**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 (**SEACH this)** to measure the concentrations of the product solutions.

Diagram of a diagram of a car filter

Description automatically generated

**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 |  |  |  |  |  |  |

Experiment 2

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.

Experiment 3

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 () using steam enthalpy data () from the steam tables:

where is the mass flow rate of condensed steam

* Calculate the heat required per time to vaporize the solvent (water) in the feed.

heat required =

where = mass of water vaporized per time

= heat of vaporization of water at the temperature of the drum

* Calculate the steam economy.
* Analyze the impact of varying evaporator temperature on the concentration of the product.

**Questions to answer**

* 1. Where might these measurement 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?