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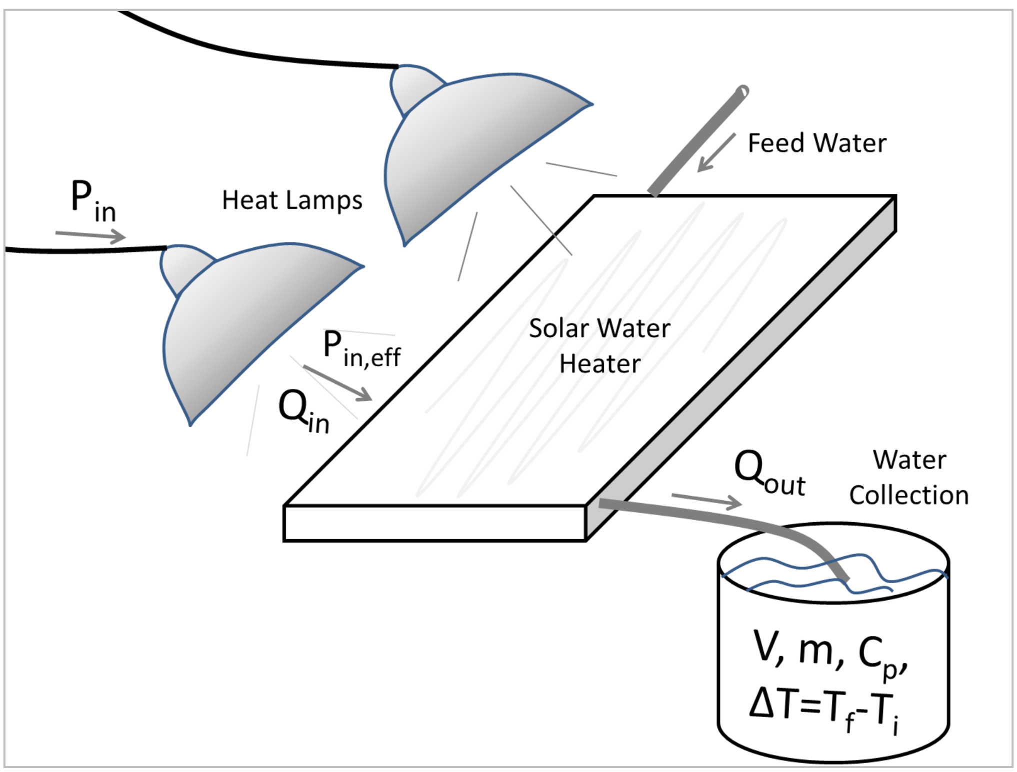
Solar Water Heater Efficiency Analysis

This worksheet will help you evaluate the performance of your solar hot water heaters.

1) During testing, record the following information:

Parameter	Symbol	Value	Units
Total Volume of Water:	V		Gallons
Initial Temperature of Water:	T_i		°F
Total Power of Heat Lamps:	P_{in}		Watts
Time Passed:	Δt		Hours
Final Temperature of Water:	T_f		°F



Schematic of solar water heater setup.

To evaluate how well the solar hot water heater performed, we will calculate its **EFFICIENCY**:

$$Efficiency = \eta = \frac{Heat\ Energy\ Out}{Heat\ Energy\ In} = \frac{Q_{out}}{Q_{in}}$$

2) So first, we'll need to calculate how much **ENERGY** was put **INTO** to the system by finding the total POWER, P_{in}, used by the heat lamps – our simulated sun. The P_{in}, in Watts, is indicated on the light bulbs used:

From above, P_{in} = __________ Watts

Heat lamps are approximately 96% efficient, meaning that they convert 96% of their energy directly into heat. So, we need to figure out how much heat energy came out of the heat lamps based on the power that was used by them.

$P_{in,eff}$ = (96%) * P_{in} = __________ Watts

($P_{in,eff}$ is the total **HEAT POWER** coming out of the heat lamps)

Finally, we need to convert **HEAT POWER** (P_{in}) to **HEAT ENERGY** (Q_{in}). Power is an instantaneous measurement (like miles per hour for measuring the speed of a car). To get to energy (like total miles traveled by the car), we take the **POWER** and multiply it by the **TIME** that the system had that power.

Q_{in} = $P_{in,eff}$ * Δt = __________ Watt-hours

(This is the total **HEAT ENERGY** that came out of the lamps)

For this exercise, we'll convert our **HEAT ENERGY** (Q_{in}) **,** from "Watt-hours" to units of "BTU" which stands for British Thermal Units. Just like comparing inches to centimeters, BTUs are the American (IP) units and Watt-hours are the international (SI) units. One Watt-hour = 3.41 BTUs.

Q_{in} = Q_{in} (units of Watt-hours) * (3.41 BTU/Watt-hour) = ____________BTUs

(This is the total **HEAT ENERGY** (Qin) put into the system)

3) Next, we need to figure out how much **HEAT ENERGY** our solar hot water heaters were able to collect (Q_{out}) and use from the heating lamps (our simulated sun)! The equation we will use to calculate how much **HEAT ENERGY** (Q_{out}) we were able to transfer to our water is:

$$Q_{out} = m * C_p * \Delta T$$

Where, "m" is the total **MASS** of the water (in lbs), " C_p" is the **SPECIFIC HEAT** of water and "ΔT" is the **TEMPERATURE CHANGE** during the test period (in °F). Let's calculate each of those values individually first. Remember to keep track of your units!

Let's start by determining the total **MASS** (m) of the water that we heated. We recorded the total **VOLUME** (V) of water in gallons. First, we'll convert the total **VOLUME** from gallons to ft^3 (cubic feet), knowing that one gallon is equal to 0.1336 ft^3.

$$V = (V \text{ in gallons}) * (0.1336\ ft^3/gallon) = \_\_\_\_\_\_\_\_\ ft^3$$

To convert **VOLUME** (V) to **MASS (m)**, we need to know the **DENSITY** of water, which is equal to 62.42 lbs/ft^3. So,

$$m = (V \text{ in } ft^3) * (62.42\ lbs/ft^3) = \_\_\_\_\_\_\_\_\ lbs$$

(This is the total **MASS** (m) of water in the system)

Great! Now that we have the **MASS** (m) of the water, the next term we need to help us calculate the **HEAT ENERGY** (Q_{out}) collected by our water heaters is the **SPECIFIC HEAT** (C_p) of the material being heated, the material being water in this case. **SPECIFIC HEAT** is a property of a material that describes how much heat energy it takes to warm that material up. Every material has its own specific heat. For water, the specific heat, in IP units, is:

$$C_p \text{ of water} = 1.0\ BTU/(lb\text{-}°F)$$

→This means that it takes 1 BTU of energy to increase the temperature of 1 pound of water by 1°F

Finally, we need to figure out the last term in our equation: the **TEMPERATURE DIFFERENCE** (ΔT) of the water. This **TEMPERATURE DIFFERENCE** (ΔT) of the water was achieved by putting **HEAT ENERGY** (Q_{out}) into the system:

$$\Delta T = T_f - T_i = \_\_\_\_\_\_\_\_\_\_ \ ^\circ F$$

(This is the **TEMPERATURE DIFFERENCE** caused by putting the **HEAT ENERGY** (Q_{out}) into the system)

Alright! Now, we're able to plug in our three values to calculate how much **HEAT ENERGY** (Q_{out}) our water absorbed from the water heater.

$$Q_{out} = m * C_p * \Delta T = \_\_\_\_\_\_\_\_\_ \ BTU$$

4) Now that we've calculated how much **HEAT ENERGY** (Q_{in}) was put **INTO** to the system (our solar water heaters) and how much **HEAT ENERGY** (Q_{out}) we were able to get **OUT** of the system in order to increase the water temperature, we can determine the **EFFICIENCY** our hot water heater:

$$\eta = \frac{Q_{out}}{Q_{in}} = \frac{\_\_\_\_\_\_\_\_\_\_\_\_\_}{} = \_\_\_\_\_\_\_\_ \%$$

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Record your final results here:

Q_{in} =		**BTUs**
Q_{out} =		**BTUs**
η =		**%**

Provide a written interpretation of these results, using complete sentences:

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For example, "Our solar hot water heater was able to heat 2 gallons of water from a starting temperature of 60°F to a final temperature of 106°F after being exposed to two 250 Watt heat lamps for a total of one hour. The efficiency of our hot water heater was 35%, which means that 35% of the energy created by the heat lamps was captured and able to heat the water by 46°F. I would definitely take a shower with that water!"