# STEAM, EVAPORATION AND DEHYDRATION.

## I. Steam

### INTRODUCTION

Steam is defined as vapour form of water. Steam is generated using a boiler. Water is heated in an enclosed vessel and converted into vapour. Steam is one of the most essential utility in food processing and has wide applications as a source of heat. Steam can be classified into three forms namely, wet steam, dry steam and super heated steam.

**Objective**: Is to generate steam as a source of heat, for use in food processing industry.

### Types of steam

- **Wet steam**: is the one which has moisture in it. The heat contained is majorly sensible heat and the steam is at saturation temperature.
- **Dry steam**: is the one which has no moisture. The heat contained in the steam is majorly latent heat.
- **Super heated steam**: is the one which is heated above the dry steam temperature. The heat contained in the super-heated steam is indicated as degree of super heat.

**Dryness fraction of steam:** The steam dryness fraction is used to quantify the amount of water present in steam. If steam contains 10-30% water by mass, it's said to be 70-90% dry, or having a dryness fraction in the range of 0.7 to 0.9. The dryness fraction is one for dry steam.

**Boiler:**

Boiler is a closed vessel in which water is heated, and converting it into vapour form. Different heat sources are used based on availability, say fire wood, coal, saw dust, rice husk, LPG, diesel are a few to mention. Based on the calorific value of the fuel, the heat is generated by burning the fuel and the heat transferred to the water. During the process, the water boils and converts into vapour under pressure.

**Types of boilers:**

Boilers can be broadly classified as

1. Water tube boiler.
2. Fire tube boiler.

**Water tube boiler:** in the water tube boiler (as shown in figure), water is allowed to pass through a set of hollow pipes and the pipes are heated from outside. The water level in the tubes is maintained at constant level.

Soft water is allowed to pass through feed water tank. The tubes are surrounded by fire inside the furnace. As the water is heated, the density of hot water will reduce and starts rising in the tubes and finally into the vapour form. High pressure steam is allowed into the main header pipe. A chimney is provided to allow the smoke to pass through into the atmosphere.

Boiler has a few safety accessories such as steam safety valve, for its safe and continuous operation. Some of the accessories are water softener, soft water tank, feed water pump, feed water indicator steam pressure gauge, fuel level indicator, fuel pump, chimney, and economizer. This type generally gives high steam production rates, but less storage capacity. Water tube boilers are preferred in high-pressure applications since the small diameter pipes can withstand the pressure with a thinner wall.

**Fire tube boiler**: is one wherein (as shown) the hot gases are burnt in the furnace and passed through the set of hollow tubes. Soft water covers the fire tube completely for better thermal efficiency. Fire-tube boilers usually have a comparatively low rate of steam

production, but high steam storage capacity. Fire-tube boilers mostly burn solid fuels, but are readily adaptable to those of the liquid or gas variety.

## II. EVAPORATION

Process of heat transfer accompanied by phase change (of a boiling liquid) is often a requirement in food process technology. These processes are more complex than simple heat exchange between fluids.

A phase change involves an addition or subtraction of considerable amount of heat, at constant or nearly constant temperature. The rate of phase change may determined by the rate of heat transfer but it is often influenced by the rate of new phase formation and by the behaviour of new phase after it is formed.

A special case of heat transfer to a boiling liquid is another unit operation is called 'Evaporation'. Evaporation, as the name suggests, involves evaporation of a solvent, essentially water in food processing. By comparing this unit operations, with other unit operation increases our clarity.

Evaporation differs from 'drying' in the sense that what remains in evaporation it is a liquid concentrate while in drying the residue is often a dry solid. It differs from 'distillation' in that the vapour usually is a single component (say water). Even if the vapour is a mixture and no attempt is made in 'Evaporation' to separate the vapour into fractions. It differs from 'crystallization' in that emphasis is placed on concentrating a dilute solution into a thick liquid (concentrate) rather than forming and growing crystals.

Most popular application of evaporation is the, production of common salt from brine or sea water by evaporation (only a thin line exists between evaporation and crystallization). Normally in evaporation the thick concentrated liquor is the product. The evaporation will be discussed in terms of the following.

1. Definition
2. Objectives
3. Factors affecting Evaporation
4. Types of Evaporators

5. Performance of Evaporation
6. Application in Food processing

## 1. Definition

Evaporation is a unit operation to remove the solvent (water) in order to produce a liquid concentrate from a dilute solution.

## 2. Objectives

The objectives are to reduce the volume to facilitate transport and storage.

## 3. Factors affecting the performance

The character of the liquid that is to be concentrated itself is most important. The wide variation in liquid characteristics demands judgement and experience in designing and operating evaporators that distinguishes this unit operation from a simple heat transfer to a separate art in itself. The important properties of liquids that play a role include concentration (initial and final), foaming, temperature sensitivity; scaling. Invariably, stainless steel is used for the contact parts and mild steel for other parts of the Evaporator.

## 4. Types of Evaporators

The main types of evaporators can be classified –

Tubular evaporators and Agitated film evaporators

i. Long tube vertical evaporators
   a) Climbing film (upward flow)
   b) Falling film (downward flow)
   c) Forced circulation

Coming to mode of operation, evaporators may be operated either once-pass through or circulation mode. The extent of evaporation is limited in single-pass mode and thus these are adapted for a multiple-effect operation, where the total extent of concentration can be spread over several effects. Agitated film evaporators are always operated as once pass.

Once pass evaporators are especially useful for heat sensitive liquids. By operating under high vacuum, the boiling temperature of the liquid can be kept low in this evaporators.

i. **Long tube vertical evaporators**

a) **Climbing film (upward flow):**

For a single pass operation, valve in the recirculation line will be closed, permitting once through operation to attain the shortest possible retention time. This is effective where high evaporation percentage is not required.

Climbing film evaporators are usually circulation units.

b) **Falling film (downward flow):**

Concentrating heat sensitive materials like orange juice requires a minimum exposure to heated evaporation surface. This can be achieved in once-through operations. In this, liquid enters the large (relatively) tubes at the top and flows down before leaving the equipment.

The tangential entry to the vapor-liquid separators ensures effective separation of vapor from liquid. Weir provided at the periphery of the calendula (tubes) ensures proper distribution of liquid into the tubes.

The main problem with these falling film evaporators is that of distributing the liquid uniformly as a thin film inside the tubes. To prevent the extent of heat damage residence time are kept low. Plate heat exchangers are most commonly used for the evaporation of milk.

**c) Forced circulation:**

Significant improvement can be seen over natural circulation evaporators especially in case of viscous liquids. The calendula/tubes can be horizontal or vertical. The heat transfer coefficients are high and residence times are low due to high circulation velocities.

In forced circulation evaporators, feed mixes with the liquid held in the tubes of the evaporator and mixture passes through the equipment and un- evaporated liquid returns to the equipment as recirculation. Only part of the total evaporation occurs in one pass.

Forced circulation evaporators are not well suited for the heat sensitive fruit juices (flavour loss) as they get exposed to heat repeatedly although low temperature is maintained through vacuum.

Forced circulation evaporators can work either with natural convection; (where, circulation flow through the tubes is induced by density difference) or with forced circulation (where circulation flow is caused by a pump (figure).

**ii. Agitated- film evaporator.**

The principle resistance to overall heat transfer from the steam to the boiling fruit juice to an evaporator is on the liquid side. One way of reducing this resistance, especially with viscous liquids, is by mechanical agitation of the liquid film as shown in figure.

With some modifications these are also called as scraped surface evaporators. They are best suited for heat sensitive viscous juices say mango pulp, gelatine, antibiotics.

Feed enters at the top of the jacketed section and is spread out into a thin film by the vertical blades of the agitator. Concentrate leaves from the bottom of the jacketed section and vapour rises into the unjacketed vapour separator.

The major disadvantages are high cost, high maintenance of the internal moving parts and small capacity of single unit which is far below that of multi-tubular evaporators

**5. Performance of tubular Evaporators**

The principal measures of the performance of a steam-heated tubular evaporator are the capacity and the economy. Capacity is defined as the number of kilograms of water vaporized per hour. Economy is the number of kilogram of water vaporised per kilograms of steam fed to the unit. In a single effect evaporator the economy is always less than '1' but, in multiple effect evaporators it can be considerable greater. The steam consumption, in kg/hr, is also important. It equals the capacity divided by the economy.

### 6. Applications in Food processing

Many fruit juices such as, pineapple, apple, orange, passion fruit are concentrated using evaporation. The juice concentrate can be easily transported and reconstituted as and when required to the desired consistency at the user end. Tender or mature coconut water is also evaporated; Honey is subjected to evaporation to reduce the moisture content in order to increase the shelf life.

## III.DEHYDRATION-DRYING

Drying generally refers to solids and refers to the removal of relatively small amounts of water or other liquids to keep the contents of the residual moisture to an acceptable low value. Drying is usually the final step in a series of operations in a given food process.

Water (or other liquids) can be removed by mechanically pressing or centrifuging or thermally evaporating. The topic of this session refers to drying by thermal evaporation.

It is cheaper to remove liquid mechanically or osmotically (by immersing concentrated osmotic solution) prior to drying.

The following aspects of drying needs to be discussed.

1. objective
2. Theoretical Aspects
3. Drying rate
4. Drying equipment

## 1. Definition

Drying refers to removal of moisture to the desired level by employing heat by modes of conduction or convection or radiation.

## 2. Theoretical Aspects

Drying is a simultaneous heat and mass transfer process. Mass flux (J) is given by

$$J = k\ (C_i - C_b),$$

where ‘k’ is the mass transfer coefficient , (k=D/dx), ‘D’ is diffusion coefficient, ‘dx’ is diffusion thickness, $C_i$ and $C_b$ are moisture concentrations, interface and bulk, respectively.

$$q = h\ (Tb - Ti)$$

where ‘h’ is the heat transfer coefficient (h=K/dx), ‘K’ is thermal conductivity, ‘dx’ heat transfer distance, $T_b$ and $T_i$ are bulk and interface temperatures.

Reynolds Analogy is given by

$$k = h/\rho\ C_p$$

where, ρ is density and $C_p$ is heat capacity

## 3. Drying rate

Any given food material will have two types of moisture (M) - unbound and bound moisture. Unbound or free moisture can easily diffuse across the food material when gradient is induced by surface evaporation. The rate of drying remains constant until the free moisture is available in the product. since the rate of its diffusion to the surface matches the rate of evaporation at surface due to heat transfer medium (air). This is called constant rate period of drying.

Once the free moisture is exhausted or completely removed by drying, the diffusion rate to the surface significantly reduces since bound moisture comes out very slowly. As a result the drying rate falls gradually. This is called falling rate period of drying.

The moisture content at which the change occurs (from constant to falling rate period) is called critical moisture content ($M_c$).

## IV. DRYING EQUIPMENT

Drying equipments are classified mainly as conduction dryers and adiabatic dryers.

### Freeze Drying

It involves freezing of the sample and removal of water by sublimation under high vacuum by heat transfer,it results in high quality in terms of colour, volatile and nutrients. High rehydration ability due to the porous structure heat transfer occurs by conduction. Most suitable for high value low volume products especially those meant for export. Examples are coffee, strawberries, peach, prawns, blue berries, raspberries, crane berries. Typical freeze drier is shown in the figure.

The disadvantages are high capital and operation costs. Very slow drying process that too a batch process.

There is a slight difference between a freeze dryer and lyophilize. In the former after the freezing heat is given and sublimation occurs under vacuum. In the latter, no heat is provided to aid the removal of moisture. Very small quantities of samples can be handled in lyophilizer while large quantities can be handled in freeze dryer depending on the number of trays and the dimension of them.

### Spray Drying

Spray drying is the most popular and competitive method of drying. Examples in food area include skim milk powder, instant coffee, egg powder, soup mixes, juice powder, custard powder etc. The basic process involves atomization of liquid feed in the drier, contacting with hot air, moisture evaporation and separation of dried solid product from hot air.

The advantages are low contact time, drying at wet bulb temperature, continuous process, and high throughputs. Heat transfer occurs by convection.

In spray drier atomization can be carried out either by nozzle or rotatory atomizer. The particle size will be of normal distribution in case of a nozzle while particles will be of uniform size in that of a rotatory atomiser. Nozzle can handle high solid content (~30%), while rotary atomizer tends to get clogged at high solid content. The liquid spray and the hot air can be contacted in either co-current or counter current mode. Although the drying occurs at wet bulb temperature, the dried product sees higher temperature while it is pneumatically carried by hot air till the exit of the drier (before it is separated in a cyclone from hot air and collected). Hence, hot air temperature also has to be paid attention to minimize the heat damage to the product.

Drying can take place by radiation in equipment such as infrared, microwave and radiofrequency driers. Industrial driers can be batch or continuous type. Commonly used driers are tray or cabinet dryer, drum drier, fluidized bed drier, tunnel drier, vibro-fluidized bed dryer as shown in the figures.

**Tray/ cabinet dryer**

Tray cabinet dryer is the least expensive and hence the most common dryer. Additional effect is put by way of blowing hot air in to the space between the trays to displace the moisture evaporated from the product during drying so that effective concentration gradient (drying force) can be maintained.

**Drum dryer**

A layer of liquid is spread as to the rotary drums which are heated by steam from inside. The dried layer is scraped off from the drums at the end of the rotation and size reduced to a powder. The bulk density of the product will be high (example Complan) compared to spray dried product (Horlicks).

**Vibro-fluid bed dryer**

In this fluidization is achieved by vibration hence very little amount of hot air is sufficient for drying. In a single unit heating, resting and cooling operation are carried out in 3 decks arranged one above the other. (High temperature if hot air achieved by burning LPG) Energy efficiency is high due to recirculation of hot air.

**IR dryer and Combined IR and Hot air Dryer**

In convective hot air drying heat transfer occurs from outside to the inside of the material and mass transfer (in evaporated moisture) occurs from inside to outside. In case of IR drying heat releases at a predetermined location inside the material on incidence of IR rays and heat and mass transfer will be in the same direction. So less resistance is offered for mass transfer. In convective hot air drying, case hardening of the material surface occurs offering higher resistance to manufacturer to the outside, causing product damage.

**Microwave Dryer**

Microwave heating provides volumetric heating uniformly. Heat is generated inside the food due to higher speed of rotation of water molecules. The disadvantage is the difficulty in controlling the drying process.

**Radio Frequency Dryer**

Best part of RF dryer is that the electromagnetic field self-adjusts with respect to the moisture present. As the drying progresses,the field reduces with a decrease in moisture content, thus a product can never be over heated and product damage is practically absent.

However, due to high cost RF drying can be used for the finishing drying after hot air drying. Because the product damage occurs only towards the end of the drying where residual moisture is removed.

## V. SUMMARY

Evaporation and dehydration/drying are most popular unit operations in food processing essentially for extending the shelf life and facilitating the transport as well as storage. Evaporation evolved gradually starting from “open pan” type to “falling trailing” film type to state-of-the art agitated film or scraper surface evaporators.

Similarly, sun and solar drying has given way to controlled hot air drying and eventually to field assisted drying where hot air drying is coupled with IR or MW drying. Spray drying is the most economical way of drying and freeze drying forms the control for all types of drying