Mass Balance

Lecture Note
Principles of Food Engineering

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Mass Balance Learning Objectives

- Understand the fundamental mass balance concepts
- Be able to list and discuss important mass balance applications in food processing and handling operations
- Be able to conceptually describe how mass balance determinations or calculations are obtained

WHY STUDY MASS BALANCE???

- Fundamental for blending of ingredients in food processing operations

- Fundamental for separation processes include:
  - evaporation
  - dehydration
  - distillation
  - absorption
  - ion exchange

Law of conservation of mass :
Matter is neither be created nor destroyed

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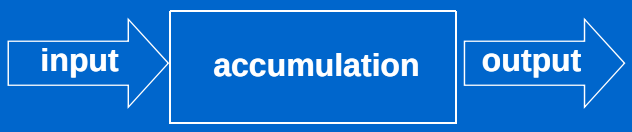
Mass Balance : Concept 1

- Law of Conservation of Mass

Input - output = accumulation



- Continuous/steady state processes :
  - No accumulation of mass
- Desired in large-scale operations :
  - process control : simpler
  - product quality : easier to manage
- In small scale operations, batch processing of ingredients is more common
- Combination of continuous and batch type operations sometimes used

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Mass Balance : Concept 2

Yield concept

- Grinding of soybean
  - Results : 93 kg soy flour are produced from 100 kg soybean
    Yield : 93%.
- (Bio)chemical reaction : Yield concept·····> stoichiometry
  - ex. $C_6H_4(CH_3)_2 + 3O_2$ ·····> $C_6H_4(CO)_2O + 3\ H_2O$
    xylene (X) phthylic anhydride (Ph)
  - Results : 108 kg of Ph are produced per 100 kg X
    Yield??

MW X = 106 kg/kg mole MW Ph = 148 kg/kg mole
100 kg X = 100 kg(1 kg mole/106 kg) = 0.944 kg mole
108 kg Ph = 108 kg(1kg mole/148 kg) = 0.730 kg mole
Yield : (0.730/0.944)100% = 77.3%

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Steps in Mass Balance Preparation

- Draw a sketch or diagram describing process
  - Identify information available
- Identify boundaries of system with dotted lines
  - Identify all input (inflows) and output (outflows)
- Use symbols or letters to identify unknown items/quantities
- Write mass balance equation :
  - choose appropriate basis of calculation
  - do total and/or component mass balance
- Solve resulting algebraic equation(s)

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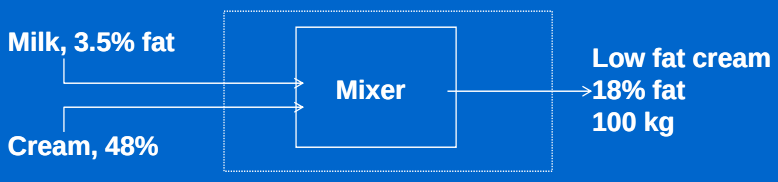
Mass Balance Example 0

Production of low fat cream (18% fat, w/w), from double cream (48% fat, w/w) and milk (3.5%,w/w).
Howmuch double cream and milk are required to produce 100 kg low fat cream?

Mass Balance Example 0 ……answer



Let the required double cream = y kg and milk = x kg
Total mass balance equation :

$y + x = 100$ kg …….. Eq.1

The componen balance on the fat :

$0.035x + 0.48y = 100(0.18)$ …….. Eq.2

Eq. 1 and 2 : $0.035(100-y) + 0.48y = 18$

$3.5 - 0.035y + 0.48y = 18$

$y = 32.58$ kg

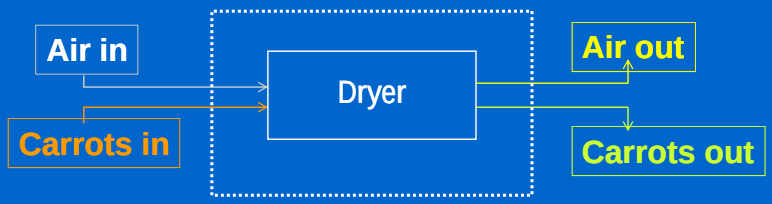
jadi …… $X = 67.42$ kg

Mass Balance Example 1

- Drying of 500 kg/h of diced carrots
- Dryer used : parallel-flow dehydrator
- Drying objective : moisture content 85% to 20%
- Air entering dehydrator
  - air humidity ratio of 0.013 kg of water per kg of dry matter entering dehydrator at the rate of 200 kg of air per kg of dry solid
- Calculate humidity ratio of the air leaving dehydrator

Mass Balance Example 1 ..... Answer (i)

Step 1. Draw a sketch or diagram describing process



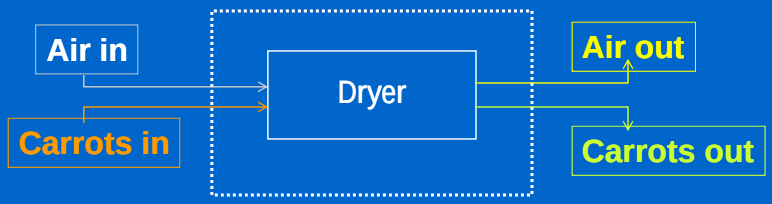
Step 2. Identify boundaries of system with dotted lines

Step 3. Use symbols or letters to identify unknown items/quantities

- ***Let m represent total water contained in 1 kg dry leaving air***

Mass Balance Example 1 ..... Answer (ii)

Step 4. Write mass balance equation



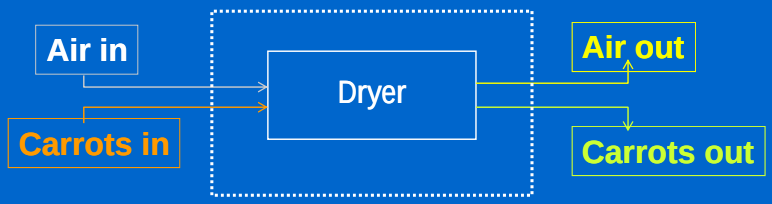
Balance of water :
Total of water in = total of water out

$(H_2O \text{ carrots} + H_2O \text{ air})_{in} = (H_2O \text{ carrots} + m)_{out}$

Basis : 1 kg dry basis
$(H_2O \text{ carrots})_{in}$: 85 parts of H_2O 15 part of dry solids
for 1 kg of dry solids : 1.0(85/15) = 5.67 kg H_2O

Mass Balance Example 1 ..... Answer (iii)

Step 4. Write mass balance equation

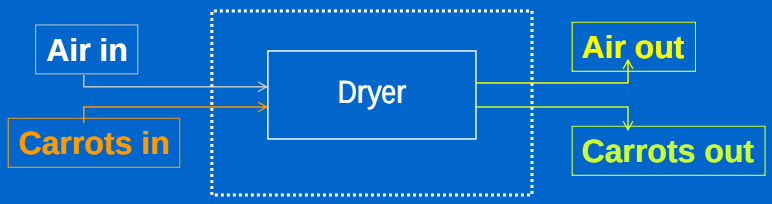


$(H_2O \text{ air})_{in}$: for 1 kg of dry solids ·····> 200 kg of dry air

$$\frac{(200)\text{ kg dry air}}{\text{kg dry solids}} \times \frac{(0.013)\text{ kg water}}{\text{kg dry air}} = 2.6 \text{ kg } H_2O$$

$(H_2O \text{ carrots})_{out}$: 1.0(20/80) = 0.25 kg H_2O

Mass Balance Example 1 ..... Answer (iv)



Water balance equation :

$$\frac{5.67 \text{ kg water}}{\text{kg dry solids}} + \frac{2.6 \text{ kg of water}}{\text{kg dry solids}} = \frac{0,25 \text{ kg of water}}{\text{kg dry solids}} + m$$

$5.67 + 2.6 = 0.25 + m$

Step 5. Solve resulting algebraic equation

$$m = 5.67 + 2.6 - 0.25 = \frac{8.02 \text{ kg water}}{\text{kg dry solids}}$$

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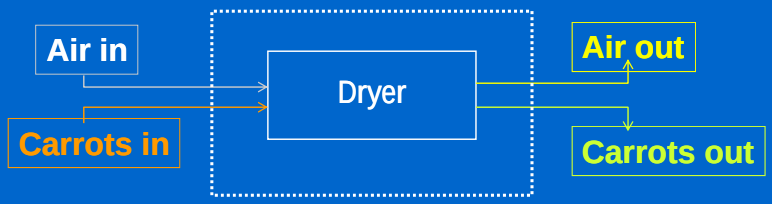
Mass Balance Example 1 ..... Answer (v)



humidity ratio, W_2 =
..... Moisture content of air leaving dehydrator

$$\frac{8.02 \frac{\text{kg water}}{\text{kg solids}}}{200 \frac{\text{kg dry air}}{\text{kg solids}}} = \frac{8.02 \text{ kg water / kg solids}}{200 \text{ kg dry/kg solids}} = \frac{0.04 \text{ kg water}}{\text{kg dry air}}$$

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Contoh Soal Neraca Massa 2

- Contoh- proses pencampuran sirup sorgum
- Pencampuran sirup murni dengan sirup jagung dan sirup-semi untuk memperoleh 100 kg “blended product”

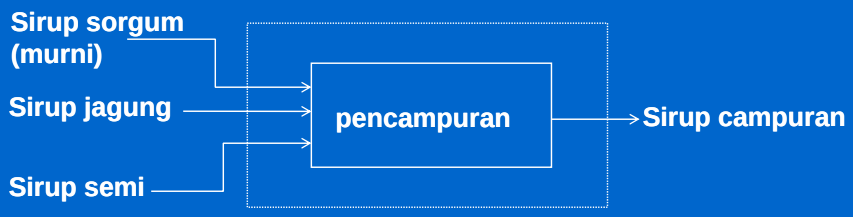
- Berikut adalah karakteristik 3 macam sirup :

Item	%H_2O	%gula	%Flavor
Sirup Sorg	23.0	76.0	1.5
Sirup jgn	20.0	80.0	0.0
Sirup-semi	40.0	60.0	1.0
Campuran	25.0	75.0	1.0

- Input - output = akumulasi

Contoh Soal Neraca Massa .....2 (jawab i)

1. Gambar diagram proses



2. Identifikasi sistem

3. Gunakan simbol-simbol : S jumlah (kg) sirup sorgum murni
C jumlah (kg) sirup jagung
P jumlah (kg) sirup semi

4. Tulis persamaan yang dihasilkan :

Diperlukan 3 pers neraca bahan; yaitu gula, flavor & total massa

Total	:	S + C + P = 100	..... (1)
Gula	:	0.76 S + 0.8 C + 0.6 P =0.75 x 100 = 75	..... (2)
Flavor	:	0.015 S + 0 C + 0.01 P=0.01 x 100 = 1	..... (3)

Contoh Soal Neraca Massa .....2 (jawab ii)

Total	:	S + C + P = 100	..... (1)
Gula	:	0.76 S + 0.8 C + 0.6 P =0.75 x 100 = 75	..... (2)
Flavor	:	0.015 S + 0 C + 0.01 P=0.01 x 100 = 1	..... (3)

5. Pecahkan persamaan yang diperoleh

Pecahkan P pada pers (3) sebagai fungsi S :

P = 100 - 1.5 S

- **Substitusi nilai P dalam pers (1) :**

  S + C + 100 - 1.5 S = 100 ·····> jadi, C = 0.5 S

- **Substitusi nilai C dan P dalam pers (2) :**

  0.76 S + 0.8(0.5 S) + 0.6(100-1.5 S)=75

  0.26 S = 15; ·····> jadi, S = 57.69

- **Pecahkan nilai C dan P :**

  C = 0.5 S = 0.5 (57.69) = 28.85

  P = 100-1.5S = 100 - 1.5(57.69) = 13.46

- **Jadi, campuran itu adalah :**

  S + C + P = 57.69 + 28.85 + 13.46 =100

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Example

Production of low fat cream (18% fat, w/w), from double cream (48% fat, w/w) and milk (3.5%,w/w).
Howmuch double cream and milk are required to produce 100 kg low fat cream?

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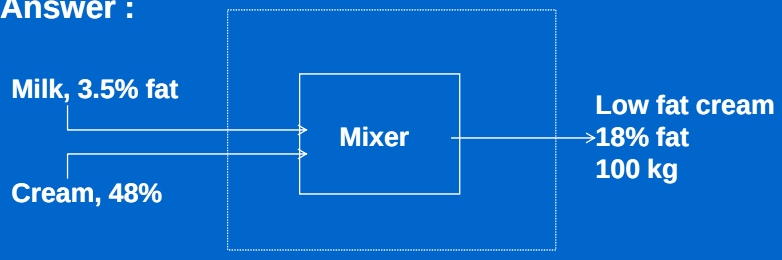
Answer :



Let the required double cream = y kg and milk = x kg
Total mass balance equation :
y + x = 100 kg Eq.1
The componen balance on the fat :
0.035x + 0.48y = 100(0.18) Eq.2

Eq. 1 and 2 : 0.035(100-y) + 0.48y = 18
3.5 - 0.035y + 0.48y = 18
y = 32.58 kg
jadi ..... X = 67.42 kg

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Mass Balance Example 3

..... DO IT!

A fruit puree is dried in a continuous flow dehydrator.
The wet puree contains 0.80 H_2O/kg puree while the dried puree contains 0.20 kg H_2O/kg puree.
Flow rates of wet puree entering the dehydrator is 100 kg/h while dry puree leaving the dehydrator is 25 kg/h .
Heated drying air flows opposite to flow of the puree.
Moisture content of drying air entering and leaving the drier are 0.01 and 0.02 kg H2O/kg, respectively.
What is the flow rate of drying air?

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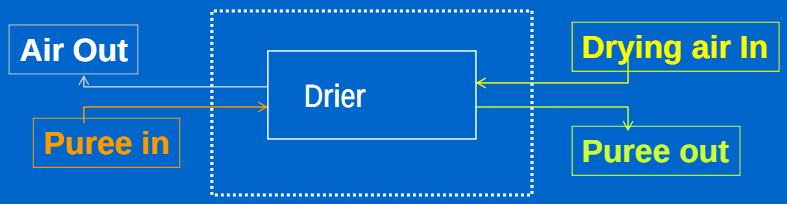
Mass Balance Example 3 ..... Answer (i)

Step 1. Draw a sketch or diagram describing process



Step 2. Identify boundaries of system with dotted lines

Input : puree in (0.80 H_2O/kg puree), at 100 kg/h
drying air in (0.01 kg H_2O/kg)

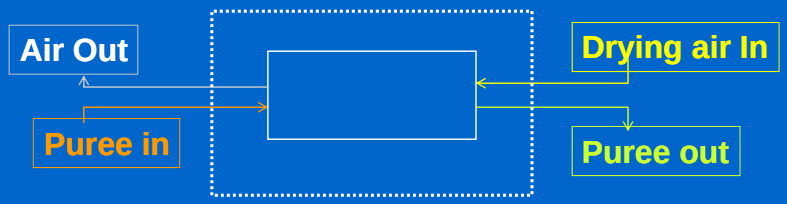
Output : dried puree (0.20 kg H_2O/kg puree), at 25 kg/h
drying air out (0.02 kg H_2O/kg)

Step 3. Use symbols or letters to identify unknown items/quantities

- Let X kg/h represent the flow rate of drying air?

Mass Balance Example 3 ..... Answer (ii)

Step 4. Write mass balance equation



Balance for water : Water $_{IN}$ = Water $_{OUT}$
Basis : 1 h

x kg DA (0.01 kg H_2O /kg DA) + 100 kg puree (0.8kg H_2O /kg puree) =
x kg DA (0.02 kg H_2O /kg DA) + 25 kg puree (0.2 kg H_2O/kg puree)

$0.01x + 80 = 0.02x + 5$
$x = 75/0.01 = 7500$

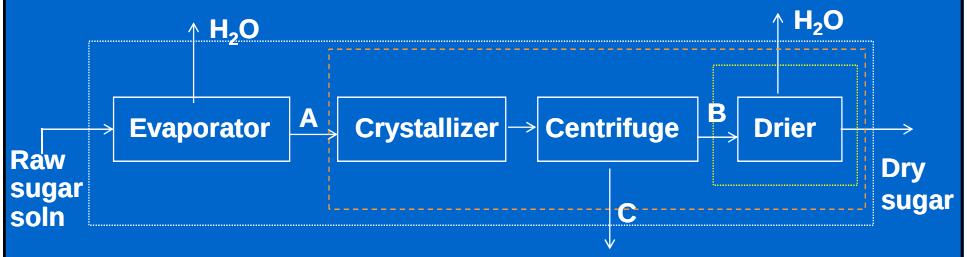
Flow rate of drying air = 7500 kg/h

MATERIAL BALANCE FOR COMPLEX PROCESSING

Example of sugar crystallization

- Determine the amount of sugar that can be produced from 100,kg of sugar solution containing 20% (w/w) sugar, 1% (w/w) water soluble (uncrystallizable) impurity.
- The process are as the following :
- Solution is concentrated to 75% sugar, cooled to 20^{o}C, and centrifuged, and the crystals are then dried.

1. Diagram



A : concentrated sugar soln (75% sugar,w/w)

B : wet sugar crystal

C : low concentration sugar soln

2. Identify system?

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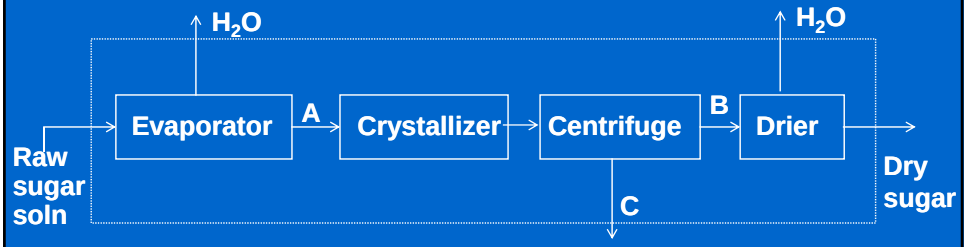
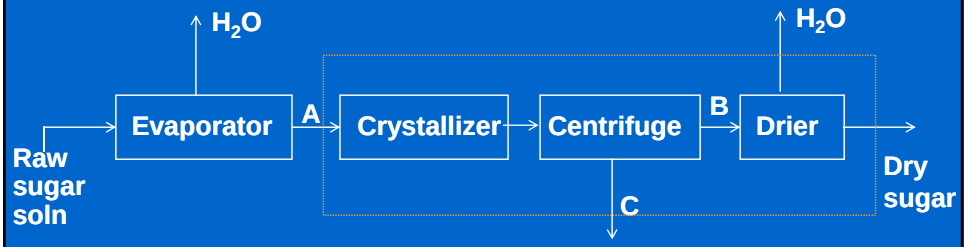
System a :



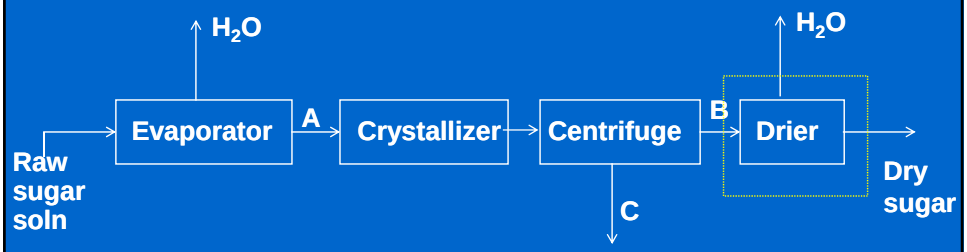
Input : raw sugar soln
Output : H_2O (from evaporator)
H_2O (from drier)
C : low concentration sugar soln
dry sugar

System b :



Input : concentrated sugar soln (75% sugar,w/w)
Output : H_2O (from drier)
C : low concentration sugar soln
dry sugar

System c :



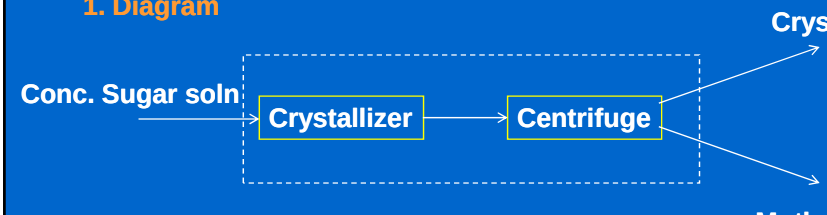
Input : B (wet sugar crystal)
Output : H_2O (from drier)
dry sugar

MASS BALANCE EXAMPLE 4.

- Crystallization of 100 kg of a concentrated sugar soln (85% sugar and 1 % inert, water soluble impurities.
- After cooling (crystallization), mixture was then centrifuged to separate crystal and a liquid fraction (mother liquor).
- Mother liquor contain 60% sucrose (w/w). Crystals slurry contain 20% (w/w) mother liquor.
- Do mass balance analysis for the process!

MASS BALANCE EXAMPLE 4.....answer (i)

1. Diagram



2. Identify system

Input : Conc. Sugar soln
(100 kg, 85% sucrose, 1% impurities, 14% water)

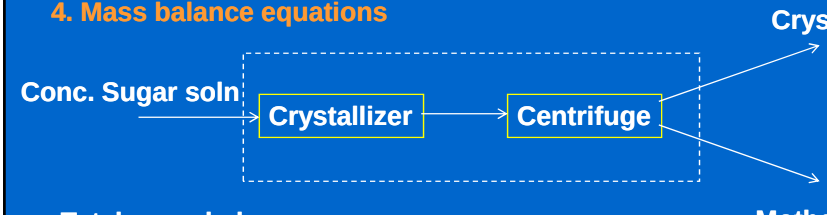
Output : Crystal slurry (20% mother liquor)
Mother liquor (60% sucrose)

3. Symbol :

let S = total mass of conc. Sugar soln
C = total mass of crystal produced
M = total mass of mother liquor produced

MASS BALANCE EXAMPLE 4.....answer (ii)

4. Mass balance equations



Total mass balance :

$S = C + M$ ..... Eq. 1

Balance of sucrose :

$0.85S = 0.6M + [\ 0.8(C) + 0.2(C)0.6\ ]$ ..... Eq. 2

Balance of water :

let x = mass fraction impurities in mother liquor

$0.14S = M\,(0.4\text{-}x) + C(0.2)(0.4\text{-}x)$ ..... Eq. 3

Balance of Impurities :

$0.01S = M(x) + 0.2C(x)$ ..... Eq. 4

..... 3 unknown, 4 equation!!

BASIS AND TIE MATERIAL

Basis of calculation :

- important if no initial quantities are given
- important for continuous process

Tie Material :

- Component used to relate the quantity of one process stream to the quantity of another
- Usually : component that does not change during process
  - * solid in dehydration process
  - * solid in evaporation process

RECYCLING ?? .... Toledo p.77

Falling film evaporator, capacity 10 kg water/h.
Feed enters at 5.5% solids and a 25% solid is desired.
To do that, system of recycling was used, at wich recycling pump moves 20 kg/h og fluid into the evaporator.

Caculate :

a. the feed rate
b. concentrate production rate
c. amount of concentrate recycled
d. concentration of mixture of feed and recycled concentrate

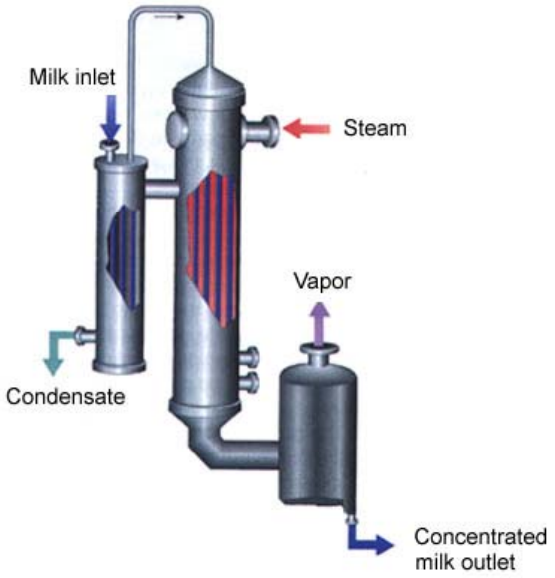


Fig. 6.5.4 Single-effect falling film evaporator.

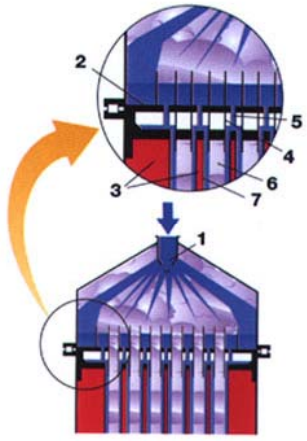


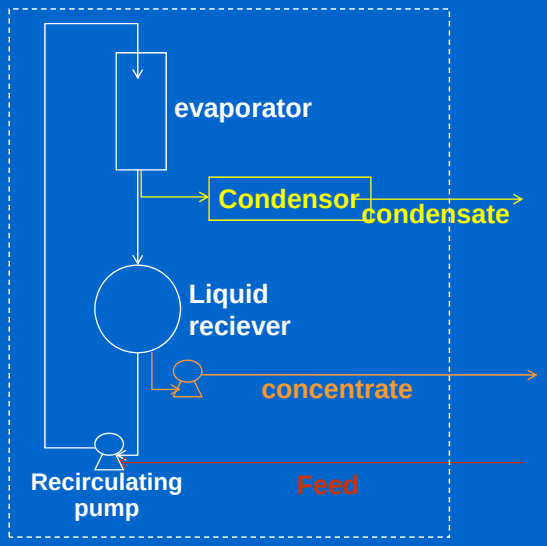
Fig. 6.5.5 Upper section of a falling film evaporator.

1 Product feed nozzle
2 Spreader plate
3 Steam for heating
4 Coaxial tubes
5 Openings
6 Vapor
7 Evaporator tubes

Product
Vapor
Heating medium

RECYCLING ?? .... Toledo p.77 ..... Answer (i)

1. Diagram?



1. Boundary of the system ?

Input :
Feed (5.5 % solids)

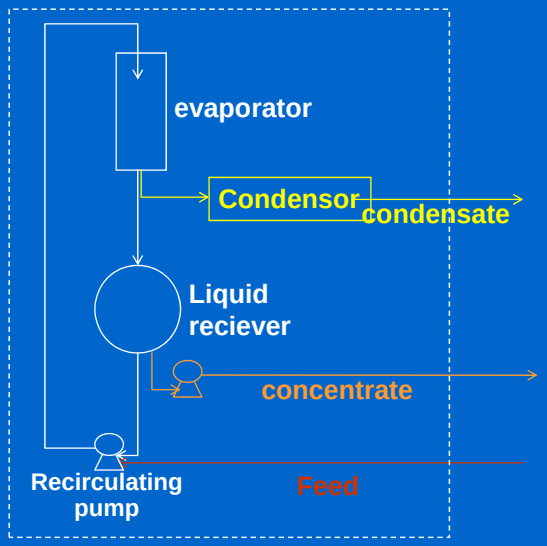
Output :
Condensate : 10 kg/h
Concentrate

3. Symbols?

Feed rate = F
Condensate rate = V=10
Concentrate rate = C

RECYCLING ?? .... Toledo p.77 ..... Answer (ii)

4. Mass balance equation(s)



Total mass balance :
F = C + V = C + 10 ..... Eq.1

Balance of Solid :
0.055F = 0.25C ..... Eq. 2

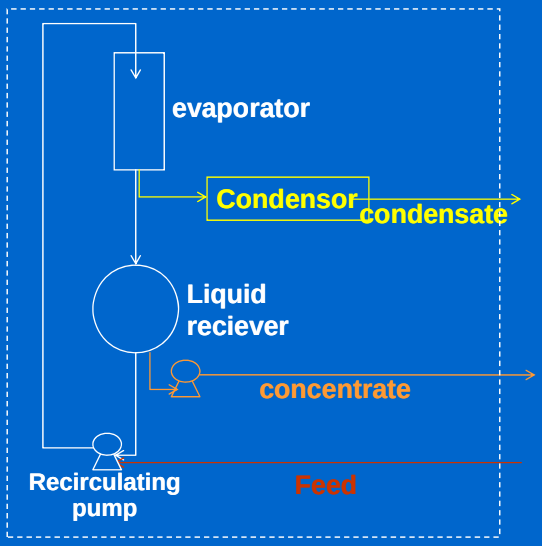
5. Solve the equations

Eq.2. F =(0.25/0.055)C
F = 4.545C Eq.3

Eq.1 dan 3 :
4.545C = C + 10
C = 10/3.545 = 2.52

Jadi concentrate rate
= 2.52 kg/h

RECYCLING ?? .... Toledo p.77 ..... Answer (iii)

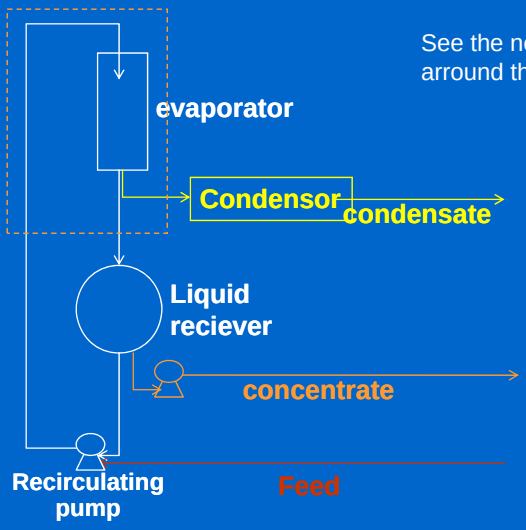


Back to eq.3.
F = 4.545C
= 4.545(2.82)
= 12.82

Feed rate = 12.82 kg/h

To answer question c and d, we need to change the (boundary of) system analyzed

RECYCLING ?? .... Toledo p.77 ..... Answer (iv)

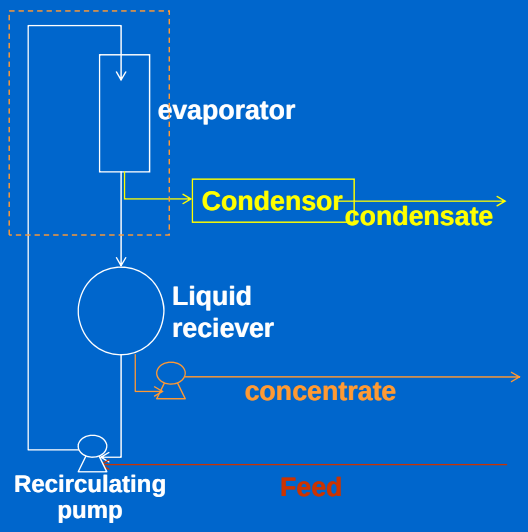


See the new system, arround the evaporator

Input :
Feed + Recycled
(20 kg/h)

Output :
Condensate
V = 10 kg/h
Concentrate total
(25% solid)

RECYCLING ?? .... Toledo p.77 ..... Answer (v)



Let total concentrate = Ct

Balance of total mass :
F+R = 20 = V + Ct
12.82 + R = 20 = 10 + Ct

R = 7.18
(amount of concentrate recycled : 7.18 kg/h)

d. concentration of mixture of feed and recycled concentrate ? x

Ct = 20-10 = 10
x(20) = 10(0.25)
x = 2.5/20 = 0.125
Concentration = 12.5%

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Material Balance for Blending Processes

- blending and proportioning is conducted to give products of desired composition

- optimization of composition with constraints on prices of raw materials is best solved by linear programming

Example

A processing plant is producing minced meat which must contain 15% of fat. If this is to be made up from boneless cow beef with 23% of fat and from boneless bull beef with 5% of fat, what are the proportions in which these should be mixed?