Laboratory Demonstration No. 2

The purpose of this experiment is to investigate the steady state solution for the IPOLA equation (DYNAMIC EQUILIBRIUM) under the conditions where production is important and to investigate the controls on the rate of change in the system and how they can be quantified. Because chemical reactions are difficult to control, we will use temperature in a flask with an inflow and outflow stream heat, and a hot plate to simulate transport and chemical reaction.

1. Place a beaker of water on the hot plate and turn the hot plate on full. Record the temperature in the beaker. (You can let the beaker boil but do not allow the beaker to run dry. If it does, DO NOT add water to a dry beaker!!) **Document and observe the apparent rate of heat production in the flask #1.** Replace the beaker with the flask to be investigated and start the clock. Record the increase in temperature with time using a thermometer from room temperature to >90C. Do not let the flask boil!

2. Remove flask#1 and place it on the magnetic stirrer (no heater) to cool. Record the temperature as a function of time. **Document and observe the apparent rate of heat loss in the flask #1.** (This information may be supplied to you by your instructor.) This determines the rate of cooling of the flask (heat loss term by conduction processes through the glass). You need to let the flask cool to 30-40C.

3. **Calculate the apparent rate of heat production in the system (flask) (calories/minute). How does the rate of heat production vary with flask temperature? If your field of vision was restricted only to the interior of the flask with not knowledge of processes ongoing outside of the flask,** is there any way you could you tell if heat was produced internally or externally? This number represents the apparent rate at which a chemical called Kalories is produced in the flask. It is obtained by:

   $$(\Delta\text{Temp}/\Delta\text{time}) \times \text{vol} \times \text{density} \times \text{heat capacity} = \text{apparent production} = P$$

   where density of water = 1 g/ml
   heat capacity = 1cal $^{o}C^{-1}$ g^{-1}

4. **Calculate the apparent rate of heat loss from the flask (calories min^{-1}). How does the rate of heat loss vary with flask temperature? Why?**

If you have already finished with Flask #1, you may want to put it on the hot plate so that it can crank up. **NEVER have the hot plate full-on without having a flask of water on it!!**

5. **Which is more important to the dynamic steady state, P or L? Discuss the validity of your estimate of P. Can you make a better estimate of P?**

6. **Create a system to achieve a dynamic equilibrium. Calculate the flow rate of room temperature water that will result in a flask temperature of 50C. Set the pump to this flow rate and test your mass (heat) balance.** Assuming that no heat is lost from the flask except by outflowing water (L<<P and the quantification of P is actually $P_{apparent} = P_{true}$-L), make a prediction for the flow rate (flow rate #1 of 25C water) that will result in a well-mixed flask temperature of 50C. This heat balance is made by:

$$F_{in} = F_{out} = F$$

$$F(T^o{}_{in})H\rho + P = F(T^o{}_{out})H\rho \qquad [\text{cal min}^{-1}]$$

7. **Establish the system as a dynamic steady-state that represents a balance between heat input from the hot plate and heat lost by outflow.** Use the set-up shown in the figure.
Turn the hot plate on full; It take 4-5 minutes for the hot plate to really crank up so start this early with flask#1. Fill the flask#2 with water. Connect the pump to the flask#2; Adjust the flow rate to your answer for part (6). Place the flask#2 on the hot plate (remove flask#1 and replace with flask #2) and start the stopwatch. **Record the temperature as a function of time and watch the temperature come to a steady temperature.**

8. **Once the equilibrium temperature has been reached, increase the flow rate by ~2x (to flow rate #2) and observe the decrease in temperature of the flask as a function of time.**

When you get home

9. Plot the increase of temperature with time and calculate the heating rate in cal/min.

10. Plot the decrease in temperature as a function time and calculate the loss rate for heat rate (from the flask to the surrounding environment) for the temperature ranges 90-75C, 75-60C, 60-45C, 45-30C.

    Does the rate of cooling increase or decrease with temperature. Why?

11. Make a heat balance for the final temperature of flow rate#1 and the final temperature of flow rate#2. Solve for the rate of heat loss from the flask. Do you think that the experiment obeys theory? Why or why not?

12. Calculate the rate constant by which temperature increased with flow rate #1.
Calculate the rate constant by which temperature decreased with flow rate #2.

13. For the final temperature of flow rate#1, calculate the residence time of heat
(a) with respect to production, (b) with respect to heat loss from flask.
Calculate the residence time of water.

12b. For the final temperature of flow rate#2, calculate the residence time of heat (a) with respect to production, (b) with respect to heat loss from flask. Calculate the residence time of water.

13. Explain why the rate constants for the dynamic equilibrium to be reached are different for the heat gain system of flow rate #1 and the heat loss system of flow rate #2. Explain why heat loss from the flask was not important in the heat balance.