Cool Science: Building and Testing a Model Radiator

Background
The combustion of gasoline creates a tremendous amount of heat in a car’s engine. To prevent the engine from overheating, a coolant system circulates fluid that extracts heat from the engine. After absorbing heat from the engine, the hot fluid is passed through a radiator. Air flows over the radiator, cooling the fluid by transferring its heat to the atmosphere. The cooled fluid is then recirculated to extract more heat from the engine. In this project, you will construct a device that will model the working of a car’s radiator. You will heat a reservoir of liquid using a microwave oven and then run the hot liquid through your model radiator. The effectiveness of your radiator will be determined by measuring the temperature (in °C) and the heat content (in calories or joules) of the fluid as it enters and exits your radiator. Success will be calculated as the percent efficiency of your radiator, as shown below:

\[
\text{Percent efficiency} = 100 \times \left(\frac{\text{Calories/Joules of heat removed from the fluid}}{\text{Calories/Joules of heat originally added to the fluid}}\right)
\]

Objective
In this lab activity, you will experiment with a variety of radiator models to discover factors that are important in producing an effective heat-exchanging system.

Materials
- 250 mL of fluid, which will either be tap water or a solution of 50% propylene glycol in water (dyed green). The density of the propylene glycol solution is 1.04 g/mL, and it has a specific heat capacity of \( \frac{0.85 \text{ calories}}{\text{gram °C}} \) OR \( \frac{3.6 \text{ joules}}{\text{gram °C}} \)
- Two 3-inch lengths of flexible plastic tubing (1/4-inch inner diameter)
- 5-feet of copper tubing (1/4-inch outer diameter) coiled into a particular shape (three or four different designs available)
- A 4-inch diameter funnel
- Wire twist ties
- A plastic pitcher in which the liquid will be heated in a microwave oven
- A plastic or glass container to capture the cooled liquid
- A ring stand with clamps to support the funnel and copper tubing
- A valve to control flow rate
- A fan
- Unlimited quantities of aluminum foil
- Scale
- Thermometer

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow the teacher’s instructions for cleanup of materials and disposal of chemicals.
- Propylene glycol solution should be recollected and stored for future use.
- Use care when pouring/transporting hot liquids. Liquids in this lab activity should not be heated above 75°C.
Procedure:
1. Measure **250 mL** of water into a beaker. Weigh the liquid if a scale is available. If no scale is available, calculate the mass of the water in your beaker using the density value of **1.00 grams per milliliter**.
2. Measure the initial temperature of the water, record it below.
3. Microwave your beaker of water for 60-90 seconds to reach a final temperature of 65 to 75°C.
4. Remove the beaker from the microwave oven and stir to create a uniform temperature within the beaker.
5. Measure the temperature of the hot water after stirring. Record this temperature on the “t = 0” line in the table below.
6. Allow the beaker to sit undisturbed while you take temperature measurements every 30 seconds. Record your temperature data in the table shown below:

### Data

<table>
<thead>
<tr>
<th>Time</th>
<th>Temp</th>
<th>Time</th>
<th>Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>original</td>
<td></td>
<td>2 min 30 sec</td>
<td></td>
</tr>
<tr>
<td>t = 0</td>
<td></td>
<td>3 min</td>
<td></td>
</tr>
<tr>
<td>t = 30 sec</td>
<td></td>
<td>3 min 30 sec</td>
<td></td>
</tr>
<tr>
<td>1 min</td>
<td></td>
<td>4 min</td>
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</tr>
<tr>
<td>1 min 30 sec</td>
<td></td>
<td>4 min 30 sec</td>
<td></td>
</tr>
<tr>
<td>2 min</td>
<td></td>
<td>5 min</td>
<td></td>
</tr>
</tbody>
</table>
Graph the tabulated data using the axes shown below. Provide a title for the graph and label each axis appropriately.

Graph Title: ____________________________________________________________

Make at least one comment that describes the data plotted in this graph. In other words, what is the message of this graph?
Calculations
A) Use the equation shown below to calculate the heat (calories or joules) added to the water by the microwave oven:

\[ Q_a = m \times C \times \Delta T_a \]

Where
- \( Q_a \) = heat (in calories or joules) added to the solution
- \( m \) = mass of water in the beaker
- \( C \) = specific heat of water (\( \frac{1.00 \text{ calories}}{\text{gram} \cdot ^\circ \text{C}} \) OR \( \frac{4.18 \text{ joules}}{\text{gram} \cdot ^\circ \text{C}} \))
- \( \Delta T_a \) = the change in the water’s temperature (hot temp minus original temp)

Note: your calculated quantity for heat added should be thousands of calories or joules, which may be more conveniently expressed as kilocalories or kilojoules.

B) Use the equation below to calculate the heat lost from the beaker as it cooled for the 5-minute interval for which you recorded data in your data table.

\[ Q_r = m \times C \times \Delta T_r \]

Where
- \( Q_r \) = heat (in calories or joules) removed from the beaker (transferred to the atmosphere)
- \( m \) = mass of water in the beaker
- \( C \) = specific heat of water (\( \frac{1.00 \text{ calories}}{\text{gram} \cdot ^\circ \text{C}} \) OR \( \frac{4.18 \text{ joules}}{\text{gram} \cdot ^\circ \text{C}} \))
- \( \Delta T_r \) = Change in temperature during the 5-minute run

c) Calculate the percent heat lost from the beaker during the 5-minute interval:

\[ \text{Percent heat loss} = 100 \times \left( \frac{Q_r}{Q_a} \right) \]
Explore/Create: Design your own radiator!

After performing the initial scripted experimental work, you should have an understanding of the methods used to calculate heat added to the original liquid and removed through passive cooling. Your challenge is now to develop a system that will enable you to more effectively cool a fluid.

In a car engine, the heat produced by the car’s engine must be transferred to the atmosphere so that the car’s engine does not overheat. To accomplish this, most cars have a coolant system that includes a radiator. If the coolant in a car overheats, the radiator may boil over, creating a hazardous situation and imperiling the workings of the engine.

General guidelines
1. Follow the guidelines in the instructional video to link together a funnel, copper tubing, and a flow-control valve. Video URL on Youtube = https://youtu.be/cnsNA5rQbQ0. Note: if video instruction is not accessible, a text-based step-by-step guide is available!

2. Experiment with your set up by pouring room temperature water through the system—look for leaks and measure the flow rate of fluid through your system.

3. You will run multiple cooling trials, investigating variables such as:
   a) the design of the copper tubing
   b) the flow rate of fluid through the radiator
   c) the use of plain water vs. a 50% solution of propylene glycol (dyed green)
   d) the presence or absence of a fan

4. You are encouraged to do internet research to discover how car radiators are constructed. This may give you some ideas for ways to improve the efficiency of your home-made radiator.

5. If you wish to use materials not on your standard-issue list, please consult your instructor.

Constraints
A. The official time for each experimental run is 5-minutes

B. The volume of fluid passed through the radiator should be 250 MI

C. The fluid that you pass through your radiator may be water, or an aqueous solution of propylene glycol (colored green). If you use the propylene glycol solution, this solution must be recycled and NOT poured down the drain!

D. The initial temperature of the hot liquid must be between 60 and 75°C.

Data collection for the unscripted experiments
A. You will be expected to produce a data table that summarizes important temperature data for each experiment that you run. This data table should also include calculated values for heat added, heat removed, and percent efficiency (i.e. percent heat loss). If your data table is well designed, it should
be easy for the reader to determine which methods/strategies were most effective in cooling the fluid.

B. You will also be expected to create a graphical representation of the effectiveness of your various trials. Consider using color in your graph as a way of illustrating the different variables you investigated.

C. You are encouraged to create both the data table and graph(s) using a computer rather than writing by hand.

**Analysis**

1. Discuss the factors that you feel led to more efficient radiator design. Try to provide scientific reasons why certain designs were more effective. It is expected that you will be able to discuss at least two important factors. *For example, if you found that a fast flow rate was more effective at cooling the liquid, provide a scientific explanation for why a faster flow rate resulted in more heat removed.*
2. Discuss reasons why cars use a 50% solution of propylene glycol (or ethylene glycol) instead of plain water as coolant. *Note: this discussion may rely on results from your experiments as well as internet research.*

**Conclusion**

Provide suggestions for an *optimal* radiator design—one that can remove a large percentage of heat in a short period of time. Discuss how a real car’s radiator addresses these factors.