Worksheet: Single-Effect Evaporator

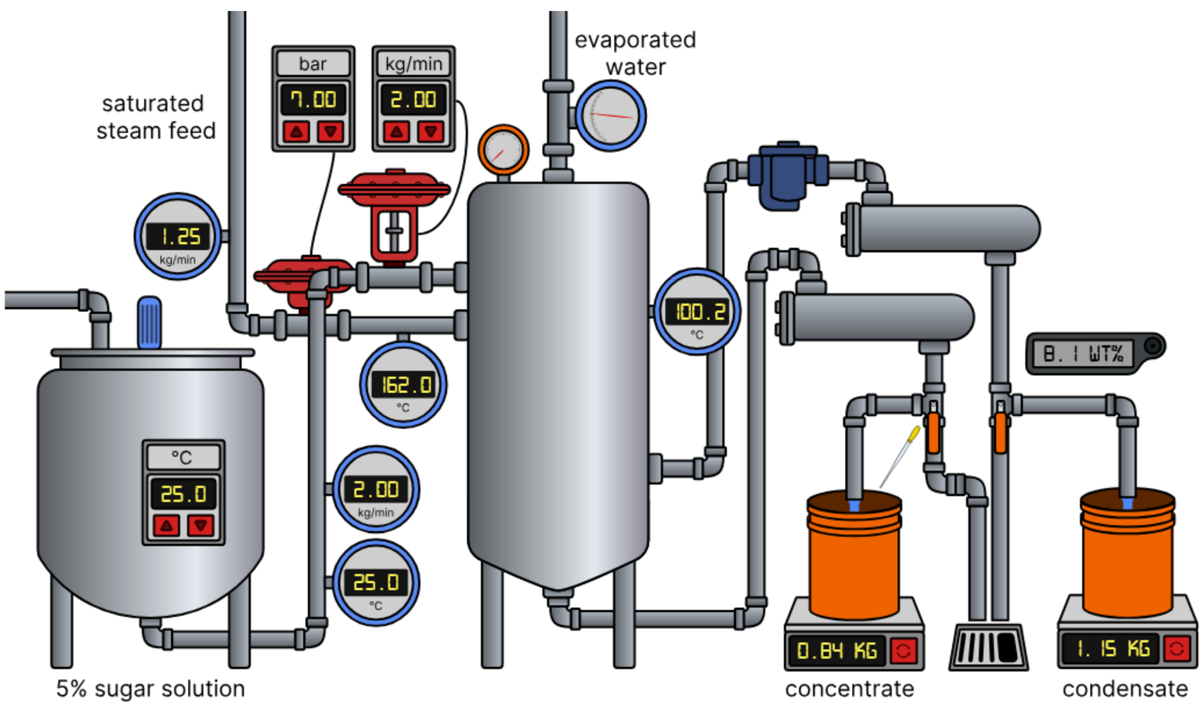
Name(s) ____

This experiment concentrates a dilute sugar solution feed by boiling off the water in a single-effect evaporator using saturated steam as the heat source. Mass and energy balances are carried out. It aims to demonstrate the effects of operating parameters on evaporator efficiency.

Student Learning Objectives

1. Be able to perform mass and energy balances on an evaporative system.
2. Be able to explain the principles of evaporation and concentration in a single-effect evaporator.
3. Be able to explain how pressure and solute concentration affect the boiling temperature of a liquid.
4. Be able to calculate the energy efficiency of a single-effect evaporator.

Equipment



- A lab-scale, single-effect evaporator with a 5.0 wt.% sugar solution feed, concentrated sugar solution outlet (concentrate), and an evaporated water outlet.
- The single-effect evaporator has a steam feed, which heats the evaporator contents, and a condensed steam outlet (condensate).
- Flow controllers that set the feed rate of the 5.0% sugar solution and a flow meter to measure the feed rate.
- A flow meter to measure the evaporated water leaving the evaporator.

- A pressure controller to set the feed pressure of the saturated steam, and a flow meter to measure the steam feed rate. The feed pressure determines the steam feed rate.
- Two containers on scales to collect and weigh the concentrate and the condensate.
- Thermocouples to measure the solution feed temperature, the steam feed temperature, and the evaporator temperature.
- A meter to measure the concentration of the concentrate.
- A pressure gauge on the evaporator. The evaporator pressure is 1.0 bar.
- A shut off system when the sugar concentration gets too high in the concentrate.

Questions to answer before starting the experiment

What is the advantage of running the evaporator at a low pressure?

What is the advantage of feeding the sugar solution at a temperature above the evaporator temperature?

Experiments

Experiment 1

1. Select the feed pressure of the saturated steam by clicking on the black triangle under the pressure readout. This fixes the steam feed temperature and the steam flow rate. Record these values in Table 1
2. Select the feed tank temperature by clicking on the black triangles below the tank temperature. Record in Table 1. The minimum feed temperature is 25^{o}C.
3. Select a feed flow rate of the 5.0 wt.% sugar solution by clicking on the black triangle below the flow rate. Record in Table 1.
4. Allow the evaporator to reach steady state (this digital experiment accelerates time).
5. Record the evaporator temperature in Table 1.
6. Click the orange valve handle that leads to the concentrate bucket. Start a timer and measure the change in mass in the concentrate tank. Record the values in Table 2. Calculate the mass flow rate of the concentrate (kg/min) and record in Table 2.
7. Mouse over the meter at the top of the evaporator to see the evaporated water flow rate. Record in Table 2.
8. Measure the concentration (wt.%) of the concentrate by clicking the dropper that is above the concentrate bucket or clicking the readout on the right side of the experiment. Record the sugar concentration in Table 2.

9. Click the orange valve handle that leads to the condensate bucket. Start a timer and measure the change in mass in the condensate bucket. Record the values in Table 3. Calculate the mass flow rate of the condensate (kg/min) and record it in Table 3. Add the steam feed rate from Table 1 to Table 3 and calculate the percent difference.

Table 1 Steam and sugar solution feeds and evaporator temperature

	Steam feed			5% Sugar feed solution		Evaporator
Exp	Pressure (bar)	Temperature (^oC)	Flow rate (kg/min)	Temperature (^oC)	Flow rate (kg/min)	Temperature (^oC)
1						
2						
3						
4						

Table 2 Concentrate and evaporated water

Exp	Elapsed time (s)	Change in mass (kg)	Mass flow rate (kg/min)	Evaporated water flow rate (kg/min)	Sugar concentration (wt.%)
1					
2					
3					
4					

Table 3 Steam condensate

	Steam condensate				
Experiment	Elapsed time (s)	Change in mass (kg)	Mass flow rate (kg/min)	Steam feed flow rate (kg/min)	% Difference
1					
2					
3					

<u>Experiment 2</u>

Increase or decrease the steam pressure to examine how it affects the evaporation rate and concentrate concentration. Wait for steady-state conditions and then empty the buckets before collecting data. Record the same information in the Tables as for experiment 1.

Experiment 3

Adjust the feed flowrate controller to observe its impact on the evaporation process. Wait for steady-state conditions and then empty the buckets before collecting data. Record the same information in the Tables as for experiment 1.

Experiment 4

Us the same conditions as in Experiment 3 but increase the feed tank temperature significantly. Record the values in Table 1. Repeat steps 6, 7, and 8 and record values in Table 2.

Analysis

Record the total mass flow rates from Tables 1 and 2 in Table 4 and calculate the percent difference between inlet and outlet. Calculate the sugar mass flow rates in the feed and concentrate and record in Table 4. Calculate the percent difference between the inlet and outlet.

Table 4 Mass balances

Exp.	Total mass flow rates				Sugar mass flow rates		
	Feed	Concentrate	Evaporated water	% difference	Feed	Concentrate	% difference
1							
2							
3							

- Calculate the heat input to the evaporator ($\dot{Q}$) using steam enthalpy data (ΔH_{steam}) from the steam tables:

  $\dot{Q} = \dot{\mathrm{m}}_{\mathrm{steam}} \Delta H_{steam}$

  where $\dot{\mathrm{m}}_{\mathrm{steam}}$ is the mass flow rate of condensed steam.

- Calculate the heat required per time to vaporize the water in the feed.

  heat required = $\dot{m}_{vaporized} \Delta H_{vap}$

  where $\dot{m}_{vaporized}$= mass of water vaporized per time

  ΔH_{vap} = heat of vaporization of water at the temperature of the evaporator

- Calculate the steam economy.

$$steam\ economy = \frac{mass\ of\ water\ evaporated}{mass\ of\ steam\ used}$$

Questions to answer

1. How is the evaporator temperature related to the concentrate concentration?
2. Where might these measurements have errors?
3. How does increasing the feed temperature affect the outlet compositions and flow rates?
4. What safety precautions would you take to conduct this experiment in the laboratory?
5. How would you use three evaporators in series? What would be the advantage of doing this?