EVAPORATION

- ✓ Evaporation is the process, which involves thermally removing a liquid from a solution, suspension or emulsion.
- ✓ The starting and the end products are in the liquid phase and the end product obtained is in its concentrated form.
- ✓ Evaporation is used extensively in concentrating fruit and vegetable juices, milk, coffee extracts and in refining sugar and salt..
- ✓ Removal of water and the consequent lowering of water activity constitute an important principle of food preservation.
- ✓ When the removal of water is carried in food materials with water content between 6 and 15-20%, the methods involved are called drying or dehydration process.
- ✓ In other cases only part of the water is removed, which results in concentrated solution or dispersion or in semi-solid products with water content in excess of 20%.
- ✓ The methods involved are called concentration processes.
- ✓ Evaporation is usually limited to the removal of a large amount of liquid solutions whereas drying applies to the partial or complete removal, by thermal means, of a liquid from a mixture of liquid and solid, or the removal of a relatively small amount of liquid from a relatively large amount of solid material.

The purpose of evaporation may be:

(a) Reduction of the water content reduces weight and volume of the product
(b) for subsequent dehydration
(c) reduce storage and transportation costs
(d) improving the storage stability of the product
(e) to prepare other food products.

Several processes are involved in evaporation, but the engineered concerned with the operation can usually consider the entire process in terms of heat transfer to the boiling liquid.

- ✓ An evaporator consists of a heat exchanger capable of boiling the solution and device to separate the vapour phase from the boiling liquid.
- ✓ One of the simplest evaporators is a steam jacketed kettle open to the atmosphere.
- ✓ In industrial operation, the equipment is usually arranged for continuous operation; the heat exchange surface is vastly increased; boiling is much more violent, and vapour evolution is rapid.

✓ Such problems as foaming, scaling, heat sensitivity, corrosion, and space limitations are met.

The basic factors that affect the rate of evaporation are the:

- rate at which heat can be transferred to the liquid,
- quantity of heat required to evaporate each kg of water,
- maximum allowable temperature of the liquid,
- pressure at which the evaporation takes place,
- changes that may occur in the foodstuff during the course of the evaporation process.

Considered as a piece of process plant, the evaporator has two principal functions, to exchange heat and to separate the vapour that is formed from the liquid.

Important practical considerations in evaporators are the:

- maximum allowable temperature, which may be substantially below 100°C.
- promotion of circulation of the liquid across the heat transfer surfaces, to attain reasonably high heat transfer coefficients and to prevent any local overheating,
- viscosity of the fluid which will often increase substantially as the concentration of the dissolved materials increases,
- tendency to foam which makes separation of liquid and vapour difficult.

Evaporation refers to the process of heating liquid to the boiling point to remove water as vapour. For heat sensitive food product, heat damage can be minimized by evaporation under vacuum to reduce the boiling point. The basic components of this process consist of:

- heat-exchanger
- vacuum
- vapour separator
- condenser

Food Properties in relation to evaporator performance

- Boiling temperature
- Viscosity and constituency
- Fouling
- Corrosion
- Heat Sensitivity

Boiling temperature

The most important factors affecting the boiling point during the concentration of liquid containing dissolved constituents are:

(a) the pressure or vacuum respectively in the evaporating space,
(b) the hydrostatic pressure of a column of liquid, and
(c) the concentration of the solution (osmotic pressure).

- ✓ In an evaporator, the boiling or evaporating temperature can be regulated primarily by the pressure.
- ✓ Vapour and liquids are in equilibrium with each other and their temperature at any time is a function of the saturated vapour pressure.
- ✓ The surface of the liquid has the same temperature as the vapor that is being generated.
- ✓ A lowering of the pressure lowers the boiling temperature while raising the pressure brings about a corresponding rise in boiling point.
- ✓ Boiling points of less than 100 ^{o}C can be produced by evacuation, i.e., lowering the pressure that must be used in calculating the boiling point at any depth must include the hydrostatic head of liquid above that point.
- ✓ It is common to base design calculations on a boiling temperature determined from the pressure at half the depth of liquid in the evaporators, where liquid depths of 7m are common.
- ✓ In such a case, the liquid enters the heated tube subcooled by flow through the down-corner and addition of the feed.

Viscosity and consistency

- ✓ Food products subjected to evaporative concentration become quite viscous when concentrated.
- ✓ The viscosity of liquid is a function of its temperature.
- ✓ The viscosity of milk decreases slightly during pasteurization.
- ✓ With the **more heat treatment**, there is an increase in viscosity during evaporation, with **a sevenfold increase** in viscosity during sterilization of evaporated milk.
- ✓ Viscosity **affects** not only the rate of heat transfer but also pumping requirements and other material handling considerations.
- ✓ When the milk is fed to an evaporator, the concentration increases, the solution becomes more and more individualistic.

- ✓ The density and viscosity increase with solid content until either the solution becomes saturated or too sluggish (slow to react) for heat transfer.
- ✓ At some **water content (20 to 40%)**, the behaviour of milk becomes more **characteristic of a solid than of a liquid**.

Fouling

- ✓ Proteins and polysaccharides in particular are capable of forming deposits which are difficult to remove and which adversely affect efficiency of heat transfer.
- ✓ When the scale is hard, the cleaning is difficult and expensive.
- ✓ Practical solutions to the problem involve design of evaporators which minimize development of stagnant layers along surfaces of heaters.

Corrosion

- ✓ Food products contain components which are corrosive to heat exchange surfaces.
- ✓ This damages the equipment and results in undesirable transfer of materials to the evaporated product.
- ✓ Special metals such as stainless steel are then used.
- ✓ Since this metal is expensive, high heat transfer rates become especially desirable to minimize the initial investment on the equipment.

Heat Sensitivity

- ✓ Heat sensitivity is a problem of particular concern since it affects the quality of food.
- ✓ The operational factors: time, and temperature affect the degree of damage caused by heat.
- ✓ In concentrating such materials, special techniques are used to reduce both the temperature of the liquid and the time of heating.
- ✓ The portion of the liquid immediately adjacent to heat exchanger surfaces may be at a temperature significantly higher than the mean temperature (boiling point) of the liquid.
- ✓ Heat damage at the surface of the heat sources is more likely when the liquid heat-transfer coefficient is low.
- ✓ This condition arises when viscosity of the liquid is high and/or there is inadequate motion of the liquid.
- ✓ The driving force for heat transfer is the temperature difference Δt, i.e., (t_1-t_2), which depends upon the temperature of steam (t_1) in the heat exchanger and on the boiling point of the liquid (t_2).

- ✓ It is often desirable to have a larger Δt, because, as the Δt increases, the heating surface (and therefore the cost of the equipment) decreases.
- ✓ By the addition of a condenser and vacuum pump, the pressure in the vapour space can be made less than 1 atm.
- ✓ If the pressure in the vapour space is brought down, the boiling point of the liquid (t_2) will be reduced and Δt will be increase, with a consequent decrease of the heating surface required (since Q = UAΔt) without affecting the quality of the product.

Evaporators have to work under vacuum:

- ✓ because it is most economical to feed them with steam at modest pressures,
- ✓ a vacuum is necessary in order to get an economical Δt.
- ✓ Further, if high pressure steam is used, they call for much more expensive construction of the evaporator than when operating at lower pressures.
- ✓ The low boiling temperature protects the milk against the damaging effect of the high heat and preserves the quality of the milk.
- ✓ Evaporation of milk under reduced pressure is more rapid than under atmospheric pressure when using low temperature saturated steam.

Adjustment of Fat Content

To obtain the desired fat content, the original milk has to be standardized i.e., it has to be adjusted to the correct fat content. The required fat content of the original milk F_o can be calculated from equation:

$$F_o = \frac{F_c}{\left[1+\left(\frac{X_o}{1-X_o}\right)\right]\left[1-X\right]}$$

Where F_c = fat content of the evaporated milk

X_o = water content of the original milk

X = water content of the evaporated milk

Example:

F_c = 7.5%; X_o = 87%; X = 75%

$$F_o = \frac{0.075}{\left[1+\left(\frac{0.87}{1-0.87}\right)\right]\left[1-0.75\right]}$$

$$= 0.039 = 3.9\%$$