# Evaporation Problems

280.371 Process Engineering Operations

***Question 1: Mass and energy balances on a single stage evaporator.***

A 10wt% aqueous lactic acid solution (470 kg/hr) at 36°C is concentrated to 30wt% solution in a steam heated evaporator. Solvent vapour (steam) and concentrated solution leave the evaporator at 46°C and 10 kPa absolute. The steam heat source is at -61 kPa gauge. Assume $c_p$ liq = 4 kJ/(kg.K).

(a) Calculate the amount of concentrated lactic acid produced, the amount of solvent (steam) vapourised and the amount of heat supplied in the evaporator heat exchanger.

(b) What size heat exchanger would be required if the overall heat transfer coefficient is 2000 W/(m$^2$.K) ?

(c) How much -61 kPa gauge steam was consumed to provide the necessary heat? What is the energy efficiency and steam economy?

(d) How much heat must be removed to condense the solvent vapour produced at 10 kPa ? How much 25°C water would need to be injected into a direct contact heat exchanger (at 10 kPa absolute) to condense the steam ?

***Question 2: Mass and energy balances on a single stage evaporator.***

A 50 $m^2$ heat exchanger is currently used in an evaporator to concentrate 0.72 kg/s of waste slurry from 20 wt% to 50wt% solids. The feed enters at its boiling point of 80°C and is heated with 20 kPa gauge steam .

(a) Calculate the amount of concentrated waste produced, the amount of steam vaporised and the amount of heat supplied in the evaporator heat exchanger. What is the overall heat transfer coefficient of the heat exchanger ?

(b) It is desired to process 20% more feed. What will be the new outlet solids concentration if the pressures are unchanged ? What pressure steam would be required to keep the outlet solids concentration at 50wt% ?

***Question 3: Evaporator selection***

What evaporator components would you consider using for the following tasks and why?

(a) Concentrating a low viscosity, corrosive salt solution to give a crystalline product.

(b) Concentrating a fruit juice.

(c) Concentrating a non-corrosive, non-heat sensitive liquid solution.

(d) Concentrating a corrosive liquid solution inside a building with a low ceiling.

**Boiling point elevation: Iterative Solution Procedure (for calculating solution temperature from solute conc)**

Step 1. Determine the pure component boiling point

Step 2. Assume a boiling point rise

Step 3. Calculate the solution temperature

Step 4. Use the chart to obtain the boiling point rise for that solution temperature

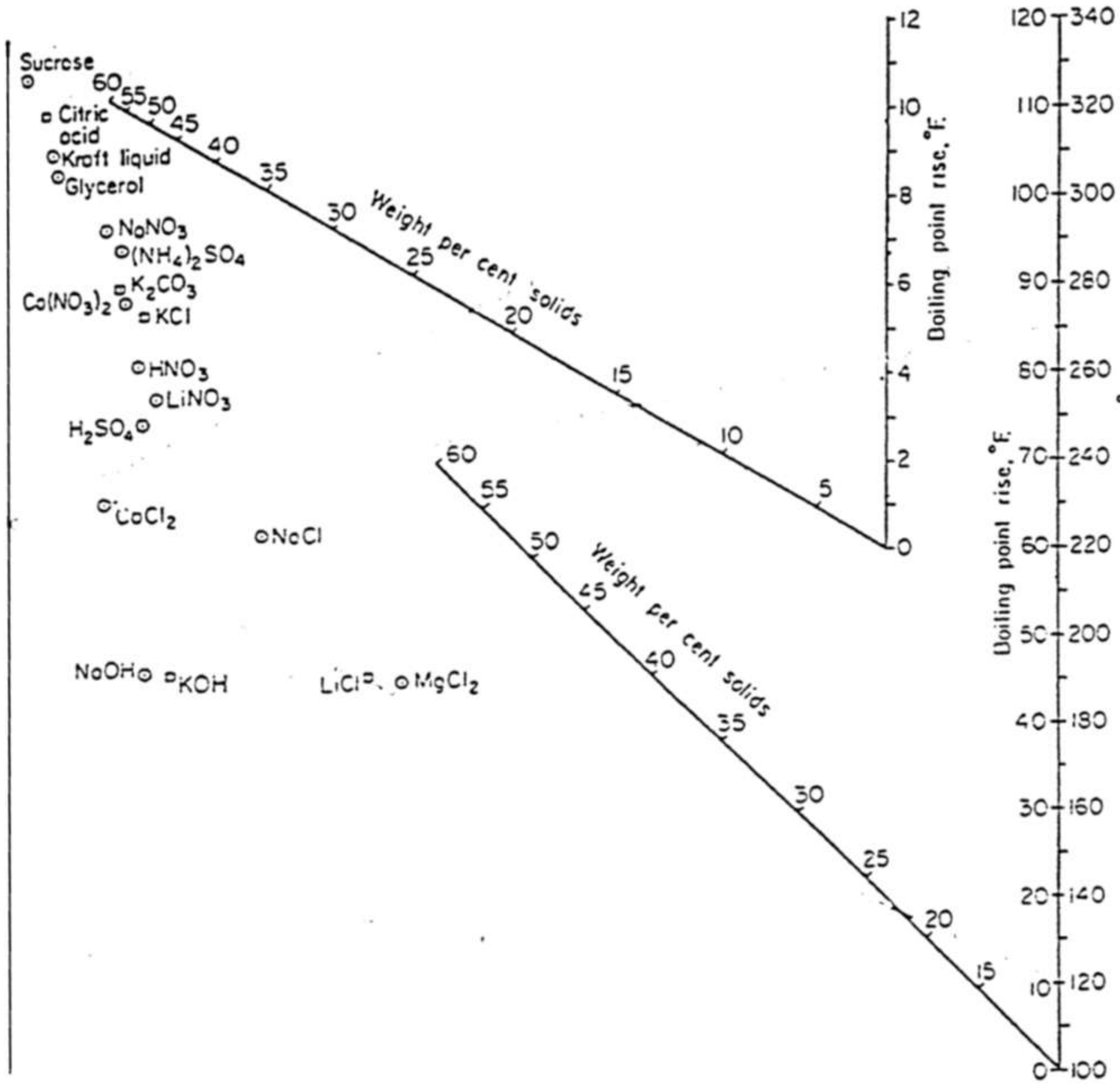
Step 5. Compare the assumed boiling point rise with that obtained from the graph. If not the same assume a new boiling point rise and return to step 3

***Question 4: Using the chart and steam tables (not iterative)***

(a) What concentration of NaCl is required to give a boiling point rise of 9°F at atmospheric pressure ?

(b) What will be

- The solution temperature?
- The vapour enthalpy ($c_{pg}$ = 1.88 kJ/kg°C)?
- The liquid enthalpy assuming that the specific heat of the salt solution is 4 kJ/kg°C?


Sucrose
Citric acid
Kraft liquid
Glycerol
NaNO3
(NH4)2SO4
K2CO3
Ca(NO3)2
KCl
HNO3
LiNO3
H2SO4
CaCl2
NaCl
NaOH
KOH
LiCl
MgCl2
Weight per cent solids
Weight per cent solids
Boiling point rise, °F
Boiling point rise, °F
Solution Temperature, °F

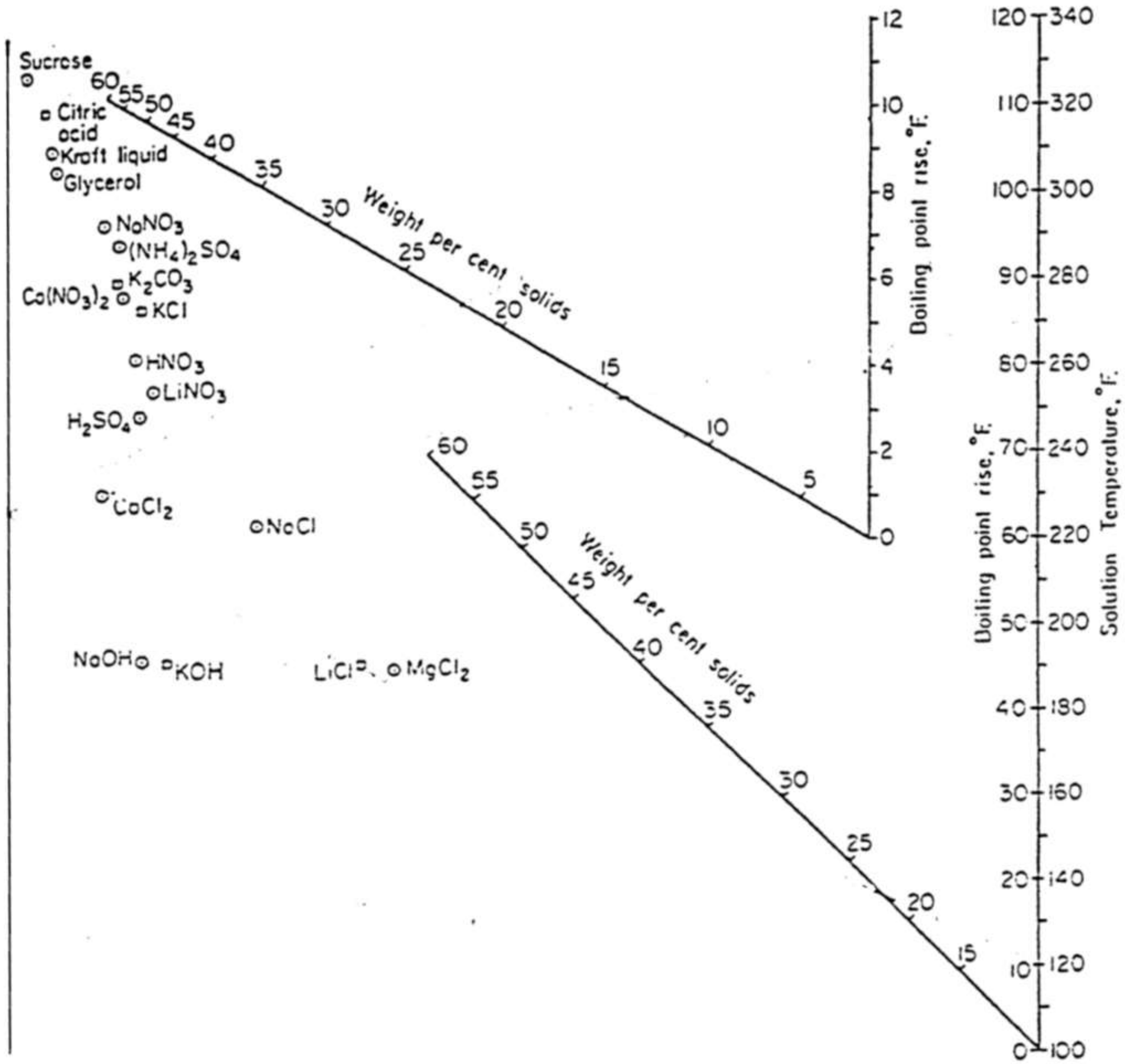
°F

***Question 5: Using the chart and steam tables (iterative).***

(a) What is the solution boiling point of 40wt% LiCl solution at 50 kPa absolute.

(b) What will be

- The boiling point rise?
- The vapour enthalpy ($c_{pg}$ = 1.88 kJ/kg°C)?
- The liquid enthalpy assuming that the specific heat of the salt solution is 3.5 kJ/kg°C?


Sucrose
Citric acid
Kraft liquid
Glycerol
$NaNO_3$
$(NH_4)_2SO_4$
$K_2CO_3$
$Ca(NO_3)_2$
KCl
$HNO_3$
$LiNO_3$
$H_2SO_4$
$CaCl_2$
NaCl
NaOH
KOH
LiCl
$MgCl_2$
Weight per cent solids
Weight per cent solids
Boiling point rise, °F
Boiling point rise, °F
Solution Temperature, °F

°F

**Multi-stage evaporator - General Solution Procedure**

Step 1 Solve equations mass balance equations to determine the amount of water evaporated $(m_{V1} + m_{V2} + m_{V3})$ and the missing solution flow rate or composition.

Step 2 Determine the steam heat source temperature ($\theta_s$) and allowable last stage condensate temperature and pressure.

Step 3 Determine the boiling point elevation in the last stage and hence determine the last stage solution temperature ($\theta_3$)

Step 3 Determine the temperature difference across the heat exchanger for each stage

Step 5 Determine the amount of water evaporated in each stage

Step 6 Determine the area of the heat exchanger

## *Question 6: Three stage feed forward evaporator*

Ten kg/s of 2 wt% NaCl is being concentrated to 20wt% NaCl in a three effect feed forward evaporator. Steam is available at 150 kPa abs and a vacuum of 500 mmHg (below atmospheric) is being pulled by the vacuum pump. The overall heat transfer coefficients for the first, second and third heat exchangers are 1000 $W/m^2K$, 900 $W/m^2K$ and 800 $W/m^2K$ respectively and the area of the three heat exchangers are identical.

(a) Determine the size of the heat exchangers.

(b) What increase in production would be expected if the steam pressure was increased to 200kPa.a?

## *Question 7: Three stage feed forward evaporator*

A 5 wt% citric acid solution is concentrated in a triple effect feed forward evaporator to 60 wt% using steam at 20 kPa gauge. 10 kg/s of cooling water at 20°C is injected into the final stage condenser of operating at 10 kPa absolute.

(a) Calculate the amount of water evaporated in the final stage and hence the production rate of 60wt% citric acid.

(b) Both the overall heat transfer coefficient and the temperature difference across each heat exchanger is identical. Determine the size of each heat exchanger if the overall heat transfer coefficient is 1000 $W/m^2K$.