A Simple Introduction to EES Version 7.441 (Handout version 5.1)
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The BE-381 textbook, Cengel & Turner, 2 ed., comes with a limited version of the EES software package. The academic version of this software (good until next fall) is available as *setup_ees.exe* in the be381 folder of Dr. Tritt's faculty out directory. The software is designed for solution of engineering problems involving multiple equations and unknowns. It includes thermophysical properties for common substances and can check units. It is a very useful tool and I encourage you to use it on at least some homework problems.

This handout is intended to introduce the key features of the EES software package. For more information, see Appendix 3 in the textbook, the sample problems in the electronic EES textbook (described below) and EES's online help.
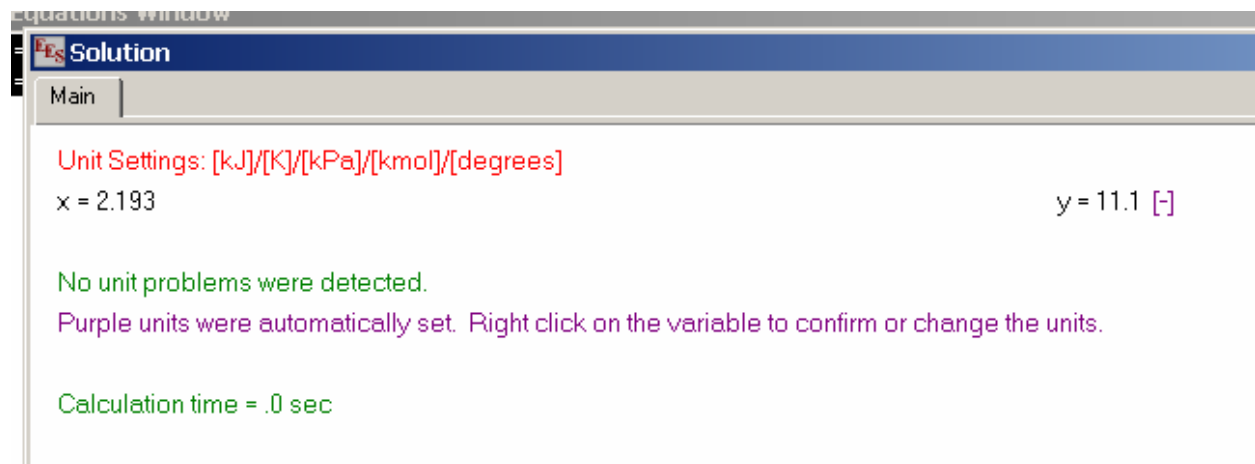
Example 1 – Find the point where the line $y = 0.5x + 10$ intersects the cubic $y = 2x^3 – 10$.

Start EES and select *File | New* to create a new workspace.

Enter the following text in the *Equations Window*:

```
y = 0.5*x + 10
y = 2*x^3-10
```

Select Calculate | Solve (or just press F2) to solve the system of equations. The following *Solution* window should appear showing the results.

Example 2 – Find the volume of 3.00 kg of a mixture of water liquid and vapor 20.0 kPa having a quality (mass fraction of vapor) of 0.90.

If necessary, create a new EES workspace.

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Check the default units in effect by selecting *Options | Unit System* and confirm default units of *SI*, *Mass basis*, *kPa* and *Celsius* are selected. Close the dialog (by clicking on *OK* or *Cancel*) to continue with the specification of your problem.

Activate the EES function selection dialog by selecting *Options | Function Info*. Select *Fluid properties*, *VOLUME [m3/kg]* and *Steam* (or *Water*). View the help text for the enthalpy function and steam proprieties by clicking on the *Function Info* and *Fluid Info* buttons, respectively. For more information on functions, click on the *Thermophysical Function* help link at the bottom of the enthalpy help text.

The following has been taken in part from the EES Thermophysical Functions and Fluid Properties help text (from an older version of EES):

> Built-in thermophysical property functions include CONDUCTIVITY (thermal conductivity), DENSITY, DEWPOINT, ENTHALPY, ENTROPY, HUMRAT (humidity ratio, m_{H2O}/m_{BDA}), INTENERGY (internal energy), ISENTROPICINDEX (isentropic index, C_p/C_v), MOLARMASS, P_SAT (saturation pressure), PRANDTL (Prandtl number), PRESSURE, QUALITY, RELHUM, TEMPERATURE, T_SAT (saturation temperature), VISCOSITY, VOLUME and WETBULB.

> The first argument of all built-in thermophysical property functions is the name of the substance. This argument is a string, which may be provided as a string constant (enclosing quote marks are optional) or a string variable. Whenever a chemical symbol notation (e.g., N2, CO2, CH4) is used, the substance is modeled as an ideal gas and the enthalpy and entropy values are based on JANAF table references. The JANAF table reference for enthalpy is based on the elements having an enthalpy value of 0 at 298 K (537 R). The entropy of these substances is based on the Third Law of Thermodynamics. Whenever the substance name is spelled out (e.g., Steam (or Water), Nitrogen, R12, CarbonDioxide, Methane, etc.) the substance is modeled as a real fluid with subcooled, saturated, and superheated phases. Exceptions to this rule occur for Air and AirH2O, both of which are modeled as ideal gases. AirH2O is the notation for air-water vapor mixtures, i.e., psychometrics.

> Aside from the substance name, all arguments in thermophysical property functions are identified by a single case-insensitive letter followed by an equal sign. Arguments must be separated with commas and may be in any order, provided that the substance name is first. The value or algebraic expression representing the value of the argument follows the equal sign. The letters which are recognized in function arguments and their meaning are: B= wet-bulb temperature (only for substance AIRH2O), D=dew-point temperature (only for substance AIRH2O), H=specific enthalpy, P=pressure, R=relative humidity (only for substance AIRH2O), S=specific entropy, T=temperature, U=specific internal energy, V=specific volume (=1/density), W=humidity ratio (only for substance AIRH2O) and X=quality

> Many of the thermodynamic functions can take alternate sets of arguments. For example, the ENTHALPY function for steam can be accessed with temperature and pressure as

arguments. Alternatively, the same function can be accessed with entropy and quality as arguments. In general, **any** valid set of arguments can be supplied for thermodynamic functions. The transport functions (CONDUCTIVITY and VISCOSITY), however, require temperature as the argument (for ideal gas substances) or temperature and pressure (for real fluids). An exception is provided for Steam (also Water and Steam_NBS which are now synonymous) in which temperature and specific volume can be provided as the arguments.

Selected EES Fluids –				
Idea Gases –	Real Fluids –			
Air	Ammonia	n-Butane	R11	R290
AirH2O	Ammonia_ha*	n-Butane_ha*	R12	R404A
C2H6	Argon*	Neon*	R13	R407C
C3H8	Carbondioxide*	Nitrogen*	R14	R410A
C4H10	Ethane*	Propane	R22	R500
CH4	Ethylene*	Propane_ha*	R22_ha*	R502
CO	Helium*	Propylene*	R23*	R600
CO2	Isobutane*	Steam*	R32*	R600a
H2	Isopentane*	Steam_IAPWS*	R114	R717
H2O	Methane*	Steam_NBS*	R123	R718
N2	Oxygen*	Water	R134a	R744
NO		Ice	R134a_ha*	RC318
NO2			R141b*	
O2			R152a*	
SO2				

Returning to the example, select *Paste*. This will copy the specified function into the *Equations Window* result in the following line: VOLUME(Water,T=T1,P=P1)). EES can only deal with equations and we were given the mass, pressure and quality, so edit the inserted text to read: V = 3.0 [kg] * VOLUME(Water,P=20.0, X=0.90). The *[kg]* in the previous equation specifies the units of the value 3.0 and is required to prevent EES from assuming the 3.0 is unitless and generating m^3/kg units for *V*. Solve the problem by selecting *Calculate | Solve*. This will open a solution window displaying the result: V = 20.68 [m^3].

Next, check the ESS solution, manually using the table A-5 in the textbook.

V = (3.0 kg)(0.90*7.649 + (1.0 – 0.90)*0.001017 m^3/kg) = 20.65 m^3 (which is close enough)

Example 3 – Find the temperature of super heated steam having an enthalpy of 3000 kJ/kg and a pressure of 200 kPa directly and by using linear interpolation using data from the tables in the back of your book.

Table 1: Interpolation table.

T	h
250	2971.0
?	3000
300	3071.8

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Delete your previous work from the equation window or create a new workspace. Specify the enthalpy value by entering `3000 [kJ/kg] = enthalpy(Steam, T = T1, P = P1)` where *T1* is the quantity to be determined. On the next line in the equations window specify the pressure by entering *P1* = 200 [kPa]. The 200 could replace the *P1* in the enthalpy function call but defining it as a separate equation illustrates the equation solving ability of EES. Solve the specified problem, in this case two equations with two unknowns, by selecting Calculate | Solve (or just by pressing F2) to give T1 = 264.7^{0}C.

To solve this problem manually, you would have to use the following linear interpolation on data from Table A-6 in your textbook as shown in Table 1.

$$y = y_1 + \left(\frac{y_2 - y_1}{x_2 - x_1} \right)(x - x_1)$$

$$T = T_1 + \left(\frac{T_2 - T_1}{h_2 - h_1} \right)(h - h_1)$$

$$y = 250 + \left(\frac{300 - 250}{3071.8 - 2971.0} \right)(3000 - 2971.0) = 264.4^0 C$$

Again, this is close enough.

Example 4

Using EES to complete the following table of properties (a slightly modified version of Problem 3-26).

T (°C)	P (kPa)	v (m^3/kg)	x (quality, unitless)	State
50		4.16		
	200		1.0 (vapor)	Saturated
250	400			
110	600			

Examining Table A-4, I noted that the specified *v* is between v_f and v_g at the given temperature and therefore concluded that the State is (saturated) liquid-vapor mixture. I next turned to EES to determine the quality. I entered the following lines in the *Equation Window*:

```
4.16 [m3/kg] = VOLUME(Water, T=50, X=x1)
P1 = P_Sat(Water, T=50)
```

Pressing F2 resulted in EES displaying an error message indicating *x1* must be between 0.0 and 1.0. The error was the result of EES trying x1 outside of the permitted range while trying to solve the equation. The solution to this problem is to select *Options | Variable Info* and 0 for the *Lower* bound and 1 for the *Upper* bound of x1. Pressing F2 after making this change resulted in the display of the answers *x1* = 0.3456 and *P1* = 12.34 kPa. I could have more easily used the

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QUALITY function, but this would not have allowed me to demonstrate the *Options | Variable Info* dialog.

Solving this problem manually using data from Table A-4 gives:

$$x = \frac{v - v_f}{v_g - v_f} = \frac{4.16 - 0.001012 \, m^3/kg}{12.03 - 0.001012 \, m^3/kg} = 0.346$$

$P = P_{sat} = 12.349$ kPa

Which are close to the values provided by EES.

Moving on to the second row in the table. By definition, saturated vapor has a quality of 1 (saturated liquid would have a quality of 0). The lines:

```
T = T_SAT(Steam,P=200)
v = VOLUME(Steam,P=200,x=1)
```

Pressing F2 produces the results T = 120.2°C and v = 0.8865 m³/kg. Looking up the values in Table A-5 (being careful with the pressure units) gives T = 120.23°C and v = 0.8857 m³/kg.

Moving to the third line of the table, the fact that both T and P are specified makes it likely the state is super heated. Checking the Table A-4 and finding P_{sat} = 3.973 MPa at 250°C and checking Table A-5 and finding T_{sat} = 143.63°C at 400 kPa confirms this. Moving to Table A-6 indicates v = 0.5951 m³/kg. Solving the equation `v = VOLUME(Steam,P=400,T=250)` with EES gives v= 0.5951 m³/kg, an exact match.

Finally, moving to the last row and comparing its temperature and pressure to those in the second row I guess that the state will be subcooled (a.k.a., compressed). I test this hypothesis by looking in Table A-5 (Table A-4 could have also been used). I note that T_{sat} = 158.85°C at 600 kPa. Since the specified temperature is less than this value, I know the state is subcooled. The rule of volumes of subcooled liquids is to use the liquid volume at the specified temperature (in this case 110°C). Using Table A-4, I find v = 0.001052 m³/kg. The given temperature and pressure volume can be entered directly into the volume function in EES (`v = VOLUME(Water,T=110,P=600)`) to give v = 0.001051 m³/kg.

The competed table (with determined values in red) is:

T (°C)	P (kPa)	v (m³/kg)	x (quality, unitless)	State
50	12.34	4.16	0.3456	Saturated
120.2	200	0.8865	1.0 (vapor)	Saturated
250	400	0.5951	n.a.	Superheated
110	600	0.001052	n.a.	Subcooled

Comments

In EES, comments may be enclosed within braces { } or within quote marks " ". Comments within braces may be nested in which case only the outermost set of { } are recognized. Comments within quotes are displayed in the *Formatted Equations* window. Comments that begin with an exclamation mark (!) will appear in a different font or color as determined by the settings made with the *Preferences* command in the *Options* menu. Comments may be of any length and may span as many lines as needed. Comments will automatically line break to fill the *Equations* window if the *Wrap Long Lines* option in the *Preferences Equations* tab is selected. The *Formatted Equations* window will also line break the comments in the display window and in the printed output.

Features not Discussed

EES is a very sophisticated problem-solving environment. In this handout, I have not described its units handling features (see *Options | Unit Conversion info*), built in constants (see *Options | Constants*), the use of *Diagram* windows, the use of *parametric* tables, using EES to generate plots and creating selection structures in EES. All of these features are covered in the EES manual (*ees_manual.pdf* in the EES folder (by default *c:\EES_AV*), online help and textbook examples.