Worksheet: Single-Effect Evaporator

Name(s) ____

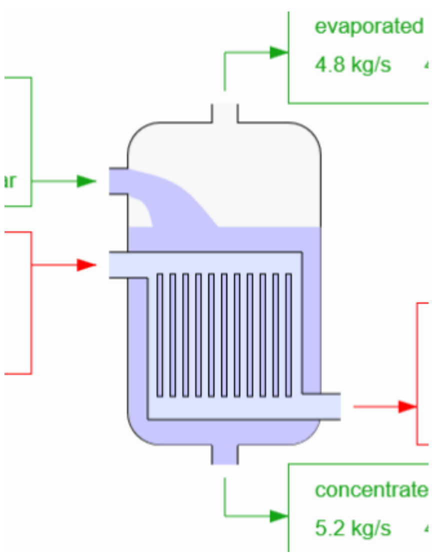
This experiment concentrates a dilute sugar solution feed by boiling off the water in a single-effect evaporator using saturated steam as the heat source. Mass and energy balances are carried out. It aims to demonstrate the effects of operating parameters on evaporation efficiency.

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 temperature and pressure controls. The evaporator has a dilute solution feed and a saturated steam feed. It has a saturated water outlet, a concentrated solution outlet, and evaporated water outlet. The evaporated water outlet is fed to a condenser. The evaporator has a pressure relief valve.
- A steam generator to supply the heat source (steam) for the evaporator.
- A sugar solution feed with 5% sugar by weight.
- A container to collect and measure the amount of concentrated solution from the evaporator.
- A condenser to condense the evaporated water and a container to collect the evaporated water.
- Thermocouples to measure the solution feed temperature, the steam feed temperature, and the evaporator temperature.
- A refractor (**SEARCH this)** to measure the concentrations of the product solutions.



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?

Start-up

- Flush the evaporator system with distilled water.
- Select and record:

  Feed temperature _______________

- Set up the steam generator to provide steam at a controlled pressure and record the steam pressure and temperature.

  Steam temperature _____________

  Steam pressure ______________

Experiments

Experiment 1

- Turn on the pump and open the valve feeding the sugar solution into the evaporator at a steady flow rate.
- Open the steam valve, allowing steam to enter the heating chamber of the evaporator.
- Allow the evaporator to reach steady state (5-10 minutes in real time).

  Feed tank temperature ____________

Experiment 1

- Record the temperature and pressure in the tank in the Table.
- Start a timer and measure the change in volume in the feed tank to determine feed flow rate. Record in the Table.
- Start a timer and measure the change in volume in the concentrate tank to determine concentrate flow rate. Record in the Table.
- Measure the concentration of the concentrated solution. Record in the Table.
- Start a timer and measure the change in volume of the condensate to determine condensate flow rate. Record in the Table.
- Start a timer and measure the change in volume of the condensed steam to determine flow rate. Record in Table

			Feed tank			Concentrate			
Exp	Tank pressure	Tank temperature	Elapsed time	Change in volume	Volumetric feed rate	Elapsed time	Change in volume	Volumetric feed rate	Concentration
1									
2									
3									

	Condensate			Condensed steam		
Experiment	Elapsed time	Change in volume	Volumetric feed rate	Elapsed time	Change in volume	Volumetric feed rate
1						
2						
3						

<u>Experiment 2</u>

Lower or increase the steam pressure to examine how it affects the evaporation rate and concentrate concentration. Wait for steady-state conditions before collecting data.

Record the same information in the Tables as for experiment 1.

<u>Experiment 3</u>

Adjust the feed valve to observe its impact on the evaporation process and allow the system to reach steady state before recording measurements.

Record the same information in the Tables as for experiment 1.

Analysis

Calculate mass flow rates and the percent difference between inlet and outlet for the Table below. Confirm that the total mass of the feed equals the combined mass of the concentrate and vapor produced for each experiment. Confirm the component (solute) balance to ensure the amount of solute in the feed equals the solute in the concentrate.

Exp	Total mass flow rates				Solute mass flow rates		
	Feed	Concentrate	Condensate	% difference	Feed	Concentrate	% difference
1							
2							
3							

- Measure flow rate of condensed steam:

  Volume change ___________________ Elapsed time _____________________

  volumetric flow rate __________________ mass flow rate ___________________

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

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

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

- Calculate the heat required per time to vaporize the solvent (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 drum

- Calculate the steam economy.

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

- Analyze the impact of varying evaporator temperature on the concentration of the product.

Questions to answer

1. Where might these measurements have errors?

2. How does changing the feed temperature affect the outlet compositions and flow rates?

3. What safety precautions would you take to conduct this experiment in the laboratory?

4. How would you use three evaporators in series? What would be the advantage of doing this?