1. **When do I use c_p or c_v?**

   First, one must apply the conservation of energy principle to the system to determine how the heat transfer and work are related to changes in enthalpy or internal energy. For ideal gas systems, the change in enthalpy is given by the integral of the specific heat at constant pressure c_p with respect to temperature ($\Delta h = \int C_p(T)\, dT$), and the change in internal energy is given by the integral of specific heat at constant volume c_v with respect to temperature ($\Delta u = \int C_v(T)\, dT$).

2. **How is the unit kJ/kg related to m^2/s^2?**

   The unit kJ/kg is related to m^2/s^2 through the definition of the Joule and the Newton and can be shown to be equal to $1000\ m^2/s^2$.

3. **How do I know when to use Δu or Δh in my energy balances?**

   When to use Δu or Δh in energy balances depends upon the type of system being analyzed. If the system is a closed system, the classical form of the first law states that the heat added to a system minus the work done by a system equals the change in internal energy of the working fluid. If the system is an open system or control volume, the open system first law requires that if there is mass crossing the control surface, then energy is transported by the mass crossing the control surface. This energy is associated with the enthalpy and kinetic and potential energies of the flow. For open systems or control volumes the heat transfer minus the work done by the open system is related to the enthalpy change of the flowing fluid.

4. **How do I know which form of the first law to apply?**

   The form of the first law used in the solution to thermodynamics problems depends upon the type of system being analyzed. If the system is a closed system, the closed system first law applies. If the system is an open system or control volume, the steady-flow form of the first law applies. If the problem is an unsteady-flow problem, one may be able to approximate the solution by applying the uniform-state, uniform-flow form of the first law.

5. **How do I find the properties of an incompressible liquid when there are no data tables for the compressed liquid?**

   When there are no compressed liquid tables, the properties of an incompressible liquid may be approximated by the saturated liquid properties at the temperature of the substance. In the case of the enthalpy one may make a correction for the effect of pressure. Since the properties of incompressible liquids are more temperature dependent than pressure dependent, a significant error is made if the incompressible liquid properties are taken to be the saturated liquid properties evaluated at the pressure.

6. How do I find the enthalpy change for an incompressible liquid?

The enthalpy change of an incompressible liquid may be calculated as the product of the specific heat of the liquid and the temperature change. If the initial and final temperatures of the incompressible liquid are known, the change in enthalpy may be approximated as the difference in the saturated liquid values of the enthalpies at the respective temperatures.

7. What is quality and how do I use it to find properties of real substances?

Quality is defined as the ratio of the mass that is saturated vapor to the total mass of saturated liquid and saturated vapor in a two phase or saturated liquid-vapor mixture. One determines the average specific volume, specific internal energy, specific enthalpy and specific entropy by summing the saturated liquid value and the product of the quality and the difference between the saturated vapor and saturated liquid values of the properties. This technique gives the mass weighted average of these properties in the saturation region.

8. Can quality be greater than 1 or less than zero?

Quality is only defined in the two-phase or saturation region and must have values in the range of zero to one. For a saturated liquid the quality is zero. For a saturated vapor the quality is one. If one tries to calculate the quality for a compressed liquid state, a negative value will be found. The quality will have a positive value greater than unity when it is calculated for a superheated state. A value of quality that is less than zero or greater than one is meaningless.

9. What have I done wrong to get a quality that is greater than one or less than zero?

If the quality is greater than one, this usually means that the state is in the superheated region rather than in the saturation region. If the quality is less than one, this usually means that the state is in the compressed liquid region rather than the saturation region.

10. What is a superheated vapor?

A superheated vapor is a substance whose temperature is greater than the saturation temperature at the pressure of the substance.

11. What is a compressed liquid?

A compressed liquid is a substance whose pressure is greater that the saturation pressure for the temperature of the substance.

12. What is a subcooled liquid?

A subcooled liquid is a substance whose temperature is less than the saturation temperature for the pressure of the substance.

13. How do I find properties of steam or refrigerant 134a?

When finding data for steam or refrigerant 134a, always begin your search in the saturation tables. When the temperature is given, use the saturation temperature table; and if the pressure is given, use the saturation pressure table. Then compare the other data that you have, such as specific volume, specific internal energy, specific enthalpy, or specific entropy, to the saturation values (v_f and v_g, u_f and u_g, etc.). Now, ask the three questions as follows (Here, specific volume is used as the example; but, the same technique applies to the other properties u, h, and s):

(a) Is $v < v_f$ at the state? If so, the state is in the compressed liquid region. Approximate all the intensive data, v, u, h, and s, as the saturated liquid value at the given value of the temperature. Do not the use the saturation data at the given pressure because this would result in a very poor approximation to compressed liquid data.

(b) Is $v_f < v < v_g$ at the state? If so, the state is in the two-phase or saturation region. Use the given value of the specific volume to determine the quality at the state. This is done by solving the mass-weighted averaged equation, $v = v_f + x(v_g-v_f)$, for the quality x. Then use the quality x to determine the other intensive properties by a similar mass-weighted average equation for those properties. The pressure and temperature for the state are those equal to the saturation values.

(c) Is $v_g < v$ at the state? If so, the state is in the superheat region. Go to the superheat table and look for the state. You may have to interpolate to get an answer.

If you are given the pressure, find the saturation temperature, Tsat, from the saturation pressure table or estimate the saturation temperature at the pressure from the saturation temperature table. If the given temperature is greater than the Tsat, the state is superheated, and use the superheat tables to determine the other data. If the temperature is less than the Tsat, the state is compressed, and approximate all the intensive data, v, u, h, and s, as the saturated liquid value at the temperature, not the pressure.

If you are given the temperature, get the Psat from the saturation table. If the given P is greater than Psat, the state is compressed. Approximate all the intensive data, v, u, h, and s, as the saturated liquid value at the temperature, not the pressure.

You may look for wording that says the state is a saturated liquid. If so, that state lies on the saturated liquid line, and use v_f, u_f, h_f, and s_f as the intensive values. Or, if the state is a saturated vapor, the state lies on the saturated vapor line, and use v_g, u_g, h_g, and s_g as the intensive values.

14. **I know that mass must be conserved for a steady-flow, one entrance, one exit control volume and that the mass flow rate into the control volume equals the mass flow rate from the control volume. However, why are the volume flow rates at the entrance and exit of the control volume not the same?**

When a gas is the working fluid in steady-flow control volumes such as compressors and turbines, the density and specific volume may significantly change as the gas flows through the device and undergoes changes of state. Mass flow rate is calculated as the product of the density and the volume flow rate or is calculated as the volume flow rate divided by the specific volume. While the mass flow rate is conserved for steady flow, the density and specific volume of the flow may change as the fluid state changes, and the volume flow rate is not constant in general. For the special case of steady flow of an incompressible fluid (a substance in which the density and specific volume are constant), one can show that volume flow rates are conserved. There is one other special case: when mixing streams of the same ideal gas in a steady-flow process, one can show that the exit volume flow rate is the sum of the inlet volume flow rates if and only if the pressure is constant, the specific heat is constant, and the process is adiabatic.

15. **Why can I not use the equation $T_2/T_1 = (P_2/P_1)^{(k-1)/k}$ to relate temperatures and pressures for any process?**

This equation is only used to relate the temperatures and pressure during an isentropic process for a ideal gas having constant specific heats. If the process is not isentropic and the working fluid is an ideal gas, the combined ideal gas equation $P_2V_2/T_2 = P_1V_1/T_1$ may be helpful in determining the required temperature-pressure relation for the process.

16. **Is there heat transfer in a polytropic process PV^n = constant?**

In general the polytropic process is not isentropic; therefore, the polytropic process does have heat transfer. To determine the amount of heat transfer for the process, apply the first law for either a closed system or an open system and use the polytropic process equation to calculate the appropriate form of the work (boundary or steady-flow) for that system. Then evaluate the heat transfer from the first law.

17. How do I determine the properties of steam or refrigerant 134a from the properties if I know only specific internal energy and specific volume (or specific enthalpy and specific entropy) at the thermodynamic state?

Since the property tables generally present the properties of steam and refrigerants as functions of temperature and pressure, it is difficult to determine the state by knowing the internal energy and the specific volume. To make it easier to determine the state at the given value of the specific volume, estimate (or guess) a value of the pressure for the state, determine the internal energy, and compare this value with the known value of the internal energy. Often a plot of u vs P at the known value of specific volume will guide you to better estimates. A similar approach may be used to determine the state of a working fluid when enthalpy and entropy are known. Also one can use the EES software to determine the thermodynamic state.

18. Can I use the saturated liquid property values at the pressure of a system to determine the properties of compressed liquids?

To determine the properties of compressed liquids, one should approximate the properties as the saturated liquid values at the temperature of the system. Since the compressed liquid properties are more temperature dependent than pressure dependent, using the saturated liquid values at the system pressure makes a significant error.

19. When a fluid such as a refrigerant is throttled why does the temperature drop?

The throttling process is assumed to be steady-flow with no work, no heat transfer, and negligible changes in kinetic and potential energies of the flow. Thus, there is no change in the enthalpy of the fluid during the throttling process ($dh = du + d(Pv) = 0$). When throttling ideal gases there is no temperature change ($dh = c_p\, dT = 0$). Depending on the range of the pressure drop during a throttling process, the temperature of a real fluid may decrease or increase. Whether the temperature of a fluid decreases or increases and the magnitude of the temperature change during a throttling process is governed by a property called the Joule-Thomson coefficient, which is discussed in Chapter 12. However, when throttling fluids that have a positive Joule-Thomson coefficient over a specified pressure drop, such as refrigerant-134a, there may be a significant increase in the $d(Pv)$ term such that the du term must decrease in order to make the enthalpy constant. This change in the du term comes about because of the decrease in the molecular kinetic energy portion of the internal energy which results in an overall decrease in the fluid temperature.

20. When charging a tank from a fluid supply line, why does the temperature of the gas in the tank rise above that of the supply line?

When filling a tank the energy of the flow entering the tank is its enthalpy ($h = u + Pv$). Part of this energy is the flow work or flow energy Pv, and this flow energy is converted to sensible internal energy once the flow ceases to exist in the control

volume of the tank, and it shows up as an increase in temperature. The reason that scuba tanks are placed in a water bath when charged with air is to encourage heat transfer from the tank to lower the temperature in the tank to allow more mass to enter the tank.

21. Is there a simple interpolation procedure for determining properties in the steam or refrigerant tables?

To determine the value of any thermodynamic property from the steam, refrigerant, or other data tables, use a linear interpolation scheme. This is easily done by first setting up a table of known independent values A, B, and C and the dependent values X, Y, and Z where X depends upon A and Z depends upon C. Then use the following interpolation scheme (called the ratio of corresponding differences) to find Y for the independent value B.

A	X
B	Y=?
C	Z

$$(Y-X)/(Z-X)=(B-A)/(C-A)$$

22. How do I find the boundary work for a process?

To determine the boundary work for a process, one must integrate the product of the pressure and the differential volume over the process, $W_b = \int P(V)dV$. To complete this integral, the process must be known so that the pressure may be determined as a function of volume.

23. Can I use temperature in degrees Celsius in my calculations?

In general the temperature required for calculations is the absolute temperature in kelvin units. However, a temperature change of 1°C is the same as a temperature change of 1 K. If the difference in temperature T_2-T_1 is required, either temperature in celsius units or kelvin units may be used.

24. When can I use the ideal gas equation?

The ideal gas equation may be used only for those substances at states that satisfy the ideal gas equation of state. In general data states for which the generalized compressibility factor is unity are ideal gas data states. These states occur when the pressure is significantly smaller than the critical pressure of the gas or when the temperature is at least twice the critical temperature and the pressure is less than ten times the critical pressure. When states of a fluid are near its saturation region, it is usually best to use tabular data and not use the ideal gas relations for data collection.

25. Can I use the ideal gas equation for steam or refrigerant 134-a?

In general the ideal gas equation of state and ideal gas relations may not be used to determine properties of steam and refrigerant 134-a. Most often the states of these two substances lie in the compressed liquid region or in the saturated mixture region and clearly do not behave as ideal gases. When these fluids are superheated and their states lie near the saturation region, the ideal gas relations most often give inaccurate results. It is the best policy to treat steam and refrigerant 134-a as real substances and to use the property tables to determine their properties.

26. Why can I treat water vapor in atmospheric air as an ideal gas?

The partial pressure of water vapor in atmospheric air, a mixture of dry air and water vapor, will be less than the saturation pressure of water measured at the atmospheric air mixture temperature. For mixture temperatures less than 50°C, the partial pressure of the water vapor present in the mixture will be less than 12.35 kPa. Since this value of pressure is much less than the critical pressure for water, water vapor can be treated as an ideal gas. The enthalpy of water vapor in atmospheric air is approximated as being equal to the saturated vapor enthalpy at the temperature of the mixture.

27. Should I use the steady-flow work equation $w_{sf} = -\int v(P)dP$ to determine the steady-flow work for an open system?

Since the integral in the steady-flow work equation is often difficult to perform, it is better to try to determine the steady-flow work from the steady-flow first law applied to the open system. However, in the case of an incompressible fluid, the specific volume is assumed to be constant, and the integral is easily completed.

28. Why should I sketch process diagrams?

Sketches of process diagrams when combined with sketches of systems provide insight to the existence and direction of any work or heat transfer that may occur during a process. A P-v plot of the process is made with P on the vertical axis and v on the horizontal axis. The vertical area under the P-v process curve represents positive boundary work when the volume increases during the process, and work is done by the fluid on the surroundings. If the system volume decreases, the area is negative, the boundary work is negative, and work is done on the system by the surroundings. The horizontal area under the P-v process curve represents steady-flow work. If the pressure increases during the steady-flow process, the process is a compressive process, the steady-flow work is negative, and work is done on the control volume. If the pressure decreases during the steady-flow process, the process is an expansion process, the steady-flow work is positive, and work is done by the control volume. One should try to determine steady-flow work by first law applications before attempting to find the horizontal area under a process curve. For

both closed and open systems a T-s plot of the process is made with T on the vertical axis and s on the horizontal axis. The vertical area under the T-s process curve represents positive heat transfer to the system when the entropy increases during the process. If the system entropy decreases, the area is negative, the heat transfer is negative or heat leaves the system.

29. Is volume flow rate conserved?

In general volume flow rate is not conserved. It is mass flow rate that is conserved in a steady-flow process. When a gas is the working fluid in a steady-flow device such as a compressor, turbine, or nozzle, the specific volume may have a significant change and while the mass flow rate is conserved, the volume flow rate is not conserved. For the special case of the steady flow of an incompressible fluid (a substance in which the density and specific volume are constant), one can show that volume flow rates are conserved. Also see answer to Question 14 above.

30. Why isn't the regeneration process in a steam cycle used same way as in the Brayton cycle?

Typically the temperature of the air (or products of combustion) at the exit of a gas turbine in the Brayton cycle has a temperature greater than that of the air leaving the compressor. Therefore, regeneration (the transfer of energy by heat transfer from the turbine exit gas to the compressor exit gas) is effective. However, the state of steam leaving a steam turbine is at such a low pressure (often a vacuum value). Because of such low pressures, the temperature of the steam is also relative low and at a value below the temperature of the water leaving the condensate pump. Thus, there cannot be an energy transfer by heat transfer from the turbine exit steam to the water leaving the pump, and regeneration using the turbine exit steam is not effective. Regeneration in the steam power cycle is accomplished by extracting steam from the turbine at pressures between the turbine inlet high pressure and the turbine exit low pressure. This steam is sent to open or closed feedwater heaters to provide energy to increase the temperature of the feedwater before it enters the steam generator.

31. How do I write the balanced chemical reaction equation for the combustion of a hydrocarbon fuel?

To balance a combustion reaction we note that the amount of air supplied for combustion is based upon the amount of theoretical air required for complete combustion. The best way to balance a combustion reaction follows:

a. Determine the theoretical kmoles of oxygen required for complete combustion. For complete combustion all of the carbon in the fuel is converted to carbon dioxide and all of the hydrogen is converted to water. For example consider the complete combustion of ethanol C_2H_6O.

$$C_2H_6O + A_{th}O_2 \rightarrow 2CO_2 + 3H_2O$$
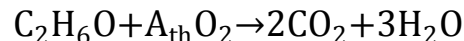
$$O \text{ balance: } 1(1) + A_{th}(2) = 2(2) + 3(1)$$
$$A_{th} = 3$$

Note: It is best to write the oxygen balance based on the atoms of monatomic rather than diatomic oxygen.

The balanced reaction is
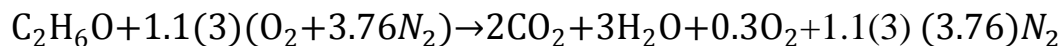
$$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O$$
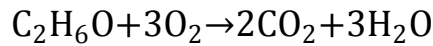
Three kmoles of oxygen are required for the complete combustion of ethanol.

b. For complete combustion with a percent theoretical or excess air, adjust the above reaction to include the amount of air supplied. Recall that for 1 kmole of oxygen we need 4.76 kmoles of air where 3.76 kmoles of nitrogen comes with the oxygen. Consider the complete combustion of ethanol with 110% theoretical air or 10% excess air which means that 1.1(3) kmoles of oxygen are supplied along with the nitrogen that came with each kmole of oxygen in air.

$$C_2H_6O + 1.1(3)(O_2 + 3.76N_2) \rightarrow 2CO_2 + 3H_2O + BO_2 + 1.1(3)(3.76)N_2$$

$$O \text{ balance: } 1(1) + 1.1(3)(2) = 2(2) + 3(1) + B(2)$$
$$B = 0.3$$

The balanced reaction is

$$C_2H_6O + 1.1(3)(O_2 + 3.76N_2) \rightarrow 2CO_2 + 3H_2O + 0.3O_2 + 1.1(3)(3.76)N_2$$

The 0.3 kmoles of oxygen in the products come from the excess oxygen supplied but not used to form carbon dioxide and water.
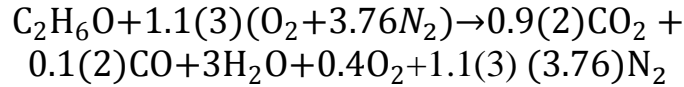
c. For incomplete combustion with a percent theoretical or excess air, adjust the simple complete combustion reaction to include the amount of air supplied. Then adjust the products to include the amount of carbon dioxide and carbon monoxide formed. Assume that all of the hydrogen in the fuel is converted to water. Consider the incomplete combustion of ethanol with 110% theoretical air or 10% excess air when 90% of the carbon is converted to carbon dioxide and 10% is converted to carbon monoxide.

$$C_2H_6O + 1.1(3)(O_2 + 3.76N_2) \rightarrow 0.9(2)CO_2 +$$
$$0.1(2)CO + 3H_2O + DO_2 + 1.1(3)(3.76)N_2$$
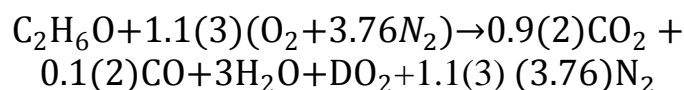
$$O \text{ balance: } 1(1) + 1.1(3)(2) = 0.9(2)(2) + 0.1(2)(1) + 3(1) + D(2)$$

$$D = 0.4$$

The balanced reaction is

$$C_2H_6O + 1.1(3)(O_2 + 3.76N_2) \rightarrow 0.9(2)CO_2 +$$
$$0.1(2)CO + 3H_2O + 0.4O_2 + 1.1(3)\,(3.76)N_2$$

The 0.4 kmoles of oxygen in the products come from the theoretical excess oxygen supplied but not used to form carbon dioxide and water plus the theoretical oxygen not used for carbon dioxide when carbon monoxide is formed.

$$D = 0.3 + \frac{0.2}{2} = 0.4$$

32. Is the enthalpy plotted on the psychrometric chart the enthalpy of dry air used in the energy balance for problems involving mixtures of dry air and water vapor?

The enthalpy plotted on the psychrometric chart is the total enthalpy of the mixture divided by the mass of dry air. The specific enthalpy of the mixture based on the mass of the dry air alone is the sum of the specific enthalpy of the dry air and the product of the specific humidity and the specific enthalpy of the water vapor. This enthalpy is calculated as shown below.

$$h = \frac{H_{total\ mixture}}{\dot{m}_{dry\ air}} = \frac{\dot{m}_{dry\ air}h_{dry\ air} + \dot{m}_{water\ vapor}h_{water\ vapor}}{\dot{m}_{dry\ air}}$$

$$h = h_{dry\ air} + \frac{\dot{m}_{water\ vapor}}{\dot{m}_{dry\ air}}h_{water\ vapor}$$

$$h = h_{dry\ air} + \omega h_{water\ vapor}$$

Thus the enthalpy plotted on the psychrometric chart is not the enthalpy of the dry air alone or the enthalpy of the water vapor. The enthalpy is the enthalpy of dry air and water vapor mixture per unit mass of dry air. For dry air-water vapor mixtures, the enthalpy of the mixture per unit mass of dry air can be determined from the psychrometric chart provided the mixture pressure is atmospheric pressure (or very near atmospheric pressure) and any two of the other independent intensive variables: dry bulb temperature, wet bulb temperature, relative humidity, specific humidity, and dew point temperature.