Week 4 Challenge Homework

Laws of Thermodynamics, Calorimetry, and Heat Transfer

Submit a digital copy (PDF, jpg, etc.) to gradescope.com. Please use the Gradescope interface to associate each page of your submission with the corresponding question number! It makes grading much easier.

Every page should be labeled on the top left with the question number and there should be only be one solution per page. If a solution takes more than one page, be sure to label that it is a continuation of the previous page's solution. If data is needed to complete a problem, be sure to cite the source you've acquired your data from. See the course website for further details.

You will be asked to apply sense-making in some problems. Use the list below as a reference to the different sense-making techniques. More information about sense-making can be found on the BoxSand menu under Math Tools => Sense-making.

- *Sign:* Check the **sign** of each quantity makes sense.
- *Dimensionality:* Check the **dimensionality** and units of each quantity makes sense.
- *Order of Magnitude:* Check the **order of magnitude** of the final answer and other important quantities is within a a factor of 10 of what you think it should be.
- *Graphical Analysis:* Use a **graph** to see if the behavior of a solution makes sense.
- *Proportionality:* Using a symbolic solution, check the behavior of the answer when you change a given quantity on which it is dependent. Does the answer vary **proportionally** to what you expect?
- *Special Cases:* Check the behavior of a derived equation in limiting (**special**) cases makes sense, e.g. as x goes to 90 degrees in sin(x).
- *Self-consistency:* Check derived equations, functions, or values, are **self-consistent**, e.g. check that the slope of a derived position plot matches the values of the given velocity plot
- *Known Values:* Compare given or derived quantities with common well **known values**.
- *Related Quantities:* Compare the relative magnitude of two **related quantities**.

Question 1:

Beer brewing begins with steeping grains in hot water, releasing the sugars inside. The sugar water is then heated to a boil and hops added. The hot temperature of the boil extracts oils from the hops and provides sanitation from unwanted bacteria. The whole mess is cooled down and once it is safe enough for yeast to survive, they are added. The yeast converts the sugars to alcohol, and the oils from the hops provide many things including flavor and antibacterial benefits.

(a) If 16.5 lbs of grain at 67 ºF are added to 5 gal of hot water and the equilibrium temperature of the mixture is to be 154 ºF, what must the initial temperature (strike temp) of the hot water be? The specific heat of malt grains is about 0.44 times that of water. Also assume no energy is lost during the time the system comes to equilibrium.

(b) How much did it cost to heat the 5 gals of tap water from 110 ºF up to the strike temp? Assume the heating takes 47 minutes, electricity costs 15 ¢ per kilowatt-hour, and only 10% energy is lost during heating.

(c) During the one hour steeping stage, where the water and grain mixture started at 154 ºF, the mixture only lost 2 ºF. What was the average energy per time lost by the mixture.

(d) The steeping was done in a cylindrical vessel (cooler) with outside dimensions 20 inches tall and 15 inches in diameter. The thickness of the walls is 1 inch. Estimate the thermal conductivity of the steeping vessel assuming a room temperature of 67 ºF.

Question 2:

At the Earth's distance from the Sun, the intensity of solar radiation is 1370 W/m^2. The temperature of the Earth is affected by the *greenhouse effect* of the atmosphere. This phenomenon is caused be our atmosphere's absorption of infrared light emitted by the surface, which makes the surface temperature of the Earth higher than if it were airless. For comparison, consider a spherical object of radius r with no atmosphere at the same distance from the Sun as the Earth. Assume its emissivity is the same for all kinds of electromagnetic radiation and its temperature is uniform over its surface.

(a) Explain why the projected area over which it absorbs sunlight is πr^2 and the surface area over which it radiates is $4\pi r^2$.

(b) Compute its steady-state temperature.

(c) Use *Known Values* sense-making to determine if this a reasonable value.

(d) Why would an increase in greenhouse gasses such as water vapor, carbon dioxide, and methane be cause for alarm?