MATERIAL BALANCE

Material balance calculations are used in:

- Preparation of formulas (such as soudjouk, fruit and vegetable nectars),
- Determination final compositions after blending,
- Calculation of yields,

Basic principle of material balance calculations

Mass can neither be created nor destroyed!!

- Based on the principles of the law of «conservation of mass.»

Inflow = outflow + accumulation

In a system where the process is taken place;

STEADY STATE

Accumulation = 0

↓

Inflow streams = Outflow streams

In a system where the process is taken place;

UNSTEADY-STATE

Accumulation ≠ 0

Concentration of components in the system changes with time

Before preparing the material balance;

- First the process is put together in a flow diagram
- Then, the boundaries of the system (process) is determined.
- A system is described by a boundary, either real or imaginary.
- The boundary of a system can be real, such as the walls of a tank,
- The boundary may be stationary or movable. For example, the system boundary can include a tank (stationary), piping and a valve (movable).
- A system boundary may even enclose an entire food processing system.

SYSTEM

If the system does not allow the flow of liquid;

CLOSED SYSTEM

In these systems and the surroundings;

- No mass transfer transfer
- Heat transfer can occur.

If the system is composed of tank and pipes;

OPEN SYSTEM

In these systems and the surroundings;

- Mass transfer can occur as a result of flow.

Isolated systems

(such as insulated vessel)

In these systems and the surroundings;

- No heat transfer,
- No mass transfer.

SYSTEMS

If no heat transfer occurs between the system and its surroundings, → **ADIABATIC SYSTEM**

If the reaction occurs at a certain temperature and heat transfer occurs, → **ISOTHERMAL SYSTEM**

In calculations involving with material balance calculations;

First:

- Determine the system
- Determine the boundaries of the system.

Second:

Choose the basis.

For example: The basis can be the followings in the concentration of fruit juice

- Amount of fruit juice entering the evaporator (for instance; 100 kg or 1000 kg),
- Amount of fruit juice concentrate leaving the evaporator (for instance; 100 kg or 1000 kg),

- Ratio of the amount of concentrate leaving the evaporator to the amont of fruit juice entering the evaporator
(for instance; 1:4 or 1:6),

- Ratio of the amount of fruit juice entering the evaporator to the amont of concentrate leaving the evaporator
(for instance; 4:1 or 6:1),

Batch system

Certain amount of substance enters the system at one time, and the same amount leaves the sytem

Continous system

As a basis, a fixed time of operation (for instance, 1 h) is taken and the same material balances are carried out as in batch systems.

The following steps should be taken into consideration in conducting material balance

- Collect all known data on mass and composition of an inlet and exit streams from the statement of the problem.

- Draw a process flow diagram, indicating the process, with inlet and exit streams properly identified. Draw the system boundary.

- Write all available data on the flow diagram.

- Select the suitable *basis** (such as mass or time) for calculations, if necessary.

- Write total and component mass balances. For each unknown, an independent material balance is required.

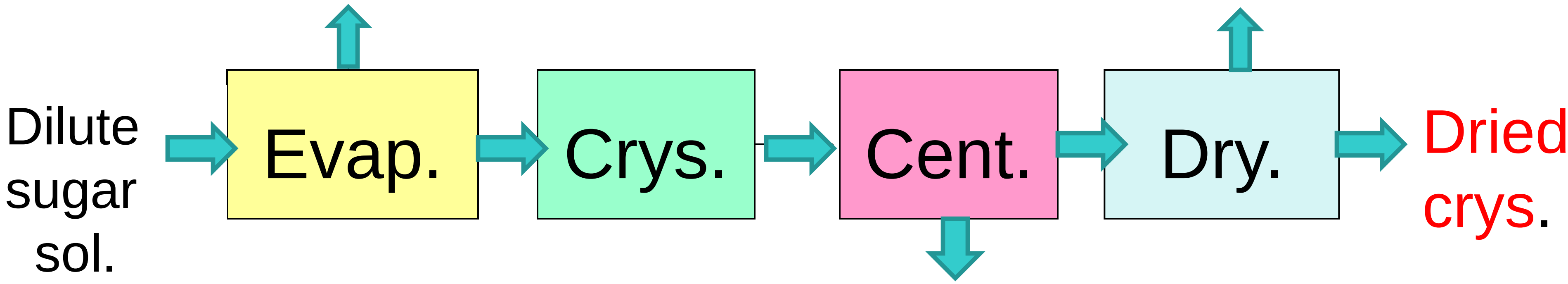
- Solve the material balance to determine the unknowns.

Process flow diagrams

Before material balance equations are formed,

Flow diagrams are formed by taking into consideration of process

Flow diagram for crystallization (crsytal sugar production)



Sugar beet


Atlas des Plantes de France,
A.Masclef 1891
Pl. 276. Bette vulgaire. (Betterave). Beta vulgaris L.

Example 1: Plot the flow diagram for the determination of the yield in tomato paste production and determine the basis in material balance calculations.

Hot-break or Cold-break processing

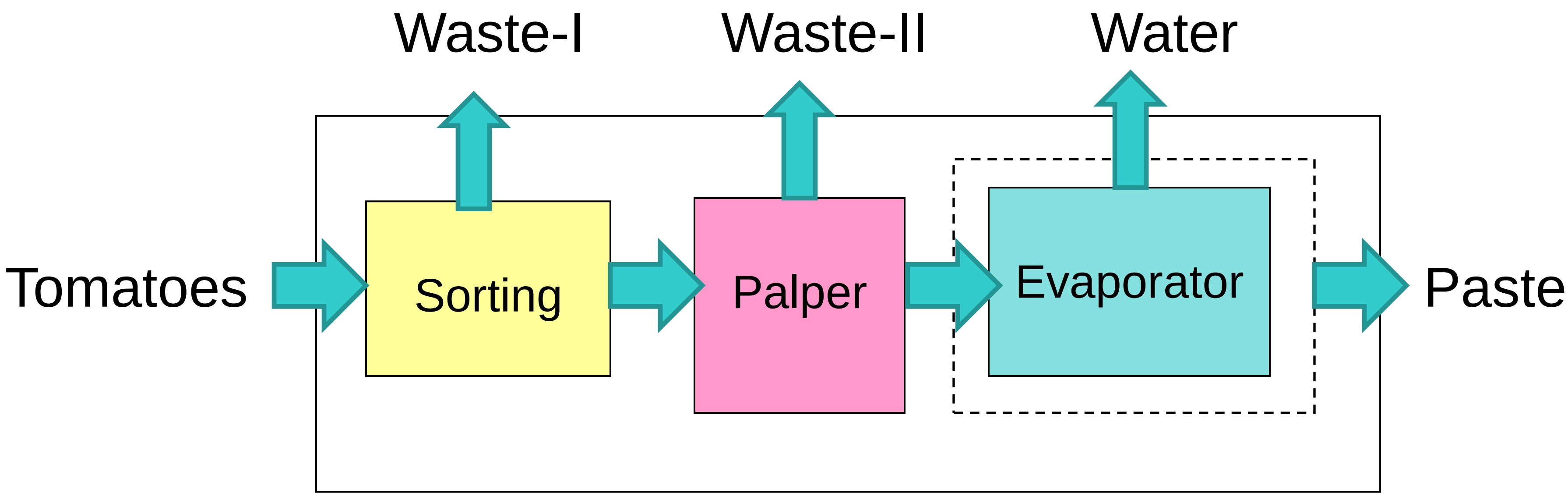
- **Hot break:** **tomato pulp** is heated to about 85°–95°C; PME enyzme is inactivated, as a result, pectin is preserved; therefore, thick paste is obtained.

- **Cold break:** **tomato pulp** is heated to about 65°–75°C; color and flavor is preserved, but thin paste is obtained because some pectin is degraded by PME.

Tomato paste production

1) Washing of tomatoes,
2) Sorting of tomatoes,
3) Chopping of tomatoes,
4) Heating of chopped tomatoes,
5) Obtaining refined juice or pulp from the heated tomato pulp (fiber, juice, skin and seeds) by palper
6) Concentration of refined juice (or the pulp) through an evaporator into paste,
7) Heating of paste in an tubular heating at usually 93°C, depending on hot- or cold-break paste production,
8) Hot filling at 93°C of paste in metal containers,
9) Cooling of metal containers,
10) Packaging of metal containers in carton packages,
11) Storage.

Flow diagram of tomato paste production



Total material balance

Equation indicating the equality of the total weight of each stream entering and leaving a system;

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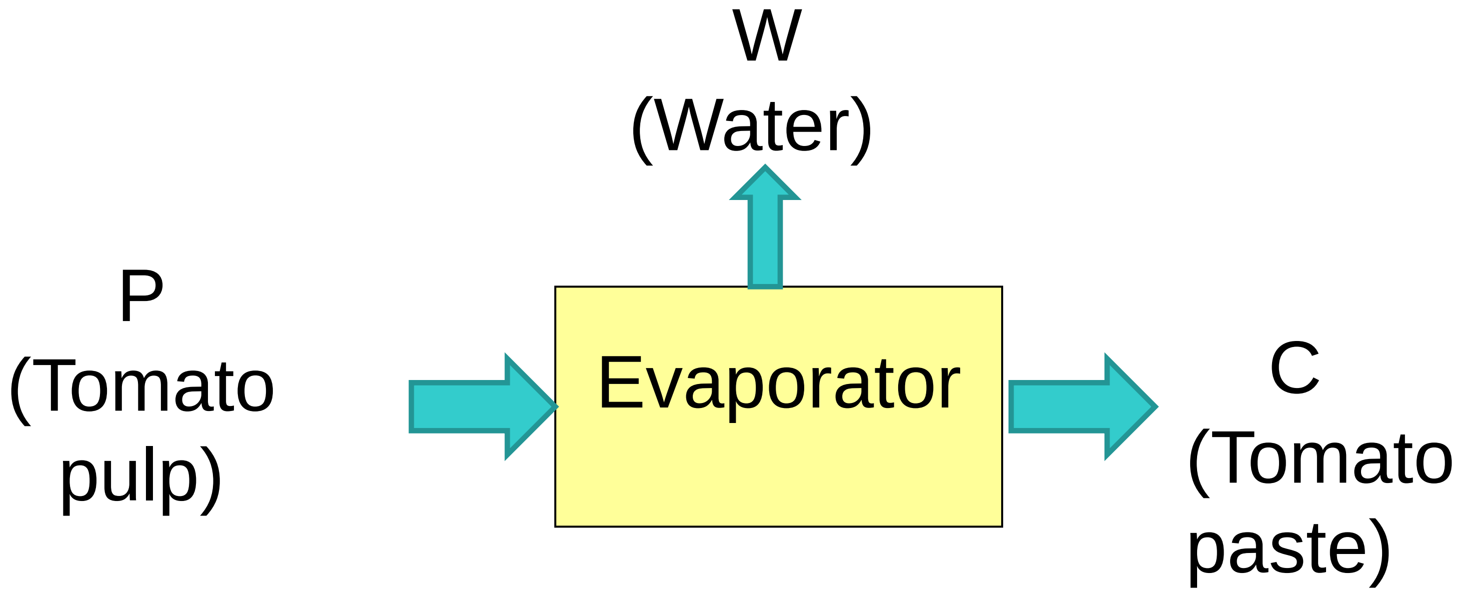
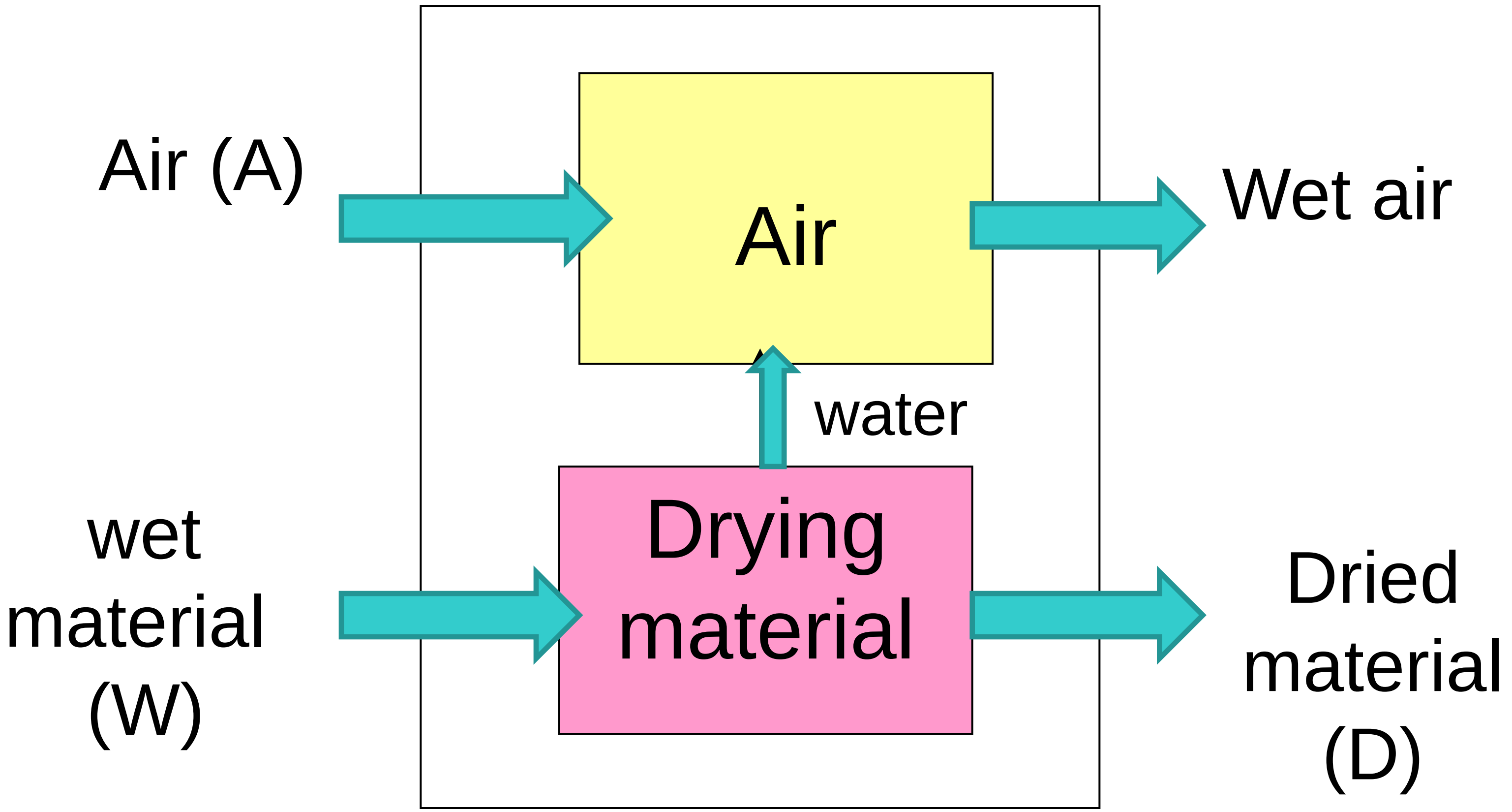
total material balance

- **Example 2:** In an evaporator, dilute material (tomato pulp) enters and concentrated material (tomato paste) leaves the system. Water is evaporated during the process. If P is the weight of the dilute material entering the system, W is the weight of water vaporized, and C is the weight of the concentrate, write an equation that represents the total mass balance for the system. Assume that a steady-state exists.


W
(Water)
P
(Tomato
pulp)
Evaporator
C
(Tomato
paste)

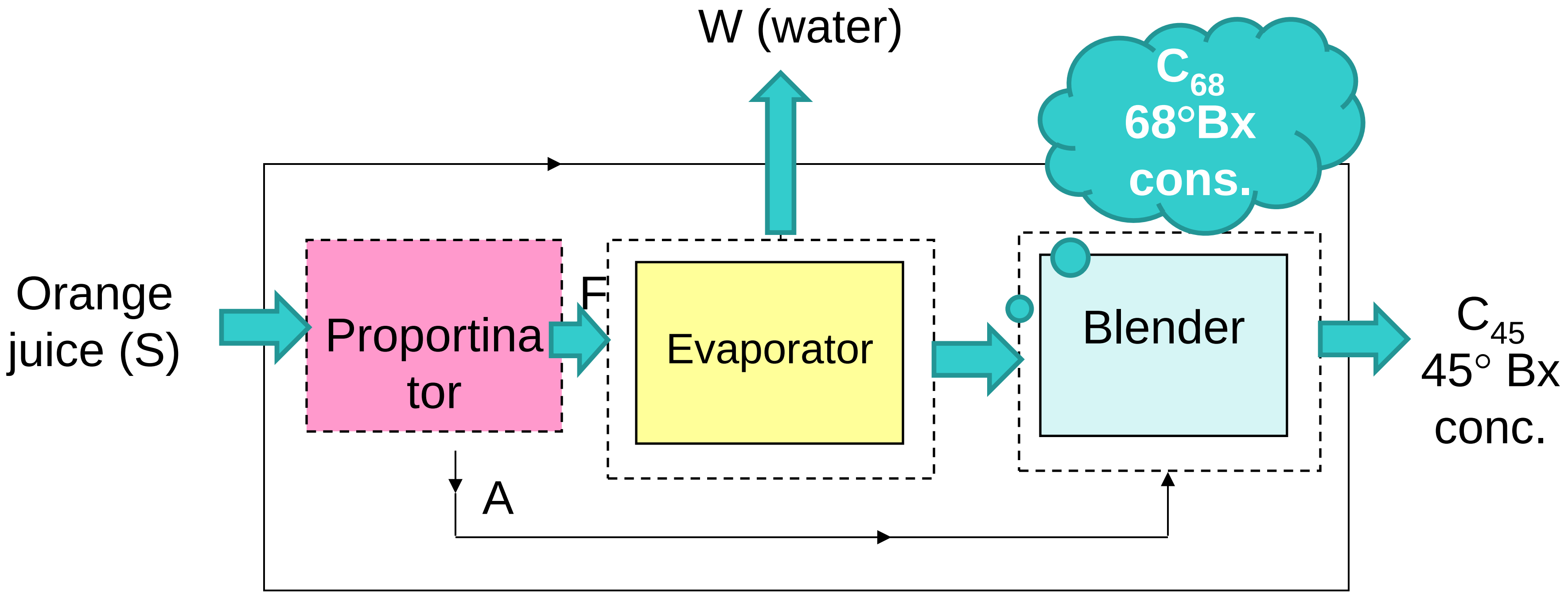
- **Example 3:** Drier is fed with W kg/min wet material and A kg/min hot air and dried material is left the system with D kg/min. Plot the flow diagram fort his process and write down the material balance equations for this process

Flow diagram for the hot air drier



- **Example 4:** Orange juice concentrate is made by concentrating single-strength juice to 68% solids (C) in an evaporator followed by dilution of the concentration to 45% solids using single-strength juice. The concentrate of 68^{o}Brix is poor in aroma; therefore, the freshly squeezed orange juice is added to this concentrate to enrich the aroma. This process is called as cut-back. Draw a diagram for the system, and set up mass balances for the whole system and for as many sub-systems as possible.

Diagram of an orange juice process involving evaporation and blending of concentrate with freshly squeezed juice



Component Mass Balance

- The same principles apply as in the total mass balance, except that the components are considered individually.

- If there are *n* components, *n* independent equations can be formulated; one equation for total mass balance an *n – 1* component mass balance equations.

- the amounts and mass percentages of the inflow and outflow streams are written in the flow diagrams

$$\text{Mass percentage} = \frac{\text{mass of component } A}{\text{total mass of mix. cont. } A} (100)$$

- If the quantities are expresses in volume units, convert them to mass units using density. This is because, the volumes change during heating.

- In the preparation of component material balance equations, the other way is to use mass fraction equation.
- This equation is especially used in the solving of problems involving with concentration and dilution.

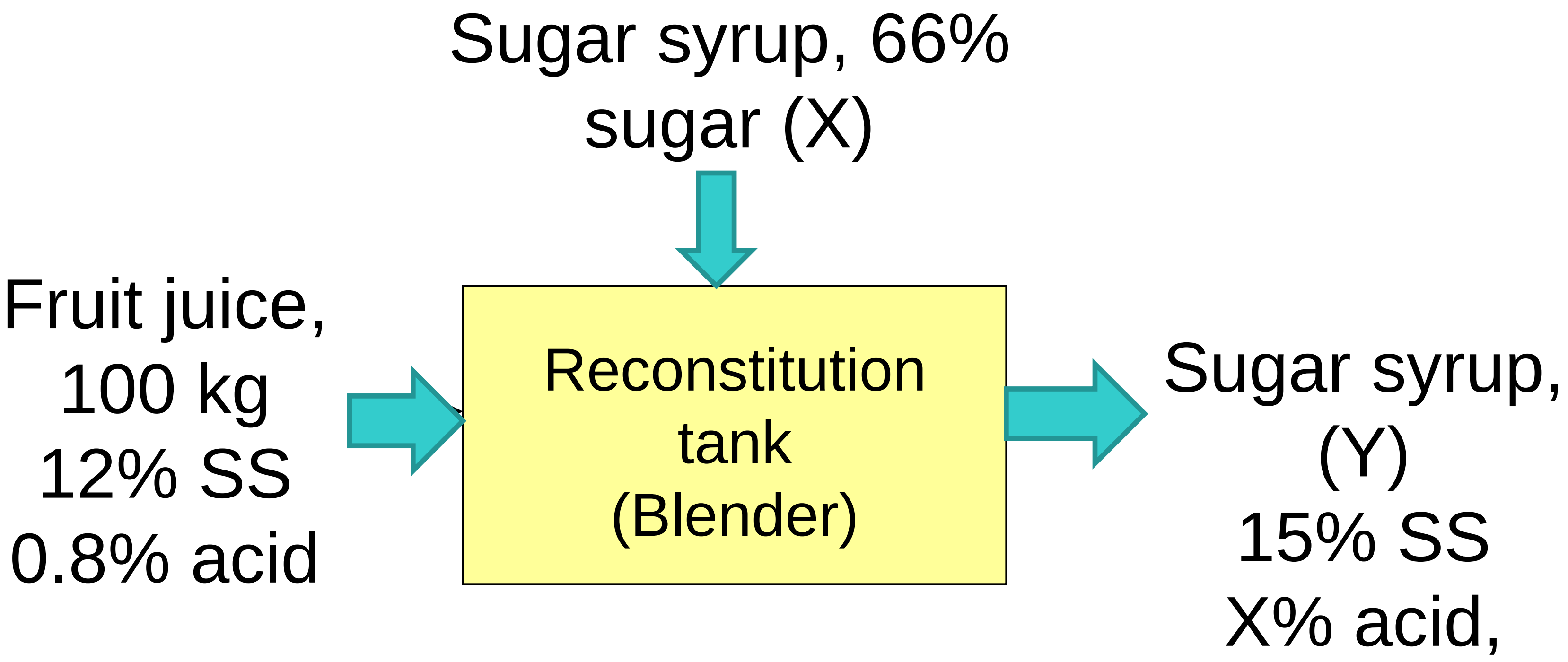
$$\text{Mass fraction} = \frac{\text{mass of component } A}{\text{total mass of mix. containing } A}$$

- If 80 kg of fruit juice contains 12% sugar, sugar (component) balance is set up as:

- **Example 5:** 7 kg of food material with 8.1% soluble solid content is dried in an air dryer and the soluble solid content is raised to 90%. Find out the weight of dried material.

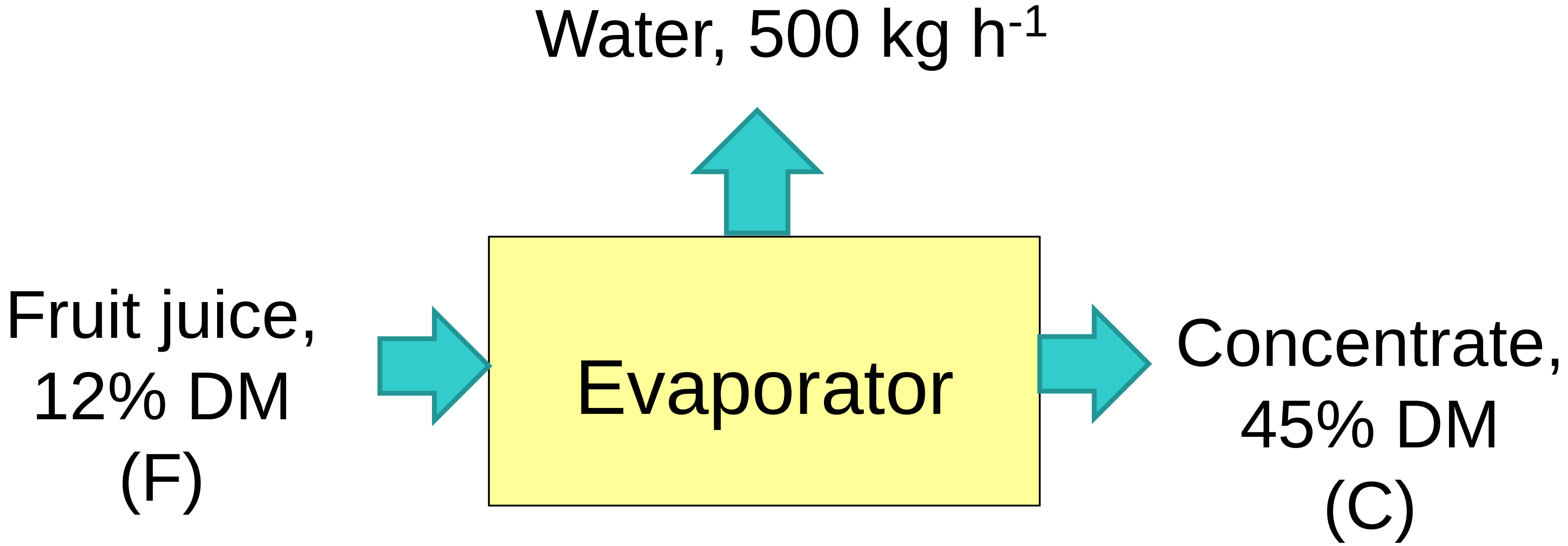
- **Example 6:** The brix of fruit juice containing 12% soluble solid and 0.8% acid was reconstituted to 15% by adding sugar syrup with 66% sugar content. Find out the weight of syrup and the mass percentage of acid content of reconstituted juice

The reconstitution of fruit juice with sugar syrup



- **Example 7**: 500 kg of water is removed in an evaporator at each hour. Fruit juice with 12% soluble solid content enters the evaporator and leaves the system as concentrate with 45% solid. Find out the concentrate production rate.

Flow diagram for concentration of fruit juice



- **Example 8:** 25 kg of sugar syrup with 66% sugar content is diluted with water. The diluted syrup contains 11% sugar. Find out the weight of diluted syrup using mass fraction.

- **Example 9 :** Find out the mass of sucrose crystals after cooling of 100 kg sugar solution with 75% sucrose content to 15°C. Sucrose solution at 15°C contains 66% sucrose. Calculate the mass of syrup after cooling.

- **Example10 :** In a crystal sugar producing plant, the sugar crystals is obtained from 100 kg of a concentrated sugar solution containing 85% sucrose and 1% inert, i.e., water-soluble impurities. Upon cooling, the sugar crystallizes from solution. A centrifuge then separates the crystals from a liquid fraction called the mother liquor. The mother liquor leaving the centrifuge contains 60% sucrose by weight. The crystal slurry fraction has, for 20% of its weight, a liquid with the same composition as the mother liquor. Find out the mass of the crystals and concentrated sugar solution.

Answers

C = 78.125 kg wet crystals

M = 21.875 kg mother liquid

- **Example 11**: Calculate the mass of beef and back fat (iç yağı) for the preparation of 100 kg of sausage. The beef contains 15% protein, 20% fat, and 63% water, and back fat contains 3% protein, 80% fat and 15% water. The sausage contains 25% fat.

Answers

B = 8.33 kg back fat

P = 91.67 kg beef