Evaporation

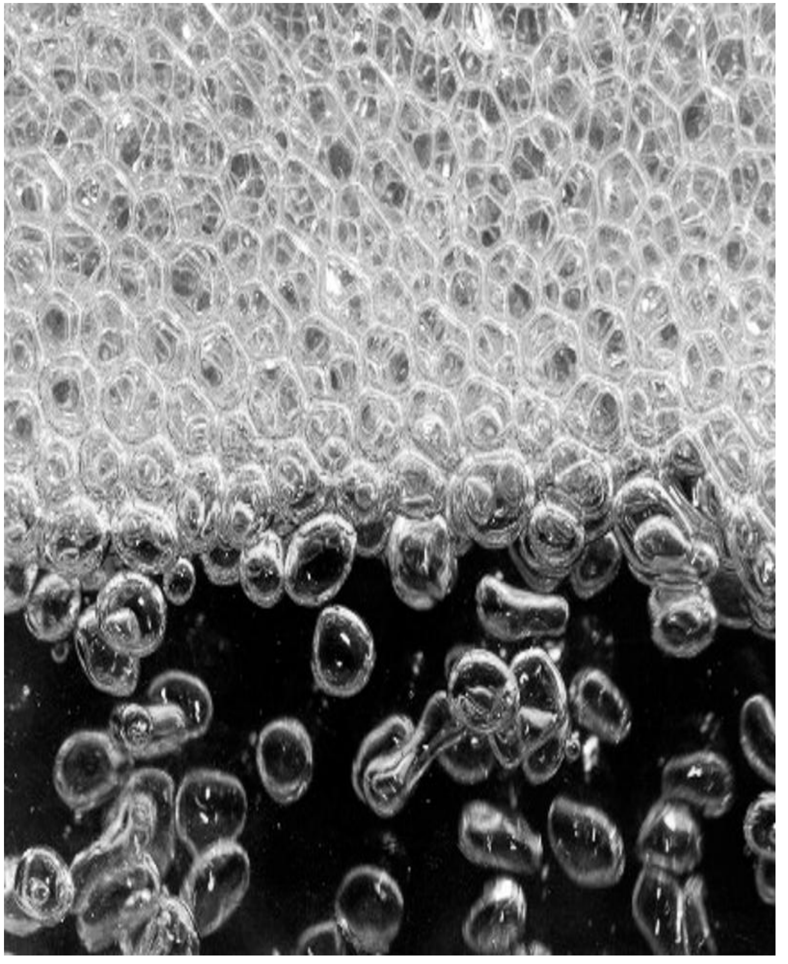
(Lecture 4)

Advanced Food Process Engineering

(PFE-503)

Evaporation

Evaporation may be defined as the vaporization of a volatile solvent *by ebullition to increase the concentration of essentially non-volatile components of a solution or suspension.*



Evaporation, dehydration and distillation

- Vaporization by **boiling** is emphasized in order to differentiate between *evaporation and dehydration.*
- *The non-volatile nature of the components* other than the **solvent** makes the difference between *evaporation and distillation .*
- *In* the case of foods, the ‘ volatile solvent ’ is, almost always, *water*

Main objectives of evaporation

- Mass and volume reduction, resulting in reduced cost of **packaging, transportation and storage**
- Preservation, by virtue of the **reduced water activity**. It should be noted, however, that the rate of chemical deterioration *increases with concentration. Thus,* concentrated juices, although more resistant than their single-strength form to microbial spoilage, tend to undergo browning more readily
- Preparation to **subsequent treatment** such as crystallization (sugar, citric acid), precipitation (pectin, other gums), coagulation (cheese, yogurt), forming (candy), dehydration (milk, whey, coffee solubles)
- Building a **desired consistency** (jams and jellies, tomato concentrates, ketchup).

Evaporation

- Evaporation is one of the most ‘ **large-scale** ’ operations in the food industry.
- Plants with evaporation capacities of up to a **hundred tons of water per hour** are not uncommon.
- Made of special types of stainless steel, constructed according to **high sanitary standards** and equipped with sophisticated automatic control systems, evaporators for the food industry are relatively expensive.
- The most important ***running cost*** *item in* evaporation is energy.
- However, energy consumption per unit production can be reduced considerably through the use of **multiple effect evaporation** or **vapor recompression** or both.

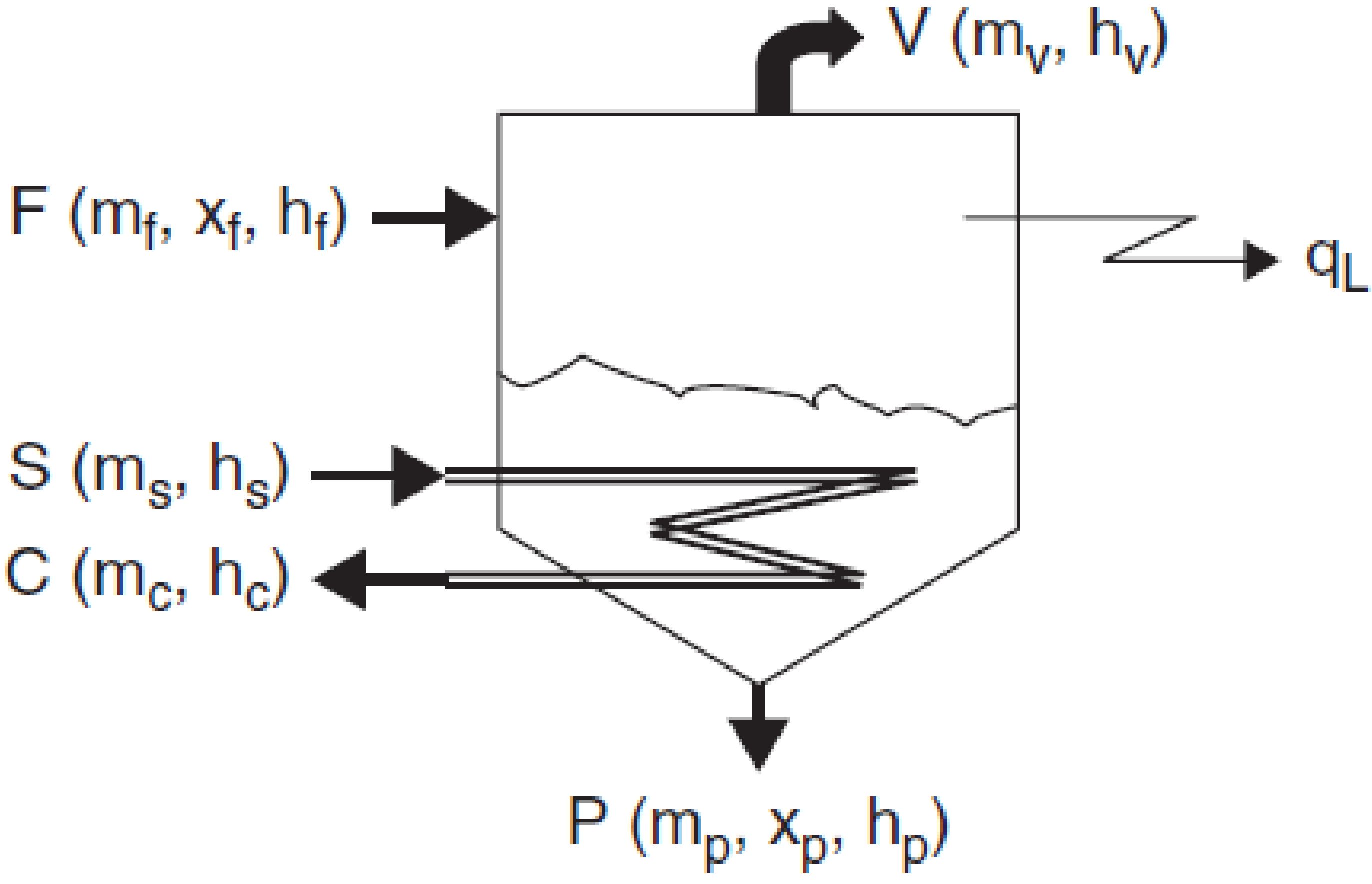
Evaporation

- Evaporation under **reduced pressure** and correspondingly lower boiling temperature is widely practiced.
- However, **lower temperature** means higher viscosity of the boiling liquid, slower heat transfer and therefore longer retention of the product in the evaporator.
- Thus, the selection of evaporation type and of operating conditions is also subject to **optimization *with respect to product quality***.

Evaporation

- One of the problems in the evaporative concentration of fruit juices is the **loss of volatile aroma components.**
- Evaporators may be equipped with **essence recovery systems** for entrapping and concentrating the aroma, which is then added back to the concentrate.
- Evaporation is not the only way to concentrate liquid foods. Alternative concentration processes are **reverse osmosis, osmotic water transfer** and **freeze concentration**.

Material and Energy Balance



Material and Energy Balance

Overall material balance gives:

$$F = V + C$$

where:

F = mass flow rate of feed, $kg.s^{-1}$

V = mass flow rate of vapor, $kg.s^{-1}$

C = mass flow rate of concentrate (product), $kg.s^{-1}$.

Material balance for the solids is written as follows:

$$F.x_F = C.x_C$$

where:

x_F and x_C = mass fraction of solids in feed and concentrate, respectively.

Material and Energy Balance

Combining Eqs. (21.1) and (21.2) and defining ‘Concentration ratio’ as $R = x_C/x_F$:

$$V = F\left(1 - \frac{1}{R}\right) \quad \textbf{(21.3)}$$

Note: Eq. (21.2) assumes that the vapor does not contain solids. In practice, the vapor does contain small quantities of solids, carried over by droplets of the boiling liquid.

Heat balance gives:

$$F.h_F + S(h_s - h_{SC}) = C.h_C + V.h_V + q_l \quad \textbf{(21.4)}$$

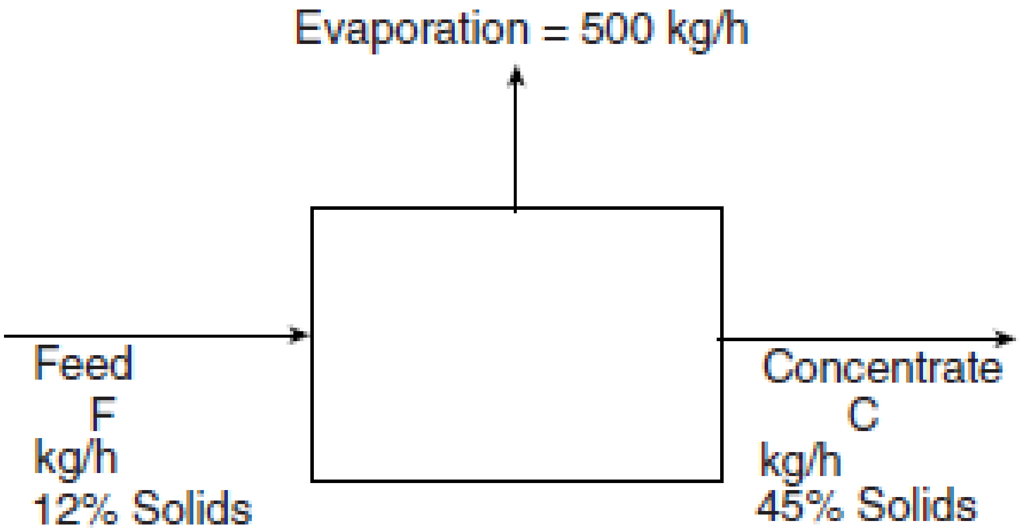
where:

h_F, h_S, h_{SC}, h_C, h_V = specific enthalpies ($J.kg^{-1}$) of feed, steam, steam condensate, concentrate and vapor, respectively

q_l = rate of heat loss, w.

Material Balance

Example 3.9. An evaporator has a rated evaporation capacity of 500 kg water/h. Calculate the rate of production of juice concentrate containing 45% total solids from raw juice containing 12% solids.



Material Balance

Solution:

The diagram of the process is shown in Fig. 3.10. Use as a basis 1 hour of operation. Five hundred kg of water leaves the system. A component balance on solids and a total mass balance will be needed to solve the problem. Let F = the feed, 12% solids juice, and C = concentrate containing 45% solids. The material balance equations are:

Total mass:

$$F = C + 500$$

Solids:

$$0.12\,F = 0.45\,C;\ F = \frac{0.45\,C}{0.12} = 3.75\,C$$

$$C = \frac{500}{3.75 - 1} = 181.8\ \text{kg}$$

Substituting and solving for C: $3.75\,C = C + 500.$

Because the basis is 1 hour of operation, the answer will be: Rate of production of concentrate = 181.8 kg/h

EXAMPLE 21.1

A single-effect continuous evaporator is used to concentrate a fruit juice from 15 Bx to 40 Bx. The juice is fed at 25°C, at the rate of 5400 kg/h (1.5 kg/s). The evaporator is operated at reduced pressure, corresponding to a boiling temperature of 65°C. Heating is by saturated steam at 128°C, totally condensing inside a heating coil. The condensate exits at 128°C. Heat losses are estimated to amount to 2% of the energy supplied by the steam. Calculate:

a. the concentration ratio R
b. the required evaporation capacity V (kg/s)
c. the required steam consumption S (kg/s)

Solution:

a. $R = \dfrac{0.40}{0.15} = 2.667$

b. $V = 5400 \times \left(1 - \dfrac{1}{2.667}\right) = 3375\,\text{kg/h} = 0.938\,\text{kg/s}$

c. Boiling point elevation for 40 Bx will be assumed to be negligible (see Example 21.2). The vapor will be assumed to be saturated vapor at 65°C. Its enthalpy is read from steam tables as 2613 kJ/kg. The enthalpies of the steam and its saturated condensate are 2720.5 and 546.3 kJ/kg respectively. The enthalpies of the feed and the product are calculated using the approximate formula for sugar solutions:

$$h = 4.187(1 - 0.7x)T \qquad \textbf{(21.5)}$$

$h_F = 4.187 \times 25 \times (1 - 0.7 \times 0.15) = 93.7\,\text{kJ/kg}$
$h_C = 4.187 \times 65 \times (1 - 0.7 \times 0.40) = 195.9\,\text{kJ/kg}$

Substituting the data in Eq. (21.4), we find:
$S = 1.1135\,\text{kg/s}$
$V/S = 0.83$ kg water evaporated per kg of live steam consumed