EXPERIMENT 8
CO-CURRENT TWO-EFFECT EVAPORATION

1. INTRODUCTION

1.1. Definitions

Evaporation is a process which removes solvent as vapor from a solution of non-volatile solute in order to:

- Produce the concentrated solution
- Recover solvent

Evaporation can be operated at high pressure, atmospheric pressure or low pressure (vacuum condition); can be operated either continously or batch; in single-effect or in co-current, counter-current or parallel-current multiple-effect evaporation systems. Vapor of solvent usually has high temperature, high latent heat of condensation. Hence, it is used as steam for the next evaporator in the same system.

Vacuum evaporation is used to concentrate solution which has high boiling point or thermal decomposition easily. Under low pressure, boiling point of solution decreases which enhances driving force of the process (i.e.: raise different between steam temperature and mean boiling temperature of solution) as well as prevents heat lost.

1.2. Mass balance of a two-effect evapration system

$$G_đ = G_c + W \text{, kg/s} \quad \textbf{(1)}$$

$$G_đ . x_đ = G_c . x_c \text{, kg/s} \quad \textbf{(2)}$$

With:

- $G_đ$, G_c, W: feed flowrate, product flowrate and vapor flowarte, kg/s.
- $x_đ$, x_c : feed concentration, product concentration, wt %

From (1) and (2), total vapor flowrate of the system can be determined as following:

$$W = G_đ (1 - x_đ / x_c) \text{, kg/s} \quad \textbf{(3)}$$

$$W = W_1 + W_2 \text{, kg/s} \quad \textbf{(4)}$$

With: W_1, W_2 are vapor from evaporator A and C, respectively.

$$W = G_đ (1 - x_đ / x_c) \text{, kg/s} \quad \textbf{(5)}$$

W_2 can be measured in S_4 và S_7;

x_1: concentrate solution of the first effect (evaporator A).

1.3. Heat balance of evaporator A

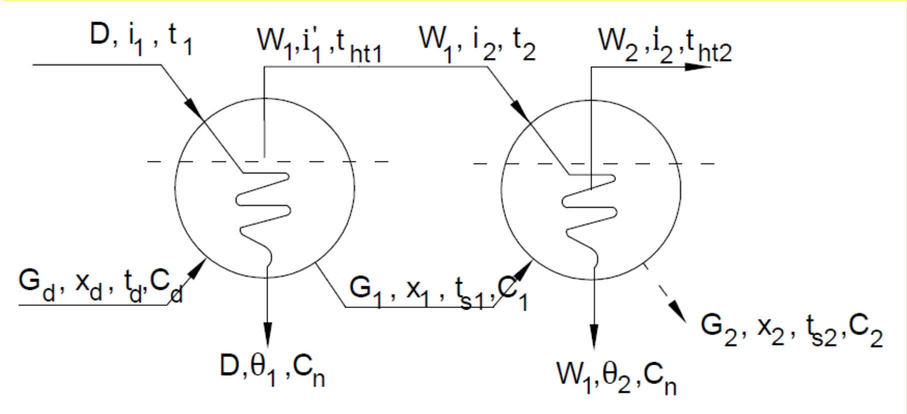

Figure 1. **Scheme of heat balance of a two-effect evaporation system**

Because product of evaporator C is taken out not continously (usually after experiment is stopped) in this experiment, heat balance calculation will be applied for the first effect (evaporator A), as following:

$$D.i_1 + G_d.C_d.t_d = W_1.i_1^{'} + G_1.C_1.t_{S1} + D.\theta_1.C_n + Q_{m1} + Q_{cd1}, \text{ kg/s} \quad \textbf{(6)}$$

Heat from steam for evaporator A:

$$Q_1 = D(i_1 - C_n.\theta_1) = D.r_1, \text{ kg/s} \quad \textbf{(7)}$$

Where:

- D, i_1, θ_1, C_n , r_1: steam flowrate, specific enthalpy of steam, condensate temperature, condensate specific heat capacity, condensate latent heat.
- G_d, C_d, t_d: feed flowrate, feed specific heat capacity, feed temperature.
- W_1, i'_1: vapor flowrate, specific enthalpy of vapor.
- G_1, C_1, t_{s1} : flowrate, specific heat capacity and boiling point of solution get out of evaporator A.
- Q_{m1}, Q_{cd1}: heat lost and evaporation heat in evaporator A.
- Assume:

$$(Q_{m1} + Q_{cd1}) = 0.05 Q_1, \text{ kg/s} \quad \textbf{(8)}$$

From equation (6) and (7), neccessary steam flowarte D and supply heat for evaporator A (Q_1) can be determined.

2. Experiment purposes and requirements

1. Have knowledge of co – current two – effect evaporation system, its operating procedure and the structure of evaporators (Figure 3 - IC 17/2D).
2. Calculate mass balance.
3. Calculate heat balance of evapporator A (in order to determine D and Q_1).

3. Experiment set up

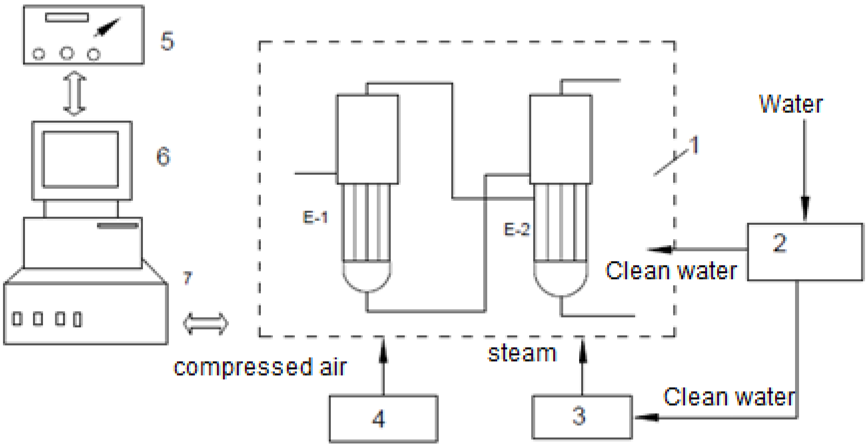

Figure 2. **Structure diagram of the evaporation system**

1	Evaporation system	5	Manual controller
2	Ion – exchange system (for hard water treatment)	6	PC
3	Boiler	7	Signal converter
4	Air compressor		

4. Experiment procedures

4.1. Preparation

4.1.1. <u>Learn about the system</u>

- Main equipments: evaporators (A and C)
- Auxiliary equiments: centrifugal pump, water rotary vacuuum pump, heat exchanger, condenser, condensate discharge line.
- Tanks
- Pipe line system, valves
- Controller (sensors, acctuators)
- Auxiliary system: boiler, air compressor, ion – exchange system (for hard water treatment)

4.1.2. <u>Operating preparation</u>

- Open water valve to supply water for ion exchanger
- Discharge a part of water in boiler (if it is full): open water discharge valve and air valve simultaneously. When water level in boiler is enough, close both valves.
- Turn on aptomat to supply electricity for computer, boiler and evaporation system.
- Check pressure in boiler. If pressure is smaller than 5 at, adjust pressure relay to change set value of steam pressure.

- Turn on computer and manual controller. If the light is off, check the power source.
- Open valve to supply water for two vacuum pumps P2, P3.
- Check water level in two condensate tanks S4, S7. If it is full, empty the tanks (should remain a small amount of condensate in S4).

4.2. Operating: <u>Manually operating</u>

- Adjust "operating mode" to "**Manual**"
- Discharge noncondensate gas in two evaporators (open valves V41 and V42)
- Open valves V50 (in feed heat exchanger), V32 and V36 (heating area in evaporators A and B).
- Open valves V2, V3 in suction pipe and discharge of the pump P1. Open steam valve to supply steam for the system (which is located close to the boiler), turn on pump P1.
- When solution level is enough in evaporator A, pump P1 will stop. Turn on vacuum pump P2 and P3.
- Switches on/off are located on manual controller.

4.3. Record data

- Record data about solution level in feed tank S1 and condensate tank S4 in the beginning and at the end of experiment. Start timer when vapor in evaporator C is appeared (i.e.: when condensate in condensate tank is observed). Experiment time can last 30 – 40 minutes.
- Sampling feed (any time), concentrate of evaporator A, concentrate of evaporator C (after stop the experiment). Concentration of solutions are measured by a refractometer.

4.4. Stop experiment

- Turn off all pumps.
- Close steam valve.
- Pump solution from evaporator C to product tank S2 or circulate all solutions in two evaporators back to the feed tank S1.
- Aerate in evaporators A, C using valves V41, V42.
- Turn off aptomats, close water valves, close valves V39, V40.
- Clean the room.
- Record data in experiment notebook: time, group, list of group, experiment data.

Note:

→ When pump to S2: open valves V9, V14, start pump P4.

→ When pump to S1: open valves V23, V20, V11, V15, start pump P4.

***4.5.* Incidents and treatments**

- If pressure relay in boiler doesn't work, turn off boiler.
- If any incidents in evaporation system happens, turn of the main aptomat.
- Report unexpected phenomenon with instructors, do not handle arbitrarily if not allow.

V. Experiment results and calculation

5.1. Experiment results

Time, s	Solution level in S1 x 2,56 (l)		Wt %			Water level in S4 x 0,177 (l)	
$\Delta\tau$	In the begining S_1^0	At the end S_1^1	$X_đ$	x_1	x_2 (x_c)	In the beginning S_4^0	At the end S_4^1

- Temperature, pressure of steam in evaporator A: T_1 = …… (°C); P_1 =……… (at)
- Feed temperature: T_d = …………(°C)
- Temperature, pressure of vapor in evaporator A: T_{ht1} = ……(°C); P_{ht1}= ………(at)

5.2. Mass balance calculation

- Feed flowrate:

$$G_d = ((S_1^0 - S_1^1).2{,}56.\rho)/\Delta\tau \text{, kg/s} \quad \textbf{(9)}$$

With:

ρ : feed density, kg/l ["Sổ tay Quá trình thiết bị tập I"].

- Condensate flowrate:

$$W_2 = ((S_4^1 - S_4^0).0{,}177.\rho_{water})/\Delta\tau \text{, kg/s} \quad \textbf{(10)}$$

With:

$\rho_{water} = 1$, kg/l

- Calculate W – total vapor flowrate after Δτ (s) according to eqt. (3)
- Calculate W_1 – vapor flowrate of evaporator A after Δτ (s) according to eqt. (4) (W_1 can also be calculated from equation (5) to re-check)
- Calcultate concentrate solution of evaporator A according to equation:

$$x_1 = \frac{G_d.x_d}{(G_d - W_1)} \text{, kg/s} \quad \textbf{(11)}$$

5.3. Calculation mass balance of evaporator A

- Look up specific heat of steam and vapor based on temperature

- Look up boiling point, specific heat capacity of solution in evaporator A based on measured x_1
- Calculate W_1
- Calculate D based on equation (6)
- Calculate Q_1 based on equation (7)

5.4. Discussion

TWO – EFFECT EVAPORATION SYSTEM

(Instruction)

System scheme IC17/2D:

A, C – evaporators
SC3 – cooling equipment
SC1 - cooling equipment
P1 – feed pump
P2, P3 – water rotary vacuum pumps
P4 – product pump
S1 – feed tank
S2 – product tank
T1 to T12 – thermal resistance type Pt100
TC – thermal resistance
V1 to V6 – pressure gauge

Valves

VV1, VV2 – magnetic valve
V1 – feed valve
V2 – valve to allow feed get in feed heat exchanger through feed pump
V3 – valve to allow feed get in evaporator A
V4 – valve to adjust feed flowrate get in evaporator A
V5 – valve for discharging product after evaporator A
V6 – valve for sampling solution get out of evaporator A
V7 – valve to allow solution which gets out of evaporator A flow to evaporation B
V8 – valve (to adjust feed flowrate get into evaporator A)
V9 – valve (to discharge product out of evaporator 2)
V10 – product sampling valve (in evaporator 2)
V11 – valve (connect to pump P4)
V13 – sampling valve
V14 – valve (from evaporator C to product tank)
V15 – valve (recirculate valve from evaporator C back to feed tank)
V16 – cleaning water valve (supply cleaning water to product tank) when cleaning system.
V17 – cleaning water valve (supply cleaning water to feed tank) when cleaning system.
V18 – product sampling valve
V19 – valve (to pump P4)
V20 – valve (to select flow)/van lựa chọn dòng
V21 – valve (to select flow)
V22 – reflux valve to feed heat exchanger
V23 – valve (to select flow)
V24 – feed valve
V25 – sampling valve
V26 – valve to supply compressed air

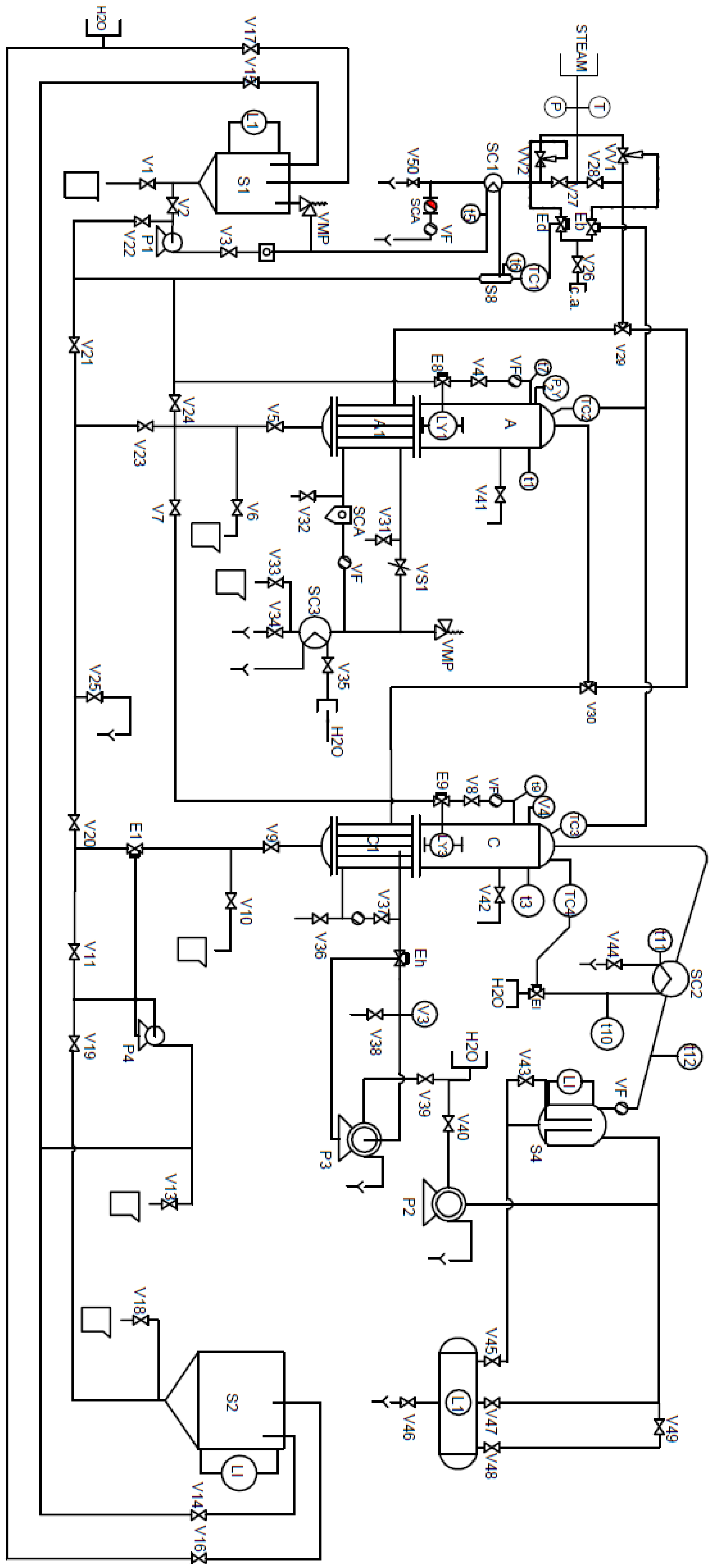

Figure 3. **Diagram of two-effect evaporation system**