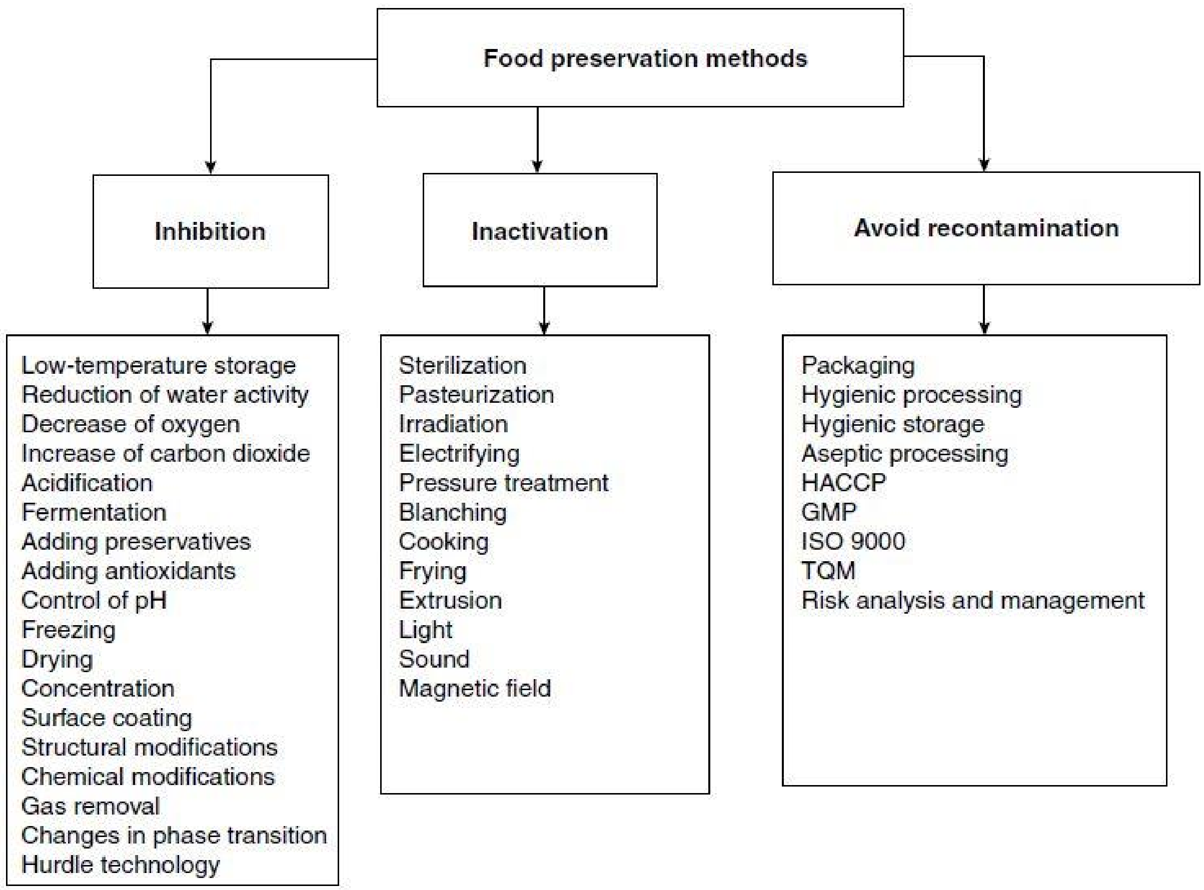
**Module 15: Food Concentration as Preservation: Different Methods of Concentration**

## 15.1INTRODUCTION

Food preservation is the process in which, food is not only processed but also its desirable attributes (sensorial andnutritional) are sustained up to the maximum possible time duration. Principle of food preservation constitutes removal of water and subsequent reduction in water activity. There are three broad categories of food preservation methods (figure 1)i.e. inhibitionof microorganisms andchemicaldegradation;inactivation of microbes and enzymes with reducing the risk of recontamination before and after processing. The various methods of food preservation are given in figure 1.




Adapted from Gould (1989, 1995)

**Figure 1 Food Preservation Methods**

The method is called dehydration process when the resulting moisture content of the food material after completion of the concentration process is between 0 and 15ï 20%. On the other hand, in concentration process, part of the water is removed results in moisture content >20%.

Concentration process is usually employed as a pre-treatment to reduce the initial moisture content of different foods like, milk, tea or coffee prior to their final dehydration in a spray or freeze dryer. It can be used to reduce the bulk by freezing or by sterilization, such as frozen orange juice or evaporated milk. It could be used as a preservation method in its own right, like maple syrup whichis resistant to deterioration after concentration.Water activity, pH and temperature are the main parameters that have a direct impact on the growth of microorganisms, thus $a_w$ and pH are two the most important parameters for food preservation.Concentration of foods can broadly be of three types: by application of heat i.e. thermal concentration; by removal of heat i.e. freeze concentration and using membranes.The methods of concentration are discussed below.

## 15.2 DIFFERENT METHODS OF CONCENTRATION

### 15.2.1 Application ofHeat

#### 15.2.1.1 Thermal concentration

Thermal concentrationmeansincreasing the total solids content of the food by evaporation of water using heat. It is moreenergy consuming processthan other concentration methods such as membrane concentration and freeze concentration.However,the degree of concentration achievedis higher.

During thermal evaporation, food is boiled which is achieved by transfer of sensible heat from energy source i.e. steam to the food. Then water gets evaporated in form of bubble by applying latent heat of vaporization.For calculation of degree of concentration, energy consumption and processing times in an evaporator, heat and mass balances are calculated. Mass balance isdefined as the feed mass entering the evaporator equals the mass of product and vapour removed from the evaporator.

For water, $m_f (1-X_f) = m_p (1-X_p) + m_v$

For solutes,$m_f X_f = m_p X_p$

The total mass balance is $m_f = m_p + m_v$

Where,

$m_f$ = mass transfer rate of feed (kg/s)

$X_f$ = solids fraction of feed

$m_p$ = mass transfer rate of product (kg/s)

$X_p$ = solids fraction of feed product

$m_v$= mass transfer rate of vapour produced (kg/s)

With the assumption that heat losses from the evaporatorare negligible, the heat balance is defined as the amount of heat given up by the condensing steam equals the amount of heat used to raise the feed temperature to boiling point and then to boil off the vapour.

$$Q = m_s \lambda_s$$

$$= m_f c_p (\theta_b - \theta_f) = m_v \lambda_v$$

Where,

Q = rate of heat transfer (J/s)

*c*= specific heat capacity of feed liquor (J/kg°C),

$\lambda_s$ = latent heat of condensing steam (J/kg),

$\lambda_v$ = latent heat of vaporization of water (J/kg)

i.e. Heat supplied by steam = Sensible heat + Latent heat of vaporization

As concentration process increases the solids content of a food, it preserves the food by reducing its water activity. During concentration microbial destruction occurs which is mainly dependent on temperature. Concentration at 100°C or above gives preservative effect as almost all pathogenic microorganisms get killed but not all the spores. Thermal evaporation because of the reduction in water activity improves microbial quality of foods.On the other hand, when concentration is done under vacuum many bacterial spores not only survives and multiplies too. Applications of thermal concentration in the food industry include concentration of fruit juices; concentrate milk, lactose andwhey; sugar syrups; vegetables to produce vegetable juices and purees. The relation between water activity and growth of microorganisms in food is given in table 1.

**Table 15.1** Water activity and growth of microorganisms in food

| **Range of $a_w$** | **Microorganisms inhibited by lowest $a_w$ in this range** | **Foods within this range** |
|---|---|---|
| 1.00– 0.95 | *Pseudomonas, Escherichia, Proteus, Shigella, Klebsiella, Bacillus, Clostridium perfringens*, some yeasts | Highly perishable (fresh) foods and canned fruits, vegetables, meat, fish, milk, and beverages |
| 0.95– 0.91 | *Salmonella, Vibrio parahaemolyticus, C. botulinum, Serratia, Lactobacillus, Pediococcus*, some molds, yeasts (*Rhodotorula, Pichia*) | Some cheeses (Cheddar, Swiss, Muenster, Provolone), cured meat (ham), bread, tortillas |
| 0.91– 0.87 | Many yeasts (*Candida*, *Torulopsis*, *Hansenula*), *Micrococcus* | Fermented sausage (salami), sponge cakes, dry cheeses, margarine |
| 0.87– 0.80 | Most molds (mycotoxigenicp*enicillia*), *Staphyloccocusaureus*, most *Saccharomyces* | Most fruit juice concentrates, sweetened condensed milk, |

| | | |
|---|---|---|
| | (*bailii*) spp., *Debaryomyces* | syrups, jams, jellies, soft pet food |
| 0.80ï 0.75 | Most halophilic bacteria, mycotoxigenic*aspergilli* | Marmalade, marzipan, glacé fruits, beef jerky |
| 0.75ï 0.65 | Xerophilic molds (*Aspergilluschevalieri, A. candidus, Wallemiasebi*), *Saccharomyces bisporus* | Molasses, raw cane sugar, some dried fruits, nuts, snack bars, snack cakes |
| 0 .65ï 0.60 | Osmophilic yeasts (*Saccharomyces rouxii*), few molds (*Aspergillusechinulatus, Monascusbisporus*) | Dried fruits containing 15-20% moisture; some toffees and caramels; honey, candies |
| 0.60ï 0.50 | No microbial proliferation | Dry pasta, spices, rice, confections, wheat |
| 0 .50ï 0.40 | No microbial proliferation | Whole egg powder, chewing gum, flour, dry beans |
| 0.40ï 0.30 | No microbial proliferation | Cookies, crackers, bread crusts, breakfast cereals, dry pet food, peanut butter |
| 0.30ï 0.20 | No microbial proliferation | Whole milk powder, dried vegetables, freeze dried corn |

Adapted from Beuchat (1981)

### 15.2.2 Removal of heat

#### 15.2.2.1 Freezeconcentration

Freeze concentration process is used to overcome the two important limitations of thermal concentration which are: volatile components lost (flavours) and product quality degradation due to heat.It has primarily been used where quality considerations are important andimportant volatile components to be retained, as in concentration of beer and wines (where flavoursand alcohol are to be preserved) and concentration of coffee beforefreeze drying (where it is important to retain flavour).

This process crystallizes water to ice as a primary step then removal of those ice crystals formed during freezing, followed by washing columnsor mechanical separation techniques. In freeze concentration, preservative effect similar to thermal concentration is attained by reducing water activity of the food without using heat.As a result,sensory characteristics and nutritional properties improved which is not the case with thermally concentrated foods. This process is slower than conventional and membrane concentration processes. Thehigh capital investment combined with highin cost due to refrigeration, results in high production costs for freeze concentrated foods.Here, the degree of concentration is lower than thermal concentration but higher than membrane processes.A comparison between energy efficiency and degree of concentration in different concentration methods is given in table 2.

**Table 15.2**A comparison of energy efficiency and degree of concentration in different methods of concentration.

| Process | Steam equivalent (cost per kg of water removed / equivalent cost of steam) | Maximum concentration possible (%) |
|---|---|---|
| Ultrafiltration | 0.001 | 28 |
| Reverse osmosis | 0.028 | 30 |
| Freeze concentration | 0.090ï 0.386 | 40 |
| Concentration | | |
| Triple effect without aroma recovery | 0.370 | 80 |
| Triple effect with aroma recovery | 0.510 | 80 |

Adapted from Thijssen (1974)

In freeze concentration, large ice crystals are desirable on economic point of view, to reduce the quantity of entrained concentrated liquidalong with crystals which is accomplishedby a *paddle crystallizer* by allowing the growth of large crystals employing slow agitation. The degree of solute concentration is calculated which is obtained by reduction in freezing, for preparation of *freezing point curves*.The crystal separation efficiency from liquid concentrate is determined by the degree of clumping of the crystals and quantity of liquid entrained with crystals. Efficiency of separation of crystals is calculated using:

$$\eta_{sep} = x_{mix} \frac{x_1 - x_i}{x_1 - x_j}$$

Where, ɖsep (%) = efficiency of separation,

$x_{mix}$ = weight fraction of ice in the frozen mixture before separation,

$x_1$ = weight fraction of solids in liquid after freezing,

$x_i$ = weight fraction of solids in ice after separation, and

$x_j$ = weight fraction of juice before freezing

Efficiency of separation using wash columns were 99.5%, for filter pressing it was 89-95%, for vacuum filtration, 71% and for centrifugation, 50%.The schematic suspension freeze concentration plant is given in figure 2.

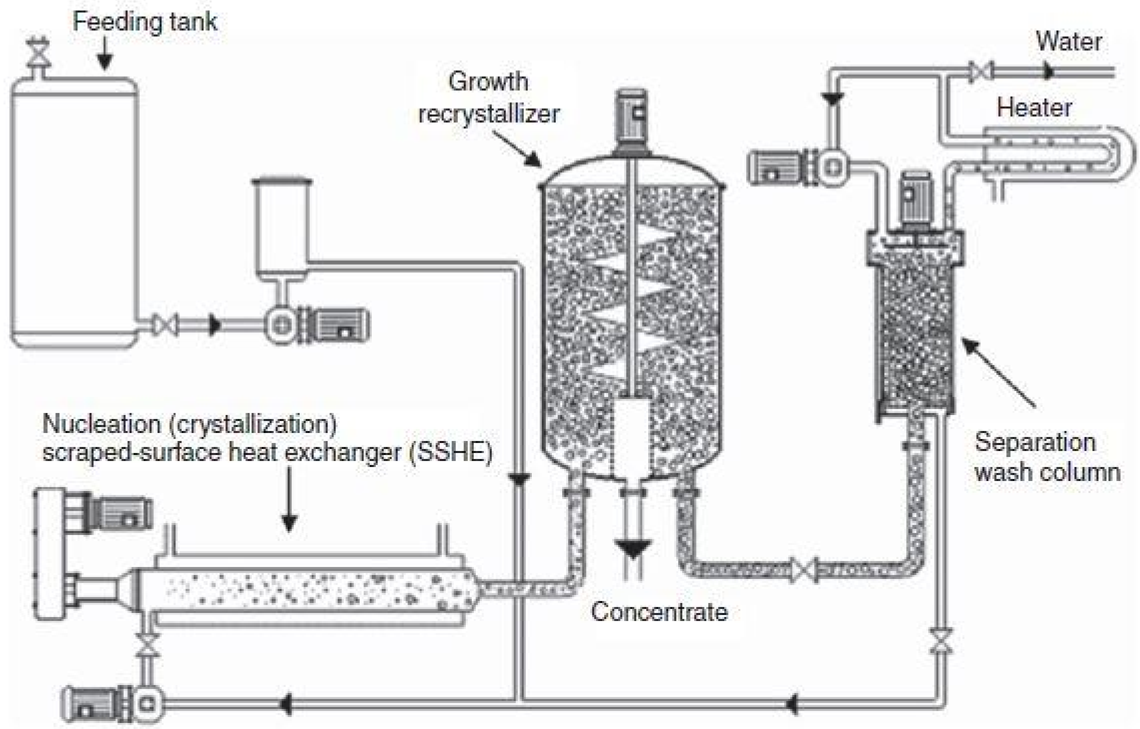



**Figure 15.2 Schematic suspension freeze concentration system (courtesy of Niro Process Technology)**

Now-a-days, suspension freeze concentration plants are extensively used in food industry for concentration of liquid food products which consists of crystallization then growth of ice crystals followed by its separation. It consists of a scraped-surface heat exchanger (SSHE) and a recrystallizer. In SSHE, ice nuclei are formed at the inner surface at high super-cooling and less residence time. These nuclei are then scrapped off by scrapping blades. Based on the Gibbs Thomson effect, nuclei grow in ice crystals in a recrystallizer then these crystals are separated from the concentrate using pressurized wash columns.Ice crystals with high purity are important feature of this system. Concentration in done either in single stage or multi stage processing. Usually, multi stage plants consume less energy and give high production rates. With improvements in technology for producing larger ice crystals along with efficient washing leads to maximum higher concentration to 45%.

The applications of freeze concentration in food industry are:increasing the concentration of alcohol in wine and beer with three main objectives i.e. for improving the stability of the liquor, reducing the transportation cost and to develop alcoholic beverages with higher alcohol content; producing good quality fruit juice concentrates, cidar concentration, vinegar production with maximum 40% acetic acid, and as discussed earlier concentration of coffee prior to both freeze and spray drying, here the maximum concentration achieved is 45%.

**15.2.2. Concentration using membranes**

Conventional evaporation, in its variant forms, is the most widely used, very common as well as cost-effective process to get higher concentration of liquid or semi liquid foods. The major limitation of this process includes, destruction of sensorial attributes and nutritional properties due to higher processing duration at higher temperatures. Although some of these changes can be reduced during well-known ñmulti effect vacuum evaporationò which reduces the operational temperature in each effect, yet it is neither suitable for heat sensitive products nor able to arrest the losses of typical volatile components. The limitations of classical evaporation is overcame in freeze concentration, another concentration process which removes water via sublimation process and results in better quality products. This process is considered efficient for highly valuable products only, not for the range of common products as, it is neither easy nor cheaper than other two concentration processes.

Reverse osmosis (RO) is one of the pressure driven, membrane based concentration process. Different technical details as well as various applications of RO have been already discussed in paper 2, module 34 and paper 16, module 29 by one of the author. This process is the most efficient and most economical concentration process for heat labile products or bioactive ingredients up to certain degree of concentration, which is established by the osmotic pressure of concentrated solution. Osmotic pressure of feed or concentrated solution is the main limiting factor for RO. The concentration processes can be operated from low temperature (5°C) to higher temperature of about 50°C. As only water can pass through the RO membrane, retention level of these membranes can reach up to 95-99% for the target solute and at the same time, the permeate water can also be used as it had excellent in quality characteristics. A number of studies reported the use of RO for concentration of a variety of fruit juices such as apple, grapefruit, kiwi, orange, passion fruit, pears and tomato. It is considered as a first-stage process with other methods like evaporation or freeze concentration completing the concentration system. It is difficult to obtain high concentrations of juice retentates like of apple juice by RO is limited to around 30-35°Brix which is the major limitation of RO. The most efficient recovery is found between 20-25°Brix. Pre-concentration of fruit juices in RO can reduce their initial moisture content up to 50 % but retains major amount of sugar (98ï 99%) and volatile flavour (80-90%) in the retentate (having 20-25°Brix).This retentate than can be concentrated >75°Brix in classical evaporation. This combination results in 60-75% saving of energy than traditional evaporation (Lipinzki, 2010). Moreover, total solids of whole milk, skimmed, sweet cream buttermilk and whey can be increased to about 25% using RO.

Lee and Lee (1998) studied the changes in quality of clarified pear juice of 10°Brix prepared by vacuum concentration, RO and freeze concentration, during storage at refrigerated conditions. The results showed no significant difference in turbidity and browning after 10 days of storage.No significant change observed in sensorial attributes of juices prepared by RO and freeze concentration but were superior tojuice prepared by evaporation. This study concludes that freeze concentration and RO even though the concentration achieved through these techniques is much lesser than thermal concentration, are the better preservation methods than latter.

Cheryan (1992) reported that the energy required to enhance total solids of whole milk from 15% to 31% in three stage reverse osmosis process was 10 kcal/kg of milk compared to triple effect evaporator with MVR system, which consumed 135 kcal/kg of milk i.e. to get the reported degree of concentration in whole milk using 3 stage RO was observed as highly energy efficient process than reported evaporation system.

**References:**

Beuchat, L. R. (1981). Microbial Stability as Affected by Water Activity.*Cereal foods world*,**26** (7): 345-349.

Cheryan, M. (1992).*Concentration of Liquid Foods by Reverse Osmosis*. In:Heldman, D. R. and Lund, D. B., eds. Handbook of Food Engineering. New York: Marcel Dekker, pp. 393-436.

El-Salam, A. M. H. (2003).*Applications of Reverse Osmosis* In: Encyclopedia of Analytical Sciences (2nd Ed.), pp. 3833-3837. Worsfold, P., Townshend, A. and Poole, C., (Eds.) Elsevier Science Ltd, Cairo, Egypt.

Fellows, P. J. (2000). Food Processing Technology: Principles and Practices. Woodhead Publishing Limited, England, pp. 157-167, 278-293, 441-452.

Gould, G. W. (1989). In*: Mechanisms of Action of Food Preservation Procedures.* Gould, G. W., Ed. Elsevier Applied Science, London.

Gould, G. W. (1995). In: New Methods of Food Preservation. Gould, G. W., Ed. Blackie Academic and Professional, Glasgow.

Karel, M. and Lund, D. B. (). Physical Principles of Food Preservation.Marcel Dekker, Inc., USA. pp. 330-377.

Kessler, H. G. (1986). Energy Aspects of Food Preconcentration. In: D. MacCarthy (Ed.) *Concentration and Drying of Foods*. Elsevier Applied Science, Barking, Essex, pp. 147-163.

Lee, Y.C. and Lee, S.W. (1998). Quality Changes during Storage in Korean Cloudy Pear Juice Concentrated by Different Methods.*Food Sciences and Biotechnology*, **7**: 127-130.

Lipinzki, F. (2010). *Cross-Flow Membrane Applications in the Food Industry.* In: Membrane Technology Volume 3: Membranes for Food Applications, Edited by Peinemann, K. V., Nunes, S. P. and Giorno, L. WILEY-VCH Verlag GmbH & Co. KGaA, (Weinheim), pp. 1-27.

Mellor, J. D. (1978). *Fundamentals of Freeze-drying.*Academic Press, London, pp. 257-288.

Muller, J. G. (1967). Freeze Concentration of Food Liquids: Theory, Practice and Economics. *Food Technology,* **21**: 49-52, 54-56, 58, 60, 61.

Rahman, M. S. (2007).Handbook of Food Preservation. CRC Press, Florida, USA. pp. 3-18, 447-476, 635-665.

Thijssen, H. A. C. (1974). Freeze Concentration. In: Spicer, A. (Ed.) *Advances in Preconcentrationand Dehydration*. Applied Science, London.