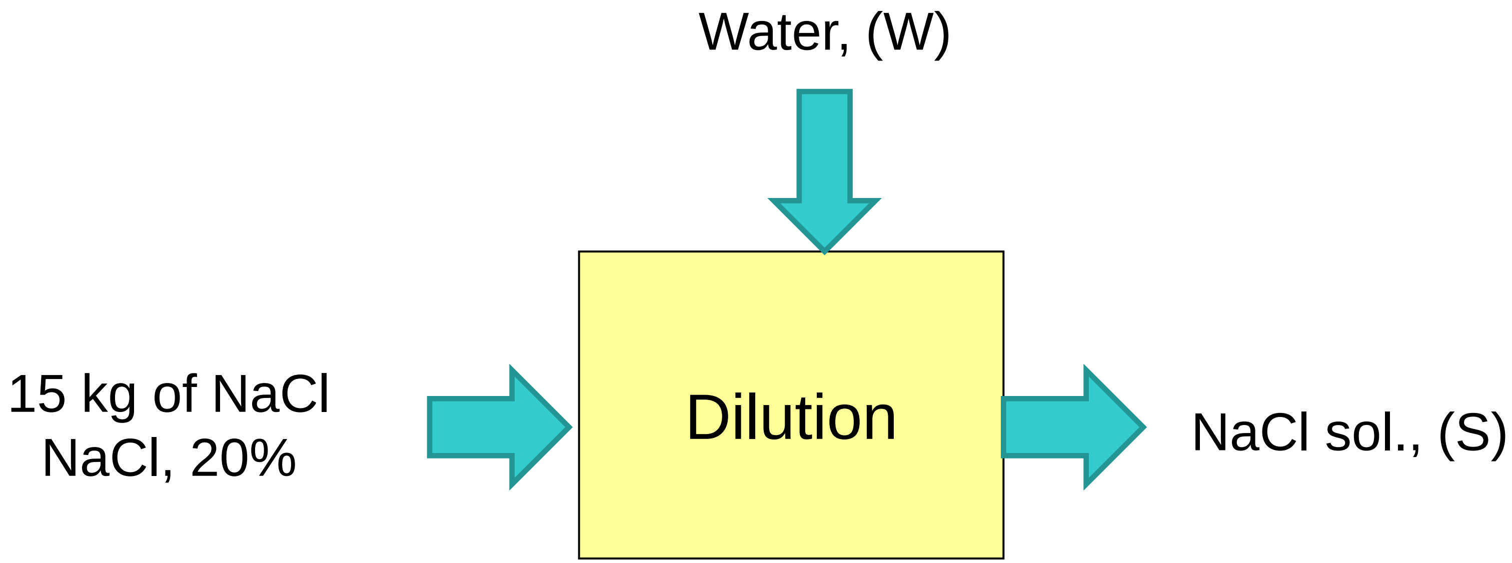
Material balance calculations involved with dilution and mixing

Dilution of NaCl



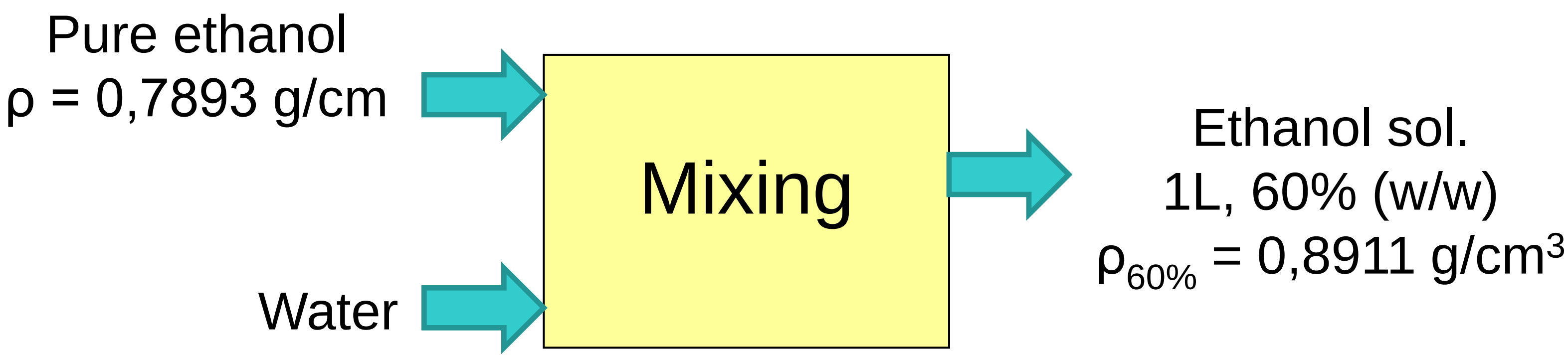
Volume changes on mixing

- When two liquids are mixed, the volumes are not always additive.
- NaCl solution, sugar solutions, and ethanol solution all exhibit volume changes on mixing.
- Because of volume changes, material balances must be based on the mass rather than the volume of the components.

Example 3.28: Alcohol contents of beverages are reported as percentage by volume. The density of absolute ethanol is 0.7893 g/cm^3. The density of a solution containing 60% by weight of ethanol is 0.8911 g/cm^3.

a) Calculate the volume of absolute ethanol which must be diluted with water to produce 1 L of 60% by weight ethanol solution.
b) Calculate the amount of water needs to be added.
c) Calculate alcohol content of 60% ethanol solution by volume.

Flow diagram for the preparation of ethanol solution



Answers

- 677.39 mL pure ethanol
- 356.44 g or mL water
- Alcohol content (v/v) = 67.74%

Continuous vs Batch

- Material balance calculations are the same for a batch or a continuous process.
- In a batch system, the total mass enters or leaves the system at one time.
- In a continuous system, a basis of a unit time of operation may be used

- **Example 3.29:** An evaporator has a rated evaporation capacity of 500 kg/h of water. Calculate the rate of production of juice concentrate containing 45% total solids from raw juice containing 12% solids.

Recycle

- **Example 3.30:** A pilot plant model of a falling film evaporator has an evaporation capacity of 10 kg/h of water. The system consists of a heater through which the fluid flows down in a thin film, and the heated fluid discharges into a collecting vessel maintained under vacuum in which flash evaporation reduces the temperature of the heated fluid to the boiling point.

- In a continuous operation, a recirculating pump draws part of the concentrate from the reservoir, mixes this concentrate with feed, and pumps the mixture through the heater. The recirculating pump moves 20 kg/h of fluid. The fluid in the collecting vessel should be at the desired concentration for withdrawal from the evaporator at any time. If feed enters at 5.5% solids and a 25% concentrate is desired, calculate;

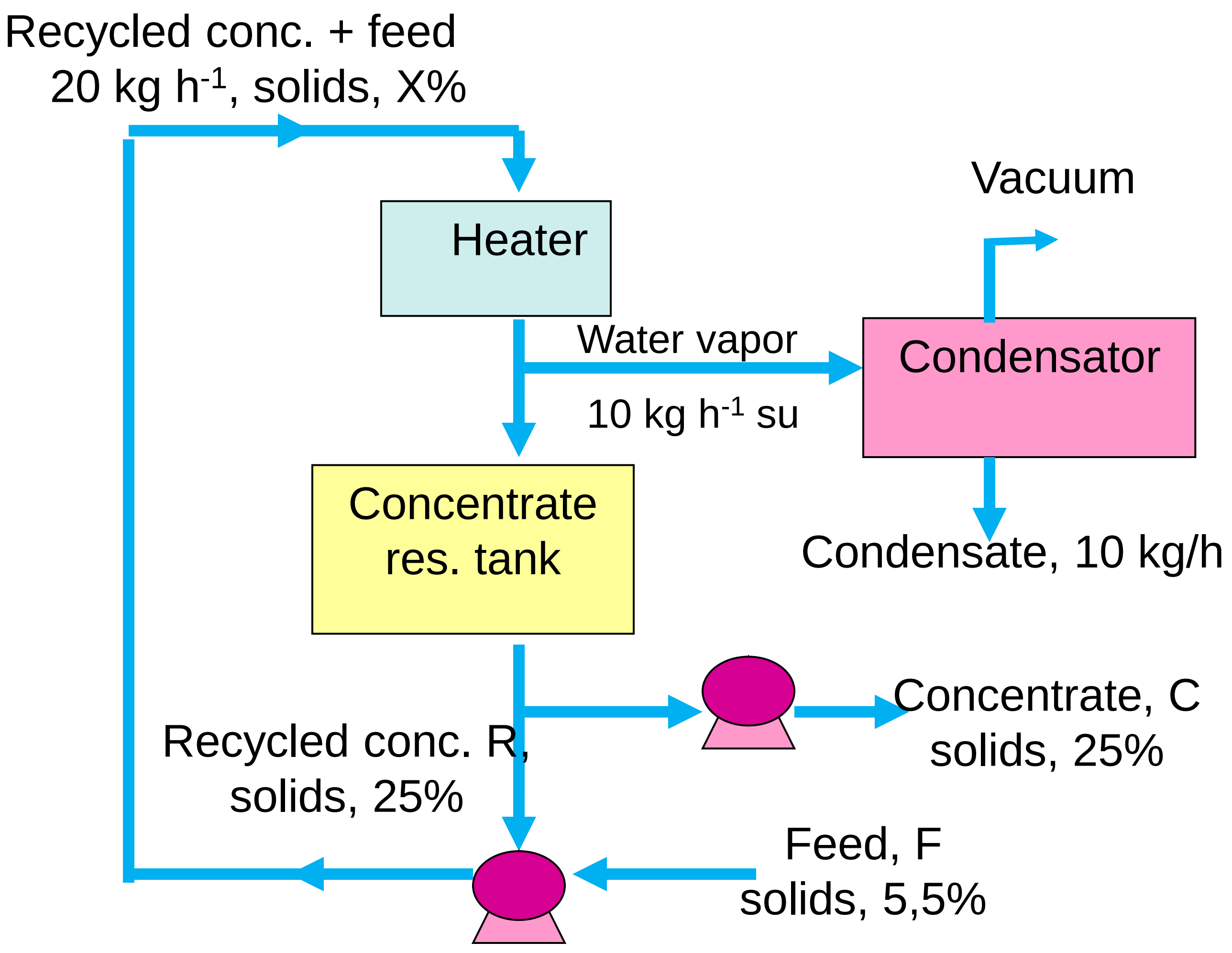
a) the feed rate

b) the concentrate production rate

c) the amount of concentrate recycled

d) the mass fraction, mass percentage and the amount of solids in the mixture.

Concentration of a food material using falling film evaporator



Answers

C = 2.82 kg (conc. production rate is 2.82 kg/h)

F =12.82 kg (feed rate is 12.82 kg/h)

R = 7.18 kg (recycle rate is 7.18 kg/h)

X = 0.125 (mass fraction)

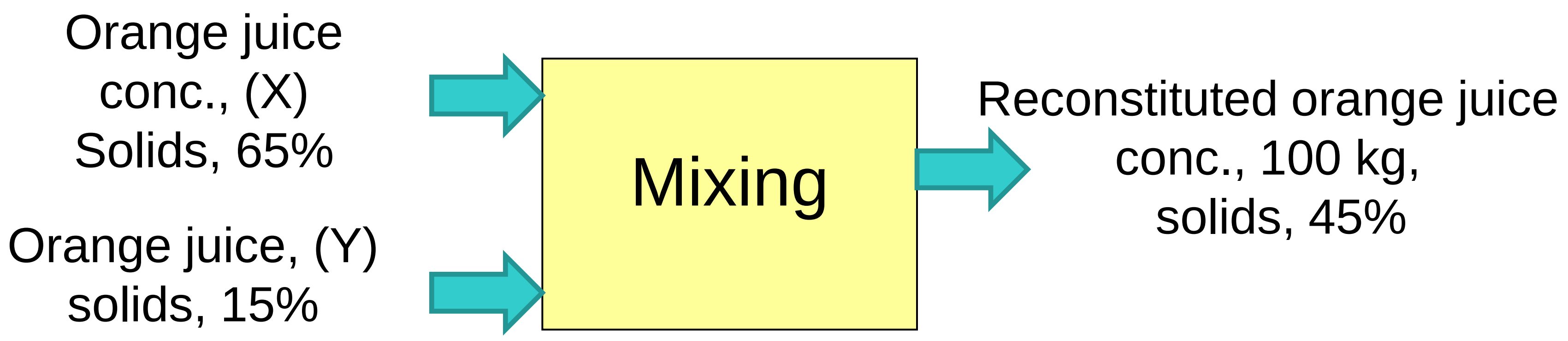
12.5% (mass percentage)

20 x 0.125 = 2.5 kg solids

Material balance problems involved with blending food ingredients

Example 3.31: Determine the amount of a juice concentrate containing 65% solids and single-strength juice containing 15% solids that must be mixed to produce 100 kg of a concentrate containing 45% solids.

Flow diagram for mixing of orange juice and concentrate



Matrices (Matrix)

- Coefficients of linear equations may be set up in matrix and the matrices are resolved to determine the values of the variables.

  - $a_1 x + b_1 y + c_1 z = d_1$
  - $a_2 x + b_2 y + c_2 z = d_2$
  - $a_3 x + b_3 y + c_3 z = d_3$

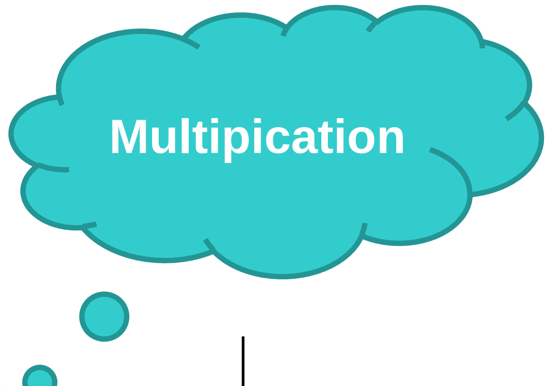
- The values of *x*, *y* and *z* are determined from the matrix calculations

Matrix

$$\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} \begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} d_1 \\ d_2 \\ d_3 \end{vmatrix}$$

$$X = \frac{\begin{vmatrix} d_1 & b_1 & c_1 \\ d_2 & b_2 & c_2 \\ d_3 & b_3 & c_3 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}} \quad Y = \frac{\begin{vmatrix} a_1 & d_1 & c_1 \\ a_2 & d_2 & c_2 \\ a_3 & d_3 & c_3 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}} \quad Z = \frac{\begin{vmatrix} a_1 & b_1 & d_1 \\ a_2 & b_2 & d_2 \\ a_3 & b_3 & d_3 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}}$$

Solution of 2 x 2 matrix



$$\begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = \boxed{a_{11}\,a_{22}} - a_{21}\,a_{12}$$

Solution of 3 x 3 matrix

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} \quad \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} \quad \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix}$$

$$a_{11}\begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix} - a_{21}\begin{vmatrix} a_{12} & a_{13} \\ a_{32} & a_{33} \end{vmatrix} + a_{31}\begin{vmatrix} a_{12} & a_{13} \\ a_{22} & a_{23} \end{vmatrix}$$

- **Example 3.32:** Determine the values of x, y and z in the following equations:

$$\begin{aligned} x + y + z &= 100 \\ 0.8x + 0.62y + z &= 65 \\ 0.89x + 0.14y &= 20 \end{aligned}$$

Answers

$x = 8.7$

$y = 87.5$

$z = 3.8$

Check: $x + y + z = 100$

$$8.7 + 87.5 + 3.8 = 100$$

$$100 = 100$$

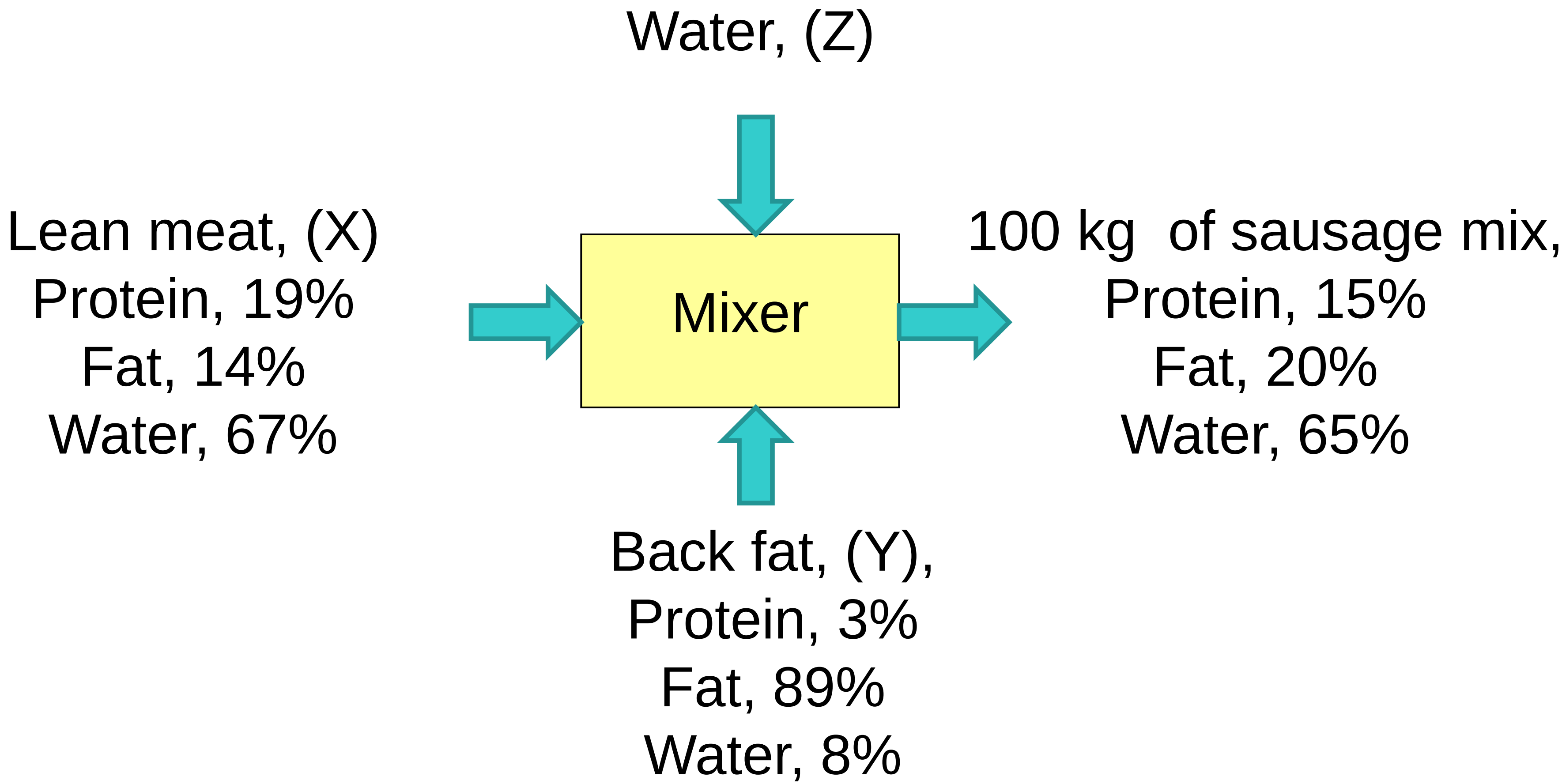
- **Example 3.33**: Determine the amounts of lean beef, back fat, and water that must be used to make 100 kg of a frankfurter formulation **using matrices**. The composition of the raw materials and the frankfurter are:

Lean beef – 14% fat, 67% water, 19% protein

Back fat – 89% fat, 8% water, 3% protein

Frankfurter – 20% fat, 65% water, 15% protein

Flow diagram for sausage production



Answers

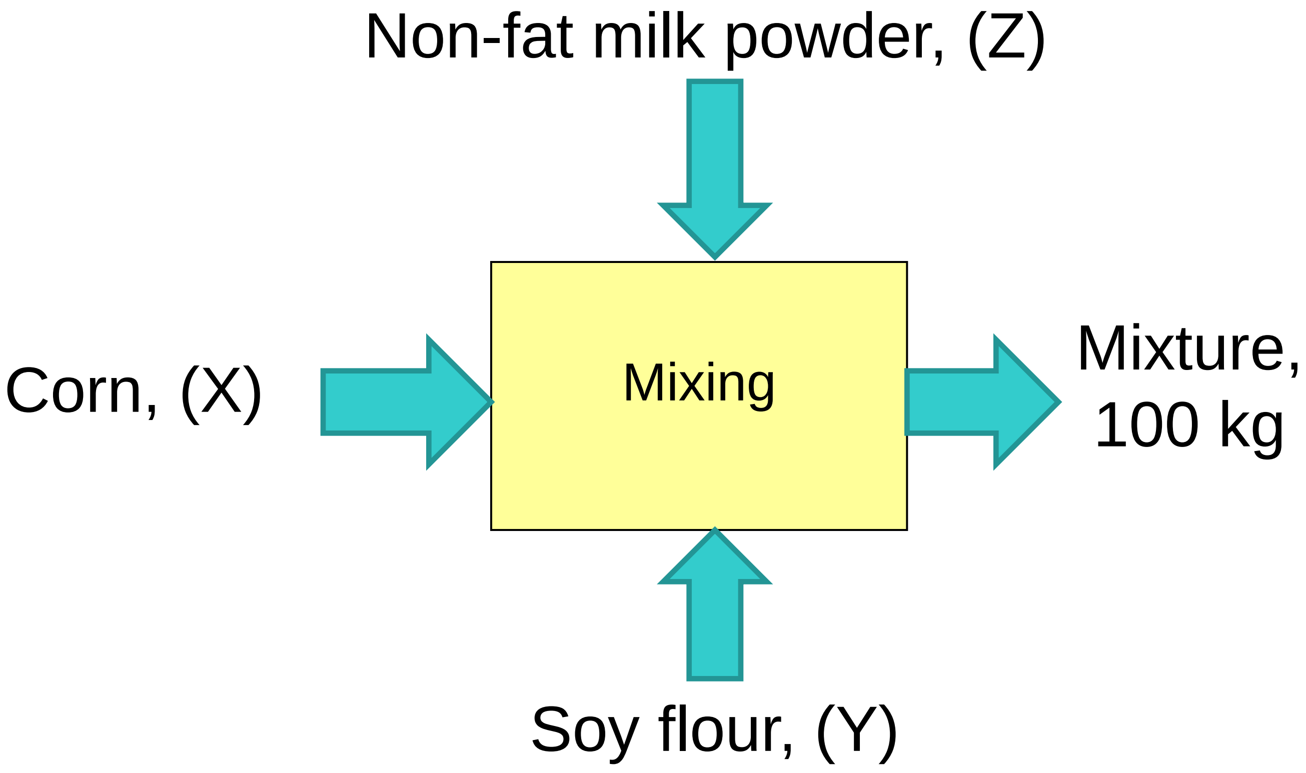
X = 77.3 kg lean beef

Y = 10.3 kg back fat

Z = 12.4 kg water

- **Example 3.34:** A food fix is to be made which would balance the amount of methionine (MET), a limiting amino acid in terms of food protein nutritional value, by blending several types of plant proteins. Corn which contains 15% protein has 1.2 g MET/100 g protein; soy flour with 55% protein has 1.7 g MET/100 g protein, and nonfat dry milk with 36% milk protein has 3.2 g MET/100 g protein. How much of each of these ingredients must be used to produce 100 kg formula which contains 30% protein and 2.2 g MET/100 g protein?

Flow diagram for Mixing of 3 different protein sources to raise MET content of the mixture



Answers

C = 46.25 kg corn

S = 19.54 kg soy flour

M = 34.2 kg non-fat milk powder

Check: $x + y + z = 100$

$$46.25 + 19.54 + 34.20 = 100$$

$$99.99 = 100$$

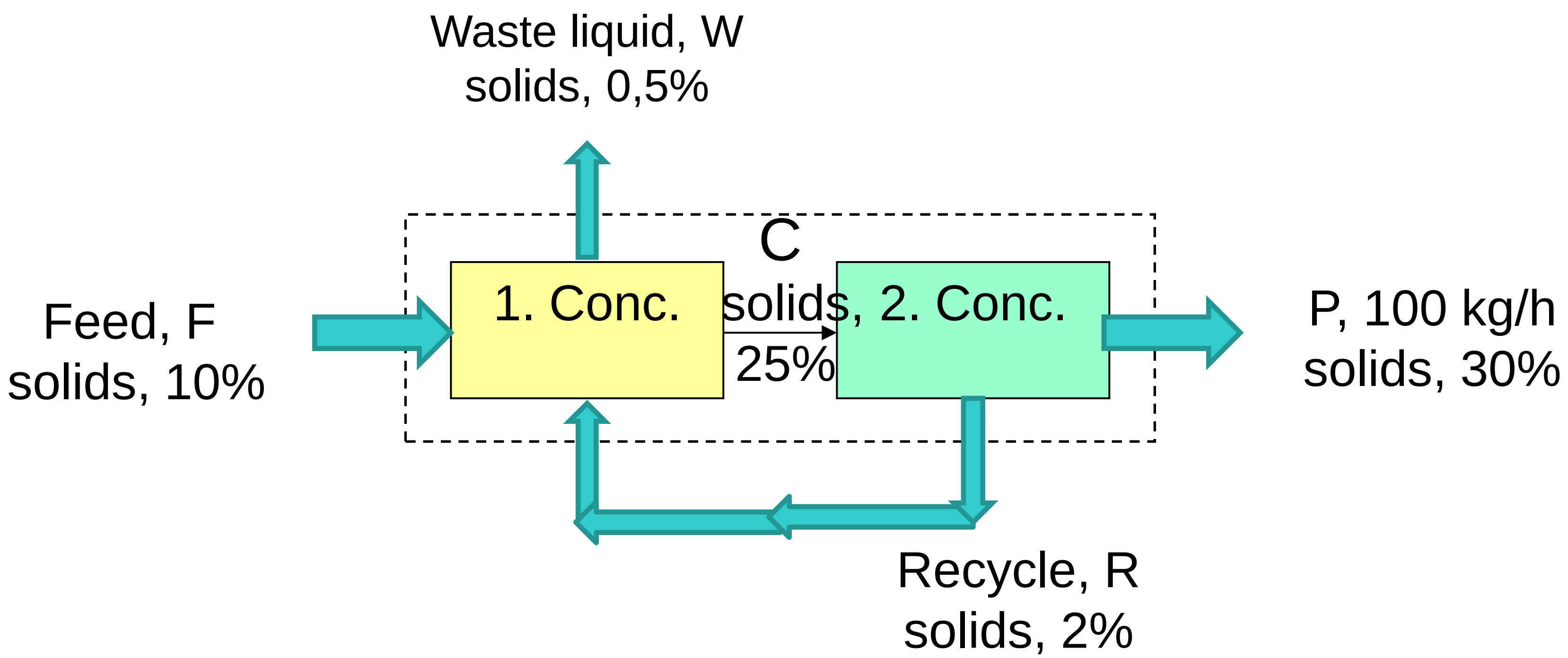
Concentration with membrane system

- **Example 3.35:** A liquid food is concentrated from 10% solids to 30% solids. The process of concentration takes place in two steps. The liquid with low percentage of solids obtained from the second step is recycled to the first step of concentration. The recycled liquid contains 2% solids, waste contains 0.5% solids, the semi-concentrate obtained from first concentration step contains 25% solids. To obtain 100 kg of the concentrated product with 30% solids, determine the rate of recycled feed per h.

Data

- Solid content of feed: 10%,
- Solid content of final concentrate: 30%,
- Solid content of recycled liquid : %2,
- Solid content of waste: %0.5,
- Solid content of concentrate obtained in the first step of concentration: %25,
- Rate of feed: 100 kg/min.

Flow diagram for concentration of food with membrane system



Answer

F = 310.5 kg/min feed

W = 210.5 kg/min waste

R = 21.73 kg/min recyle

C = 121.73 kg conc. after 1st step of conc.

$$21.73\ \frac{\text{kg}}{\text{min}}\ 60\ \frac{\text{min}}{\text{h}} = \mathbf{1304\ \frac{kg}{h}}$$

Concentration with ultrafiltration

- **Example 3.36:** Whey (peynir altı suyu) proteins are concentrated by ultrafiltration system from 1.7% protein to 14% protein. Ultrafiltration system has a membrane area of 0.75 m^2 and water permeability of 180 kg water /m^2 h. It works under the pressure of 1.033 Mpa. The system is fed by a pump which delivers 230 kg/h, and the appropriate concentration of protein in the product is obtained by recycling some of the product through the membrane. The concentrate contained 11% lactose and the unprocessed whey contained 5.3% lactose. There is no protein in the permeate.

a) The production of rate of concentrate (25% solids) through the system,

b) The amount of product recycled per h,

c) The amount of lactose removed in the permeate per h,

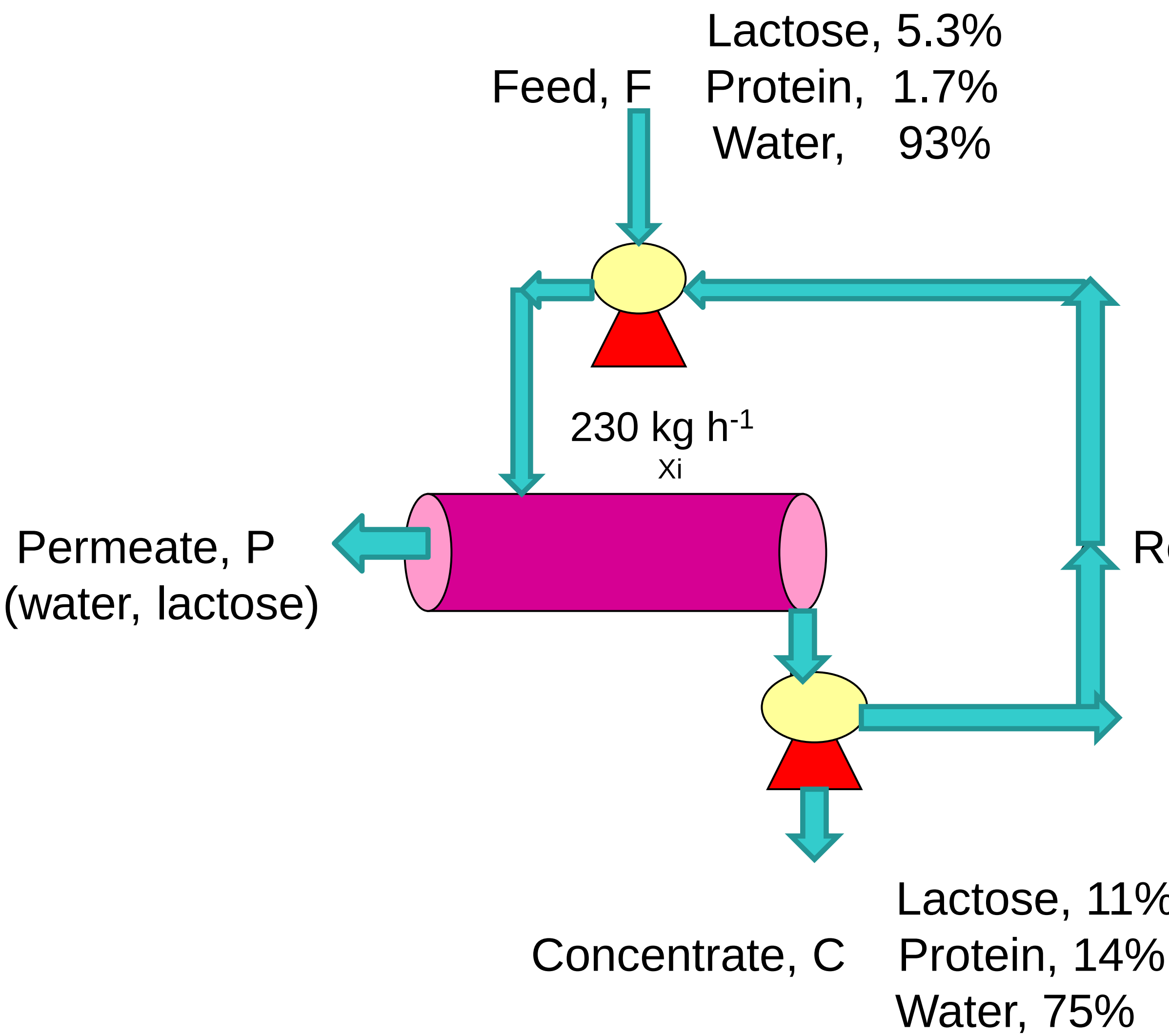
d) The mass fraction and the amount of lactose in the mixture of fresh and recycled whey entering the membrane unit,

a) The average rejection factor by the membrane for lactose based on the average lactose concentrations entering and leaving the unit. The rejection factor (F_r) of solute through a membrane is defined by:

$$F_r = \frac{X_f - X_p}{X_f}$$

- X_f : Avarage mass fraction of lactose in the fluid entering and leaving the membrane unit,
- X_p: Mass fraction of lactose in permeate.

Concentration of whey proteins with ultrafiltration



Answers

- F = 160.9 kg/h feed
- C = 19.54 kg/h conc.
- R = 69.1 kg/h recycle
- Amount of lactose in permeate = 6.3783 kg
- Amount of lactose entering system =16.1 kg
- F_R = 0.499