Investigation 10.B: Build a Heating Device Answer Key

Answers to Plan and Construct Questions

7. (a) The energy output to the water would be calculated using the formula $Q = mc\Delta t$. You would have recorded the following data:
Mass (or volume) of water (m)
Initial temperature of water (t_i)
Final temperature of water (t_f)

From this data, you would calculate the change in temperature, Δt, by subtracting t_i from t_f. You would then calculate Q.

Using the following sample data:
Mass of water = 175.35 g
Initial temperature of water (t_i) = 19.3 °C
Final temperature of water (t_f) = 22.5 °C

$$Q = mc\Delta t$$
$$= (175.35\,\text{g})\left(4.19\,\frac{\text{J}}{\text{g}\bullet{}^\circ\text{C}}\right)(22.5\,{}^\circ\text{C} - 19.3\,{}^\circ\text{C})$$
$$= 2.4\ \text{kJ}$$

(b) The theoretical energy input would be calculated by writing an equation for the combustion of the fuel, using Hess's Law and the formula and $\Delta H = n\Delta_x H$, or by looking up the theoretical enthalpy of combustion and then using the formula $\Delta H = n\Delta_x H$. The mass of the fuel before and after combustion must be collected. Using an ethanol burner, the theoretical value for the molar enthalpy of combustion of ethanol in an open system can be calculated:

$$C_2H_5OH(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$
$$\Delta_c H^\circ = \Sigma\,(n\Delta_f H^\circ_{\text{products}}) - \Sigma\,(n\Delta_f H^\circ_{\text{reactants}})$$
$$= [(2\ \text{mol})(\Delta_f H^\circ\ CO_2(g)) + (3\ \text{mol})(\Delta_f H^\circ\ H_2O(g))] - [(1\ \text{mol})(\Delta_f H^\circ\ C_2H_5OH(\ell)) + (3\ \text{mol})(\Delta_f H^\circ\ O_2(g))]$$
$$= [(2\ \text{mol})(-393.5\ \text{kJ/mol}) + (3\ \text{mol})(-241.8\ \text{kJ/mol})] - [(1\ \text{mol})(-277.6\ \text{kJ/mol}) + (3\ \text{mol})(0\ \text{kJ/mol})]$$
$$= -1512.4\ \text{kJ} - (-277.6\ \text{kJ})$$
$$= -1234.8\ \text{kJ/mol}\ C_2H_5OH(\ell)$$

Given the following sample data from the lab:
Mass of ethanol burner before = 127.32 g
Mass of ethanol burner after = 125.46 g
The mass of ethanol burned = 127.32 g – 125.46 g = 1.86 g

Investigation 10.B: Build a Heating Device Answer Key (cont'd)

Method 1 Using Formulas

$$
\begin{aligned}
n &= \frac{m}{M} \\
&= \frac{1.86\,\text{g C}_2\text{H}_5\text{OH}}{46.08\,\frac{\text{g}}{\text{mol}}\,\text{C}_2\text{H}_5\text{OH}} \\
&= 0.04036\,\text{mol C}_2\text{H}_5\text{OH}(\ell)
\end{aligned}
$$

$$
\begin{aligned}
\Delta H &= n\Delta_c H \\
&= \left(0.04036\,\text{mol C}_2\text{H}_5\text{OH}\right)\left(-1234.8\,\frac{\text{kJ}}{\text{mol}}\,\text{C}_2\text{H}_5\text{OH}\right) \\
&= -49.8\,\text{kJ}
\end{aligned}
$$

Method 2 Using Dimensional Analysis

$$
-1234.8\,\frac{\text{kJ}}{\text{mol}\,\cancel{\text{C}_2\text{H}_5\text{OH}}} \times \frac{\cancel{\text{mol C}_2\text{H}_5\text{OH}}}{46.08\,\cancel{\text{g C}_2\text{H}_5\text{OH}}} \times 1.86\,\cancel{\text{g C}_2\text{H}_5\text{OH}} = -49.8\,\text{kJ}
$$

(c) $$
\begin{aligned}
\text{Efficiency} &= \left|\frac{\text{Energy output}}{\text{Energy input}}\right| \times 100\% \\
&= \left|\frac{2.35\,\text{kJ}}{-49.8\,\text{kJ}}\right| \times 100\% \\
&= 4.7\%
\end{aligned}
$$

8. Some sources of energy loss include losses to the air, beaker (or other container holding water), the thermometer, stirring rod, box (or other container).

Answers to Evaluate and Communicate Questions

1. Design modifications should include ways to further isolate the system from the surroundings, such as using Styrofoam™ or other insulators inside your container, reflecting more heat back into the container, and perhaps trying to burn the fuel more efficiently.

2. The most common way to improve the efficiency of a storage tank water heater is to add an insulating blanket around the heater and the surrounding pipes. Experts also recommend cleaning the water heater on a regular basis to remove sediments. The first recommendation could be applied to the classroom water heaters by providing better insulation around the beaker holding the water and by isolating the heating system from the surrounding air.

3. Most designs will be quite similar and will have comparable efficiency ratings (less than 10%). The best designs will likely be smaller, which would better isolate the system (the beaker of water and the burner) from the rest of the surroundings.