaluation"
x_out=quality(Refrig$,T=T_out,h=h_out)          "x_out is the quality at the outlet"

$tabStops 0.25 2.75 in
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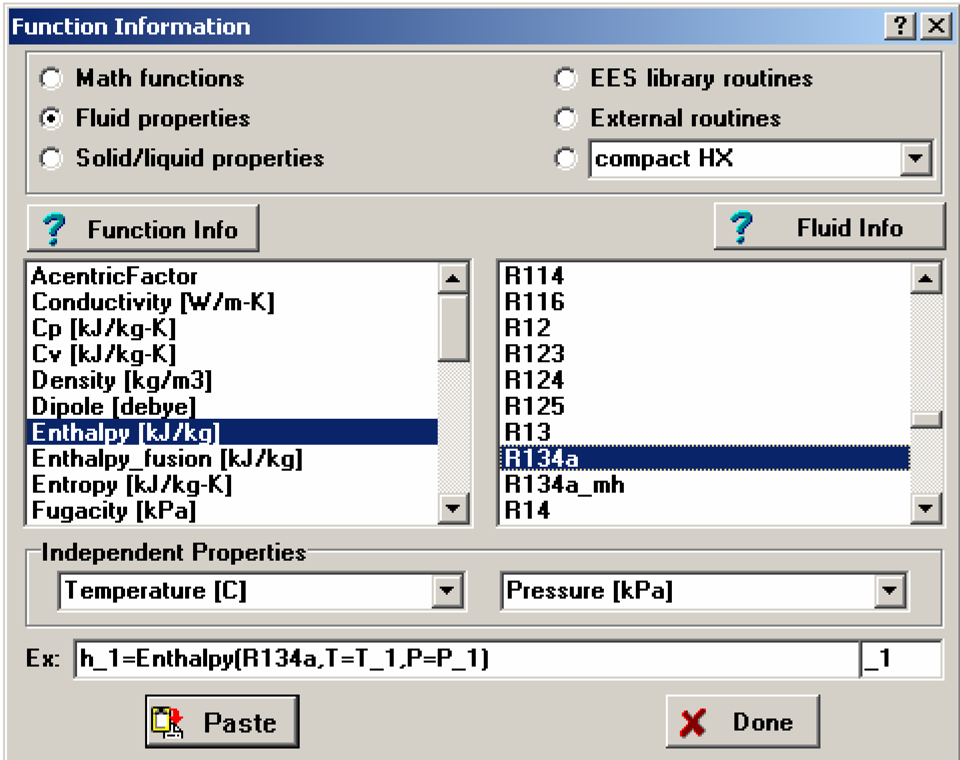
Many of the variable names include an underscore. The underscore is a special formatting character that indicates the start of a subscript. Using underscores is optional, but it improves the display of the Formatted Equations and Solutions window. Note that the units of many of the numerical constants are specified in square braces following the numerical value. The units of each variable can also be specified in the Solution window and with the Variable Information command in the Options menu. Specifying the units of each variable is very important since it allows EES to check the equations for unit consistency.

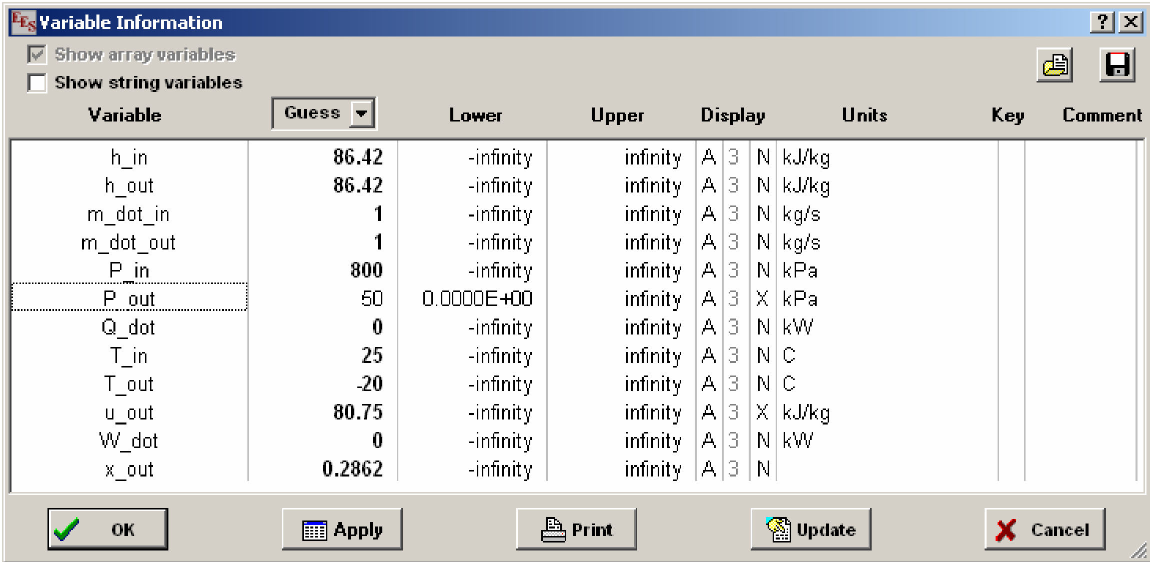
The thermodynamic property functions, such as enthalpy and intEnergy require a special format. The first argument of the function is the substance name. The substance name can be a name, for example, R134a, or a string variable which is identified by a $ as the last character in the name, for example, Refrig$. The use of a string variable as is done here makes it very easy to change the analysis for different fluids. The following arguments are the independent variables preceded by a single identifying letter and an equal sign. Allowable letters are T, P, H, U, S, V, and X, corresponding to temperature, pressure, specific enthalpy, specific internal energy, specific entropy, specific volume, and quality. (For psychrometric functions, additional allowable letters are W, R, D, and B, corresponding to humidity ratio, relative humidity, dewpoint temperature, and wetbulb temperature.)

An easy way to enter functions, without needing to recall the format, is to use the Function Information command in the Options menu. This command will bring up the dialog window as shown. Click on the “Fluid properties” radio button. The list of built-in fluid property function will appear on the left with the list of substances on the right. Select the property function by clicking on its name, using the scroll bar, if necessary, to bring it into view. Select a substance in the same manner. An example of the function showing the format will appear in the Example rectangle at the bottom. The information in the rectangle may be changed, if needed. Clicking the Paste button copies the Example into the Equations window at the cursor position.



It is usually a good idea to set the guess values and (possibly) the lower and upper bounds for the variables before attempting to solve the equations. This is done with the Variable Information command in the Options menu. Before displaying the Variable Information dialog, EES checks syntax and compiles newly entered and/or changed equations, and then solves all equations with one unknown. The Variable Information dialog will then appear.

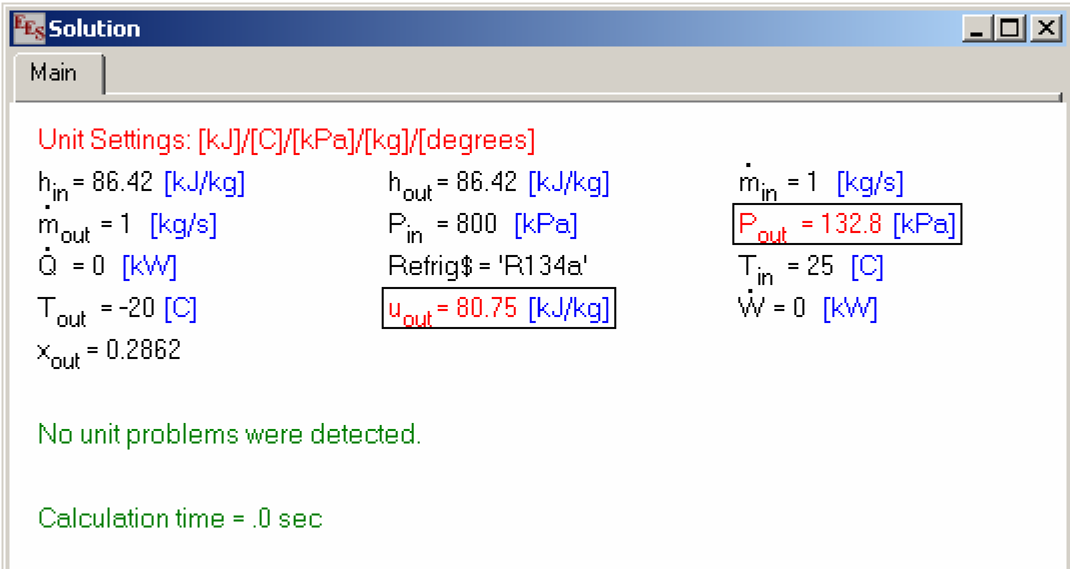
The Variable Information dialog contains a line for each variable appearing in the Equations window. By default, each variable has a guess value of 1.0 with lower and upper bounds of negative and positive infinity. If EES has already determined the value of a variables, its value (rather than a guess value) is shown in bold font. These values can still be edited, if necessary.



With nonlinear equations, it is sometimes necessary to provide reasonable guess values and bounds in order to determine the desired solution. It is not necessary for this problem. The bounds of some variables are known from the physics of the problem. In this example problem, the pressure at the outlet must be greater than 0. Set the guess value of P_out to 50 and its lower limit to 0 as shown in the figure.

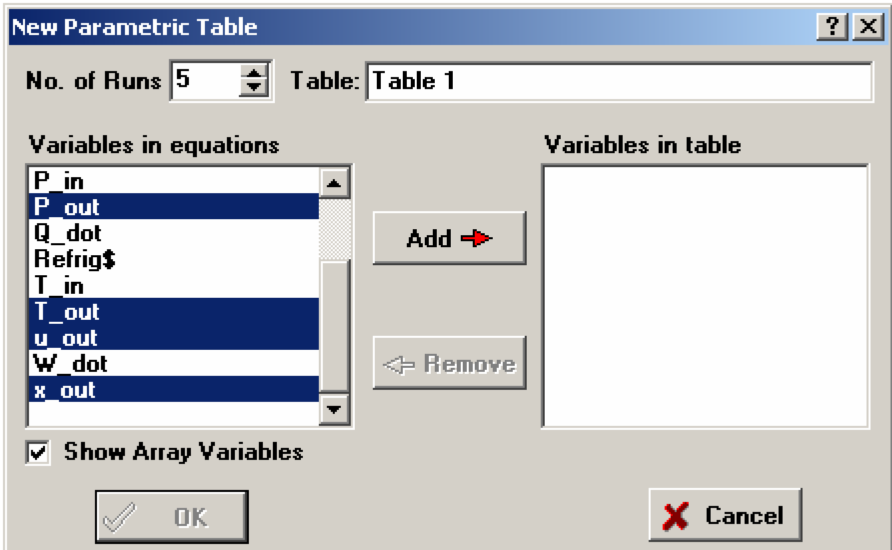
The A in the Display options column indicates that EES will automatically determine the display format for numerical value of the variable when it is displayed in the Solution window. In this case, EES will select an appropriate number of digits, so the digits column to the right of the A is disabled. Automatic formatting is the default. Alternative display options are F (for fixed number of digits to the right of the decimal point) and E (for exponential format). The display and other defaults can easily be changed with the Default information command in the Options menu. The third Display options column controls the highlighting effects such as normal (default), bold, and boxed. The Units column shows the units assigned to the variable. The units that were specified in comments in the Equations window will appear here. Units can be modified or entered. However, the units set with comments in the Equations window will override the specifications made in the Variable Information dialog. The units will be displayed with the variable in the Solution window and in the Parametric Table. EES does not automatically do unit conversions but it does provide automatic unit consistency checking. Unit errors are frequently the cause of an incorrect solution, so the unit-checking capability is quite important. Variables can be designated as key variables by clicking in the Key column. Key variables will display in a separate Solution window. The final column provides an optional comment for each variable.

To solve the equation set, select the Solve command from the Calculate menu and the Solution window will appear. The problem is now completed since the values of P_{out} and u_{out} are determined. If the Check Units Automatically control in the Preferences dialog (Options menu) is checked, EES also checks the unit consistency of the equations as it solves them and reports the results in the Solution window. The units, in addition to format information such as the number of significant figures that are displayed, can be entered by clicking the right mouse button (or double-clicking the left mouse button) on the variable name in the Solution Window. If units have not been set for a variable, EES will try to determine the units and will display these units in red in Solutions Window.



One of the most useful features of EES is its ability to provide parametric studies. For example, in this problem, it may be of interest to see how the throttle outlet pressure varies with outlet temperature. A series of calculations can be automated and plotted in EES.

Select the New Parametric Table command in the Tables menu. A dialog will be displayed listing the variables appearing in the Equations window. In this case, we will construct a table containing the variables P_out, T_out, u_out, and x_out. Click on P_out from the variable list on the left. This will cause P_out to be highlighted and the Add button will become active. Repeat for T_out, u_out, and x_out, using the scroll bar to bring the variable into view if necessary. As a short cut, you can double-click on the variable name in the list on the left to move it to the list on the right. You can also select multiple variables at one time. The table setup dialog should now appear as shown. Click the Add button to move the selected variables into the list on the right. Select 5 for the number of runs. Click the OK button to create the table.

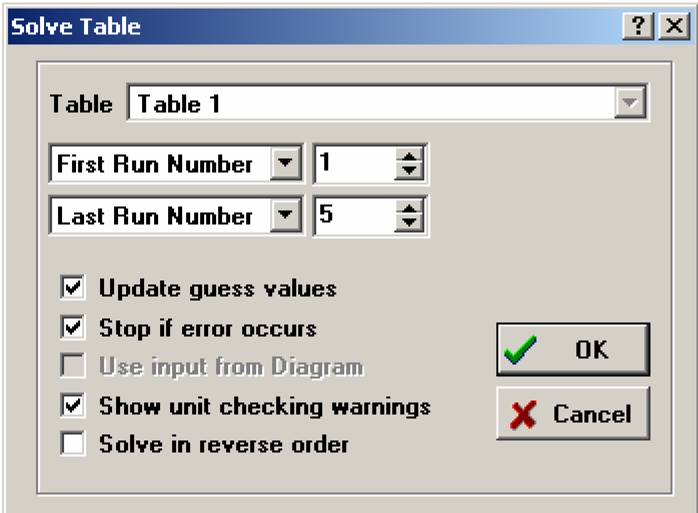


The Parametric Table works much like a spreadsheet. You can type numbers directly into the cells. Numbers that you enter are shown in black and produce the same effect as if you set the variable to that value with an equation in the Equations window. Delete the T_out = -20 equation currently in the Equations window or enclose it in comment brackets { }. This equation will not be needed because the value of T_out will be set in the table. Now enter values of T_out in the table for which P_out is to be determined. Values of T_out between -40ºC to 0ºC have been chosen for this example. (The values could also be automatically entered using Alter Values in the Tables menu or by using the Alter Values control at the upper right of each table column header.) The Parametric Table should now appear as shown.

Parametric Table — Table 1

1..5	1 P_{out} [kPa]	2 T_{out} [C]	3 u_{out} [kJ/kg]	4 x_{out}
Run 1		-40		
Run 2		-30		
Run 3		-20		
Run 4		-10		
Run 5		0		

Now, select Solve Table from the Calculate menu. The Solve Table dialog window will appear, allowing you to choose the runs for which calculations will be done.

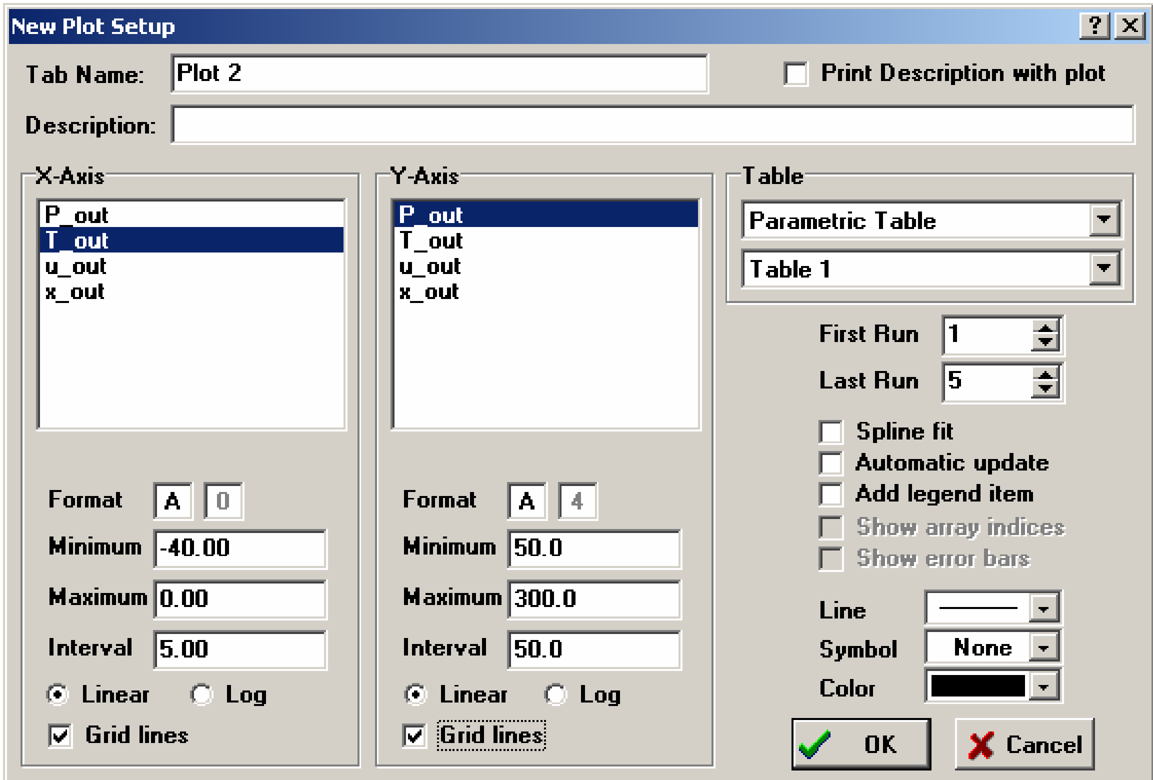


When the Update Guess Values control is selected, as shown, the solution for the last run will provide guess values for the current run. Click the OK button. A status window will be displayed, indicating the progress of the solution. When the calculations are completed, the calculated values of P_out, u_out, and x_out will be entered into the table. The values calculated by EES will be displayed in blue, bold, or italic type depending on the setting made in the Screen Display tab of the Preferences dialog window in the Options menu.

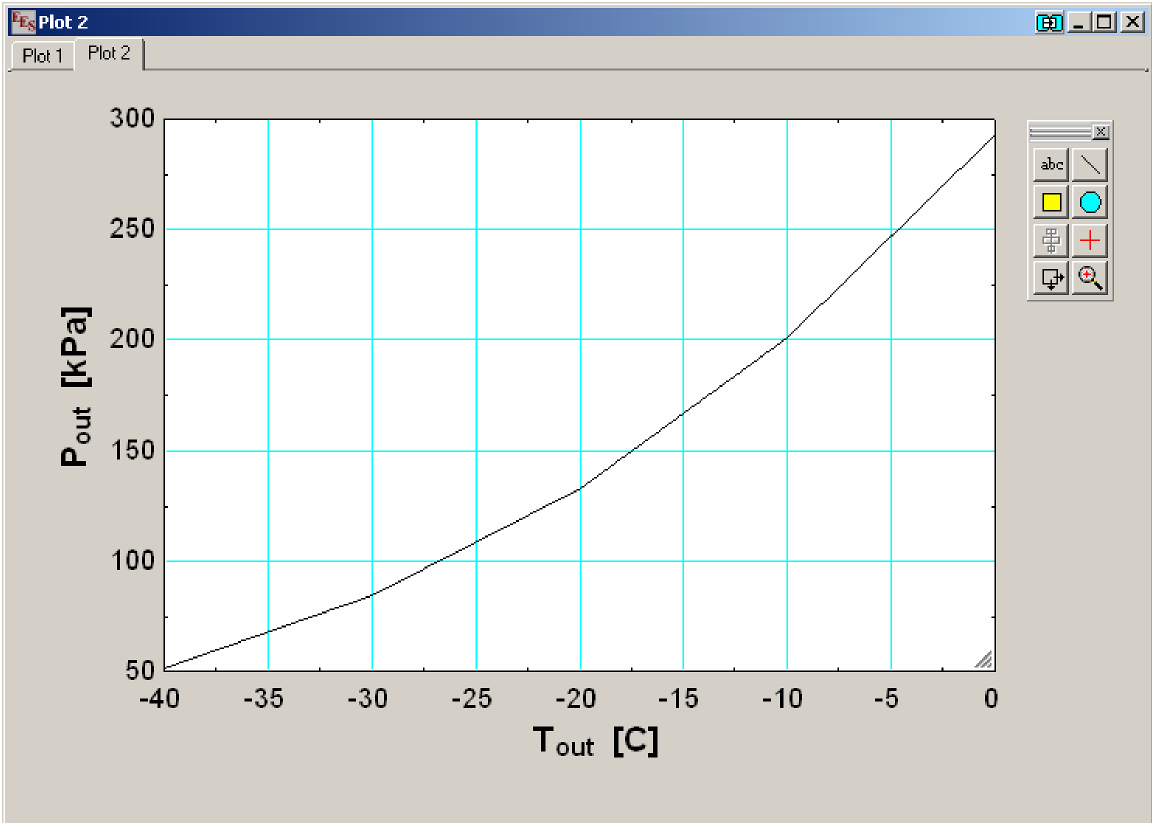
Parametric Table — Table 1

1..5	1 P_{out} [kPa]	2 T_{out} [C]	3 u_{out} [kJ/kg]	4 x_{out}
Run 1	51.25	-40	79.33	0.3826
Run 2	84.43	-30	79.98	0.3361
Run 3	132.8	-20	80.75	0.2862
Run 4	200.7	-10	81.66	0.2325
Run 5	293	0	82.7	0.1741

The relationship between variables such as P_out and T_out is now apparent, but it can more clearly be seen with a plot. Select New Plot Window from the Plot menu. The New Plot Setup dialog window shown will appear. Choose T_out to be the X-axis by clicking on T_out in the X-axis list. Click on P_out in the Y-axis list. You may wish to adjust the scale limits or add grid lines. When you click the OK button, the plot will be constructed and the plot window will appear as shown.



Once created, there are a variety of ways in which the appearance of the plot can be changed. Double-click the mouse in the plot rectangle or on the plot axis to see some of these options. For example, select the Spline Fit option to smooth the curve.



USING THE TEXTBOOK MENU

A number of problems from this textbook have been solved using EES. These examples are accessible from the Thermodynamics menu to the right of the Help menu. As an example, select Chapter 5 from the Thermodynamics menu. A dialog window will appear listing the problems in Chapter 5. Select Problem 5–70. This problem is a modification of the problem you just entered. It provides a Diagram Window in which you can enter the input variables. Enter values and then select the Solve command in the Calculate menu to see their effect on the output properties.

At this point, you should explore. Try whatever you wish. You can't hurt anything. The online help (invoked by pressing F1) will provide details for the EES commands. EES is a powerful tool that you will find very useful in your studies.