

## Worksheet: Evaporative cooling

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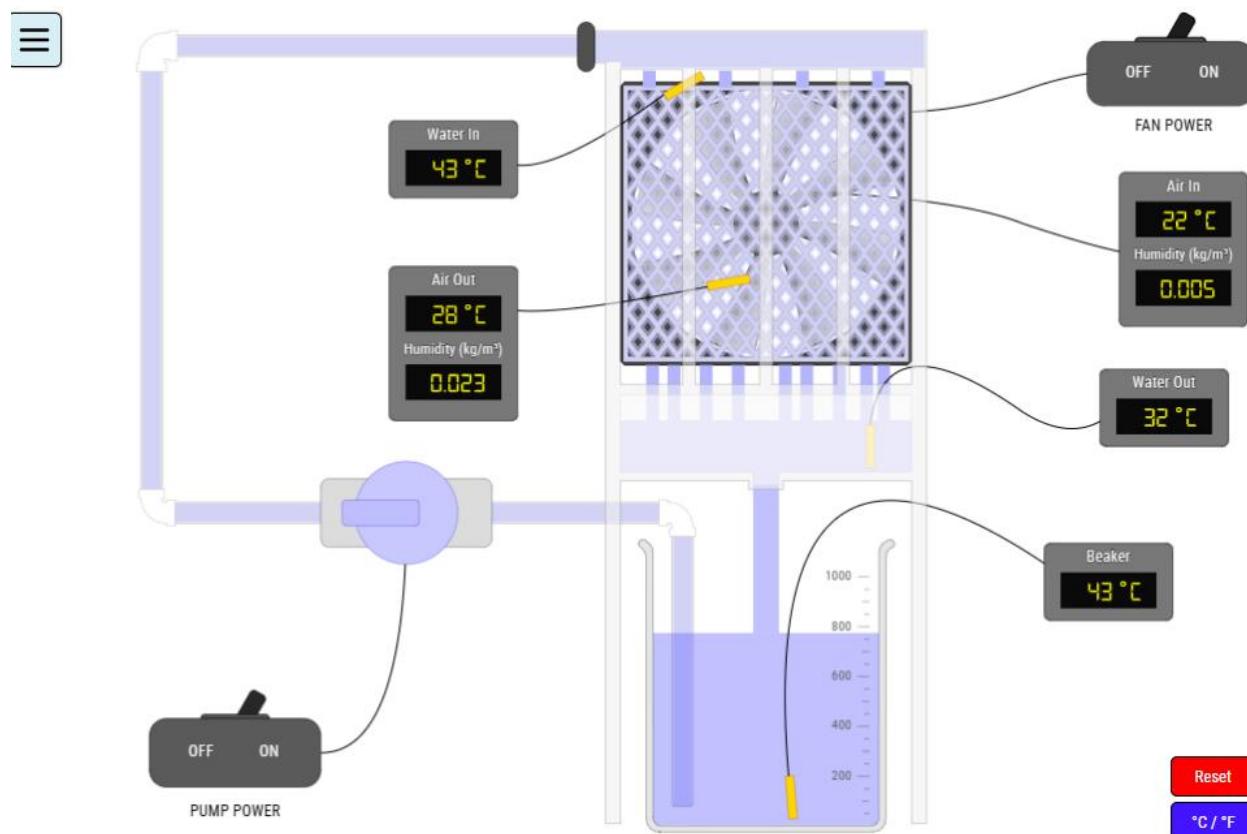
Names(s) \_\_\_\_\_

This experiment explores evaporative cooling of air by using a fan to flow air over a pad saturated with water. The energy required to evaporate the water is taken from the air so that the air temperature decreases. In dry climates, evaporative coolers lower the air temperature in buildings because they use less energy than refrigeration (air conditioners) and they also raises the humidity. In this experiment, water and air temperatures are measured.

#### Student Learning Objectives

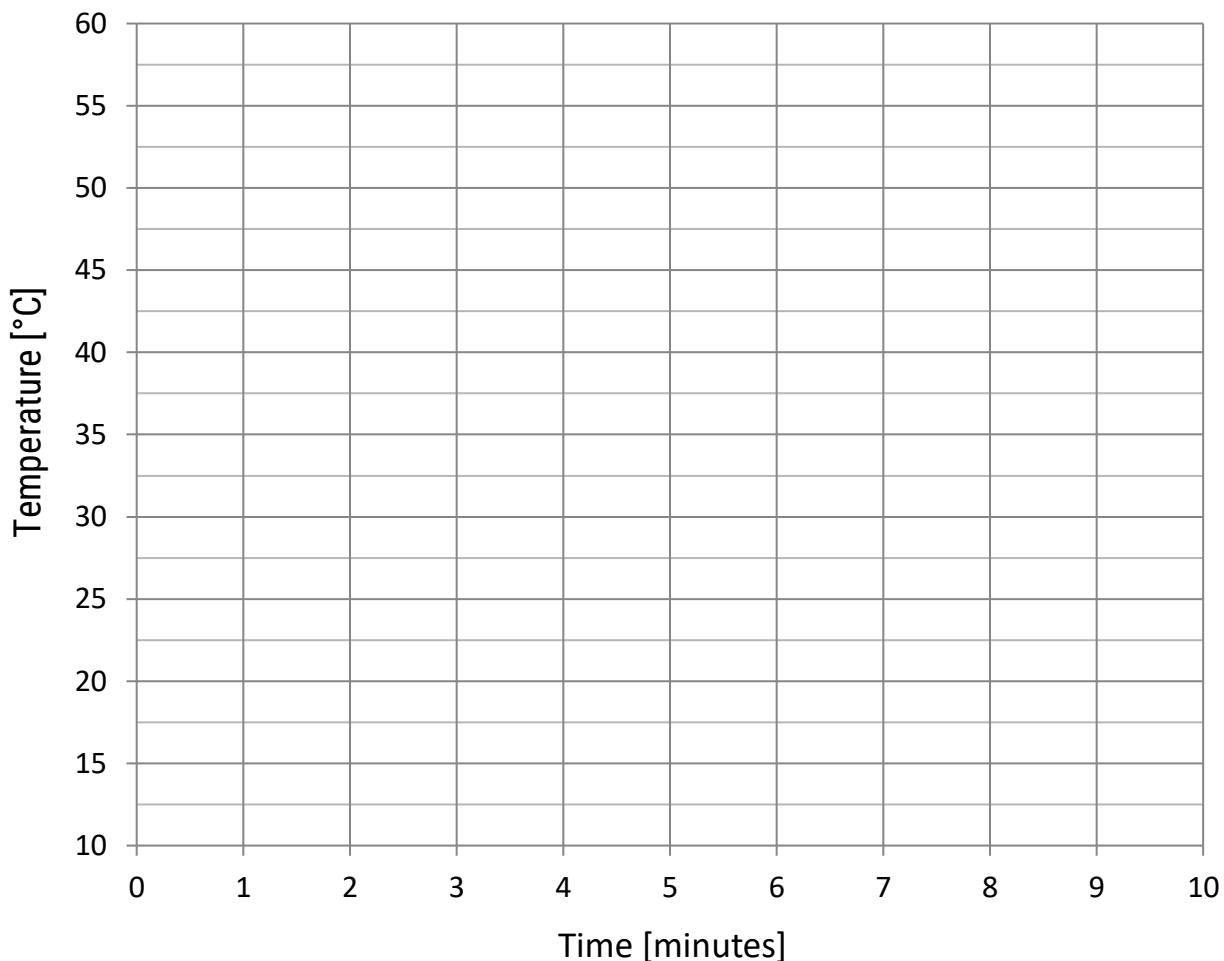
1. Understand temperature trends of air and water as water is cooled
2. Describe driving forces for convective/latent heat transfer and mass transfer at the air-water interface and how these vary for water-cooling and air-cooling
3. Describe how changes to air velocity and water temperature impact the cooling rate
4. Describe the impact of relative humidity on evaporative cooler performance

#### Equipment



### **Experiment 1: Water Cooling vs. Air Cooling**

- a. The beaker contains 800 mL of hot water.
- b. Measure the temperature of the ambient air (Air in). Draw as a horizontal line on graph below.
- c. Measure the initial temperature of the water. Plot at time = 0 on graph
- d. Turn on pump power and air fan power by clicking "ON;" **start a cell phone timer**.
- e. **Every 1 minute**, record the temperatures of the **water in the beaker and of the air flowing out of the cooler** on graph. Take measurements for 10 minutes.
- f. Note the humidity of the air coming out of the cooler in the first few minutes \_\_\_\_\_ .



1. Based on your data, does the **water temperature increase or decrease over time** when:
  - a. The water temperature is **above** the inlet air temperature:
  - b. The water temperature is **below** the inlet air temperature:

2. Based on your data, is the air heated or cooled (inlet vs. outlet temperature) when:
  - a. The water is **hotter** than incoming air:
  - b. The water is **colder** than incoming air:
3. During the experiment, was the air more humid (have more water vapor) at the inlet or the outlet of the cooler? Based on this, is water vapor added to or removed from the air?

### **Understanding Heat and Mass Transfer in the Evaporative Cooler**

Important definitions:

Sensible heat transfer: Energy/heat transfer due to a difference in temperature

Latent Heat Transfer: Energy/heat transfer due to phase change

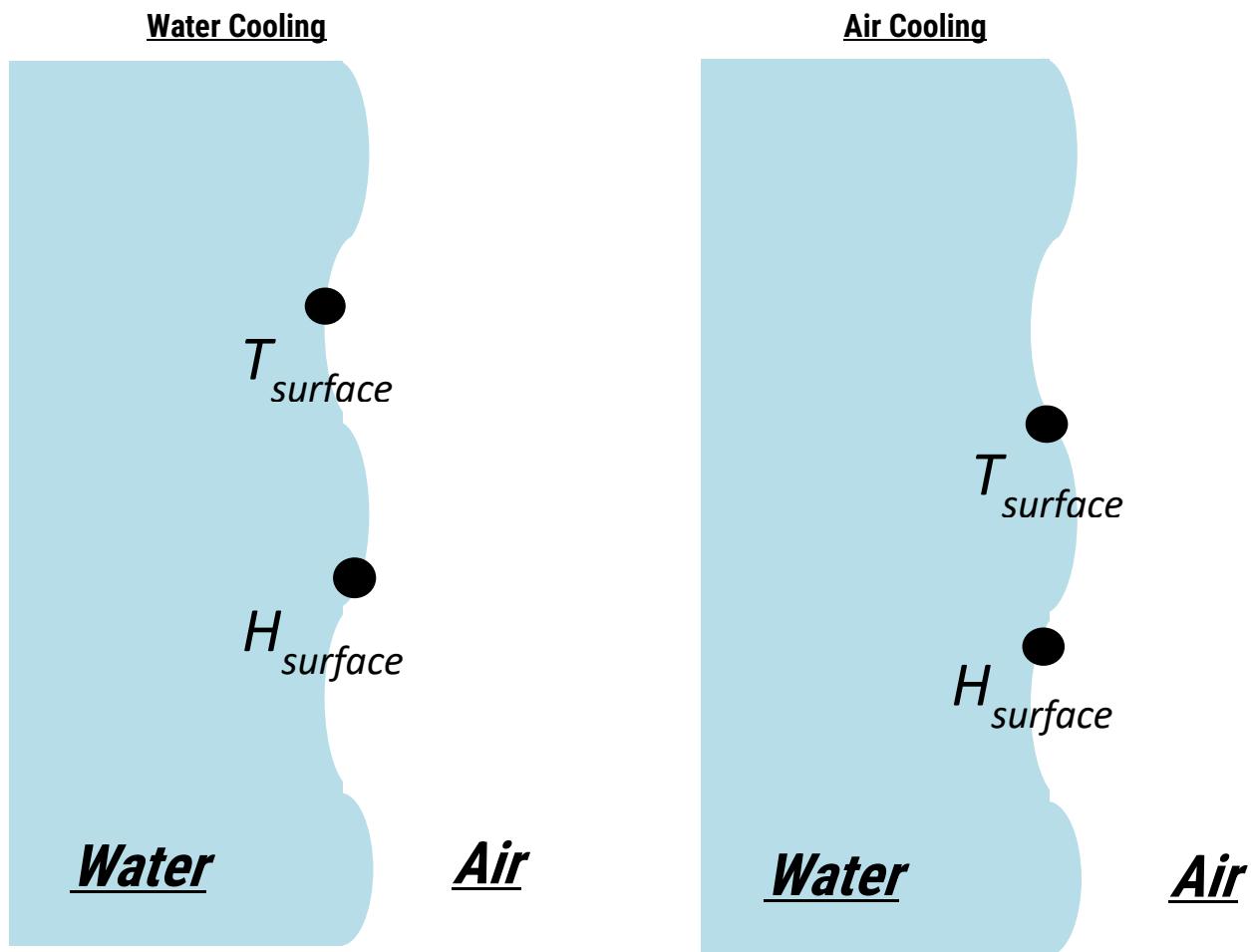
Mass transfer: Transfer of a species due to a difference in concentration

4. Based on your answer to Question 3, which direction does **mass transfer** of water vapor occur (water-to-air or air-to-water)? Is this true for all water/air temperatures in the experiment? *Hint: consider the concentration of vapor at the water surface compared to the inlet; mass moves from high to low concentration.*
5. When water evaporates, highly energetic molecules change phase from a liquid to a gas and carry latent heat/energy with them. Based on the direction of mass transfer, does latent heat flow from water-to-air or air-to-water? **Does the air gain or lose latent heat?**

6. Because of the energy required for evaporation, the surface temperature of the water decreases as water evaporates. What does this tell you about the surface water temperature compared to the bulk water temperature? Based on this, ***which direction does sensible heat transfer occur in the water*** (bulk-to-surface or surface-to-bulk)?
7. Based on your answer to Questions 6, why does the water temperature continue decreasing even when it is cooler than the air? Hint: does water vaporization still occur at low water temperatures?
8. Will more latent heat be lost from the water when the evaporation rate is low or high? Should air with a low or high humidity/vapor concentration be used in evaporative coolers? *Hint: consider the driving force for mass transfer: concentration difference between two locations.*
9. Sensible heat transfer in air occurs when there is a difference between the water surface and the air temperature. Based on your data, circle the correct options in the following statements:
- When the water temperature is **above** the inlet air temperature, air is **heated/cooled**.  
Air **gains/loses** sensible heat.
- When the water temperature is **below** the inlet air temperature, air is **heated/cooled**.  
Air **gains/ loses** sensible heat.

11. Based on your answers to Questions 4-9, label the following for water cooling and air cooling:

- The bulk water and bulk air temperatures (relative to  $T_{surface}$ )
- The humidity of the bulk air (relative to  $H_{surface}$ )
- The direction of sensible heat transfer in water and air, latent heat transfer, and mass transfer (use arrows)



#### Effect of Water Temperature on Cooling Rate

12. Calculate the temperature change of the water from 0-1 min. and from 4-5 min. Which time period had the higher temperature change? What does this tell you about the **rate of water cooling (temperature change over time)** for the first minute compared to the fourth minute?

13. Consider the temperature difference between the water and air in the first and fourth minute.

Based on this, when is more sensible heat transferred to the air?

14. Water vapor pressure (the concentration of vapor at the water surface) increases with temperature. Considering this, is there more mass and latent heat transfer occurring during the first or fourth minute?

15. How do your answers to Questions 12 and 13 explain the difference in cooling rates observed?

To achieve the highest cooling rate, should evaporative coolers be operated at high or low water temperatures?

### **Effect of Air Velocity on Cooling Rate**

16. Sensible heat transfer from the water to the air occurs due to ***forced convection***. Based on your knowledge of heat transfer, how does air velocity impact the convective heat transfer rate?

Should high or low air velocity be used in evaporative coolers to maximize the cooling rate?

*Hint: consider how heat transfer coefficients vary with velocity, in general.*