System Design and Experimental Results of Progressive Freeze Concentration System

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***Abstract*—Freezing is one of the most employed procedures in food manufacturing and preservation. Freeze concentration is the method to concentrate solution by making pure ice in the solution. —Freeze concentration freezes or crystallizes the water molecules out as ice crystals and leaves behind a highly concentrated solution. Determining the quality and safety of the final frozen product, as well as the performance in further operations, often controlled by mean size and distribution of the crystals formed during the process. Our aim here is to calculate the best degree angle of the evaporator plate for the concentration of the food sample (orange juice).The metabolic reactions of microorganisms are catalyzed by enzymes and the rate is dependent on temperature. The rate of reaction is increased with an increase in temperature However, quality improvement of eliminating impurities from wastewater is a very important task. Concentration by freezing is the system that comes closest to the ideal objective of separating water from the liquid food product without affecting the other components as its nutrition value, aroma and taste. This technique is very suitable for the concentration of thermo sensitive liquid foods.**

Keywords: Eutectic Temperature, Concentrated liquid product, Thermo sensitive liquid foods, Nuclear, Chemical, Ammunition and refrigeration systems

INTRODUCTION

Food preservation processes have evolved over significant periods of time. The evaluation and design of these processes has become quantitative, based on the results from scientific research on the processes. [1]

Freezing is a broadly active technique used in the food industry as it is used for preservation and storage of liquid solutions.[2] During the process, the available water within the product is being altered into ice progressively, as the temperature decreases and crystallization takes place. [3]

There are three methods for the concentration of liquid food: evaporation, reverse osmosis, and freeze concentration. Every process has their specific energy and among those three, the energy cost is the highest for evaporation (2.26kJ/g-water), intermediate for freeze concentration (0.33kJ/g-water), and the lowest for reverse osmosis because phase transition is not needed [4]. Evaporation is the simplest method which is worth the energy consumed, but it is very dangerous when hazardous volatile organic compounds (VOCs) are involved and it is not suited for food products with very delicate flavors. [5]. Despite of the low energy consumed in reverse osmosis, it is not a favorable method of concentration because clogging can easily occur, and the high cost involved for the osmotic pressure [6]. Among these, concentration by freezing is potentially a superior and economic process for aroma-rich liquid foods and is known to give the best quality. [7]

According to various researchers (Mu¨ller and Sekoulov, 1992; Flesland, 1995; Chen et al., 1998; Miyawaki, 2001; Wakisaka et al., 2001), there are two basic methods freeze concentration in solutions. The first is known as suspension crystallization (Huige and Thijssen, 1972; Hartel and Espinel, 1993), the second method is the crystallization of water present in the solution in form of an ice layer on a cold surface (PFC) (Mu¨ller and Sekoulov, 1992; Flesland, 1995 ;)

The suspension crystallization is a process in which many small ice crystals are formed, in a suspension of the mother liquor and is characterized by the generation of a size distribution of crystal growing isothermally due to which separation of ice is difficult. The size of the ice crystals is still very limited which will require usage of scraped surface heat exchangers, which is very expensive and accounted for approximately 30% of the capital cost. [8]

The progressive freeze-concentration (PFC) is a method with a single ice crystal formed on the cooling plate. This method is expected to be much simpler in its system as compared with the conventional method based on the suspension crystallization. [9]

Cryoconcentration (freeze concentration) is performed at low temperatures, which means that it suits to preserve the heat-sensitive liquid food compounds, retaining the nutritive value of the food and volatile aromatics in the product.

PFC is very flexible system and is applicable to various samples with wide ranged physical properties, even to emulsion and suspension. This is applicable to liquid foods and waste water. [10]

In application to liquid foods the FC is preferred when concentrating liquid food with aromatic quality that should be detained even after concentration process. In application to waste water it is used in a way that would produce almost pure water from the thawed ice crystals.

II. WORKING PRINCIPLE

The initial freezing temperature for a food product is always lower than the freezing temperature of water. Such fall of the freezing temperature for water is the result of soluble solutes in the product liquid phase. In addition, the representative shape of the temperature-history curve during freezing is the result of incessant concentration of the soluble solutes within the product. Since the concentration of solutes occurs as the freezing process continues, the formation of ice crystals and

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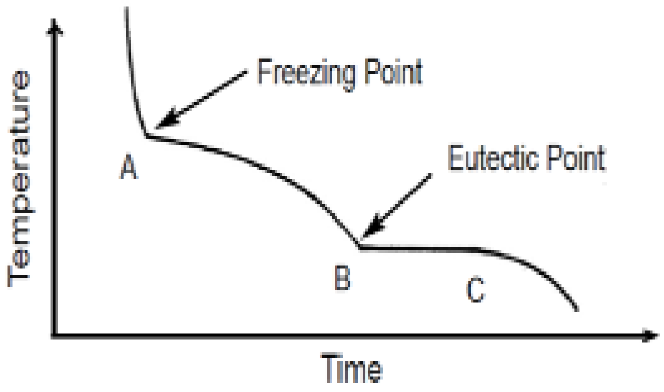
the corresponding removal of latent heat occurs over a range of temperatures. During typical food freezing, this gradual removal of latent heat will continue until the freezing process is completed and a small fraction of unfrozen water remains in the product.

In other words, freezing initiates when the temperature reaches just below 0°C, when the liquid in food becomes solid and a typical phase change takes place. It is well known that a large amount of energy exchange must accompany a phase change of materials. Hence a large amount of latent heat of fusion in addition to sensible heat must be removed in order to produce further cooling. The amount of heat extracted during a process of phase change is much greater compared with a process of sensible heat change. It is more correctly defined as the elimination of heat from a substance to bring it to or keep it at a desirable low temperature, which is below the temperature of the surroundings.

It is observed that heat and work are two mutually convertible forms of energy, and this is the basis of the First Law of thermodynamics. It is also known as the principle of the conservation of energy. It is stated in the following way, "Energy can neither be created nor destroyed but it can be converted from one form to another, when one form of energy disappears another form of energy appears while total energy of universe remains constant." [11] Initially the solution cools the same way the solvent did.



At this freezing temperature, "A", however, the solvent starts to crystallize out and the rate of cooling decreases sharply. This is because heat is added as the solvent crystallizes. As more and more solvent freezes out, the liquid portion of the solution becomes more concentrated. The increasing concentration lowers the equilibrium temperature between liquid and solid phases. Because there is only a fixed amount of solute, the concentration increases at an exponential rate, as more and more ice is formed. Finally the ratio of solvent in the liquid portion increases to the point where the solubility limit (eutectic point, "B"), is reached.

As more solvent is frozen out, the solute precipitates out at a corresponding rate which keeps the temperature constant. Finally, at "C", all the solvent becomes solid and the solid mass cools down to the bath temperature. But liquid foods have the phenomenon of super cooling then this curve changes.

Freezing gives rise to a structural change in the water and consequently these interactions are altered. A little understanding of the mode of formation of ice crystals within the tissue will assist an appreciation of the changes which accompany freezing. When the temperature of a biological system is reduced to below 0°C, the solutions it contains first supercool. Ultimately the formation of ice crystals occurs, and much of the water in the system is converted to ice. These conversions include nucleation, crystal growth and size:

A. Nucleation:

Freezing of water or a solution will not occur until nuclei are present to initiate crystallization. When the first ice crystal forms, it starts nucleation and the solidification process. Two types of nucleation are possible [12]

Homogeneous Nucleation: Water if exceedingly pure, is limited to nucleation of the homogeneous type. In very pure water, the "nucleus" is water molecules orienting as crystals. A homogeneous nucleus forms by chance orientation of a suitable number of molecules into a tiny ordered particle. Homogeneous nucleation is impossible at 0°C and does not become probable until the temperatures are reduced many degrees below 0°C, particularly if the sample is very small. Homogeneous nucleation is of no concern with most practical situation.

Heterogeneous Nucleation: Heterogeneous or catalytic nucleation is the type that occurs in foods and living specimens. Heterogeneous nucleation involves the formation of nuclei adjacent to suspended foreign particles, surface film, or on the walls of containers. Although heterogeneous nucleation necessitates some super cooling, it is more probable to occur than homogeneous nucleation at any given temperature and fixed sample. As the temperature is lowered to some critical value characteristic of the sample, nucleation begins, and further decreases in temperature result in an abrupt increase of rate.

B. Crystal growth:

Growth of a crystal nucleus constitutes the second step in the crystallization process. Unlike nucleation, crystal growth can occur at a temperature just below the melting point of the system. At temperatures near the melting point, water molecules add to existing nuclei (if present) in preference to forming new nuclei. The rate of crystallization in a complex aqueous system is governed by the rates of mass and heat transfer. During the course of crystallization, water molecules must move from the liquid phase to a stable site on the crystal surface, and solute molecules must diffuse away from the crystal. Since water molecules are small, highly mobile, and usually present in abundance, in most instances movement of water molecules is unlikely to limit the rate at which ice crystals grow.

C. Ice Crystals:

The number and shape of ice crystals has a major effect on the quality of frozen foods. Large crystals damage the tissue. Meat, poultry, fish, shellfish, fruit and vegetable cells contain jelly-like protoplasm. Large ice crystals puncture cells. After thawing, they cannot reach their former state. Small crystals

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do not injure the tissue as much. When thawed, they can be reabsorbed into the protoplasm. Thaw-drip is minimized. The location of ice crystals in food tissues depends on freezing rate, temperature, nature of the cells. Slow freezing (less than 10C/min) causes the crystals to form exclusively in the extracellular spaces. This shrinks the cells, disrupts tissues and results in lower quality. Freezing starts at extracellular space. Inside the cell is a super cooled solution. Its water vapor pressure is higher than that of extracellular ice. This difference in vapor pressure causes water to migrate from inside the cell to extracellular space.

III. METHODOLOGY

The system was maintained at a constant power supply to compressor and the following considerations were considered to acquire the results:

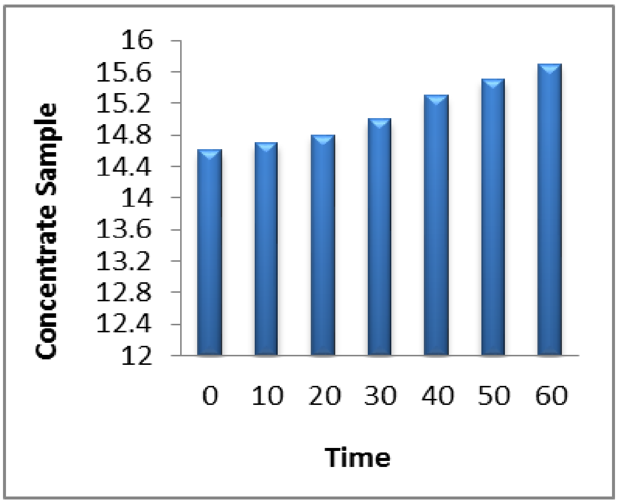
1) Maintain the required pressure in the system.
2) Maintain the required level of water in the storage tank.
3) Do not open charging valve unless required for charging.

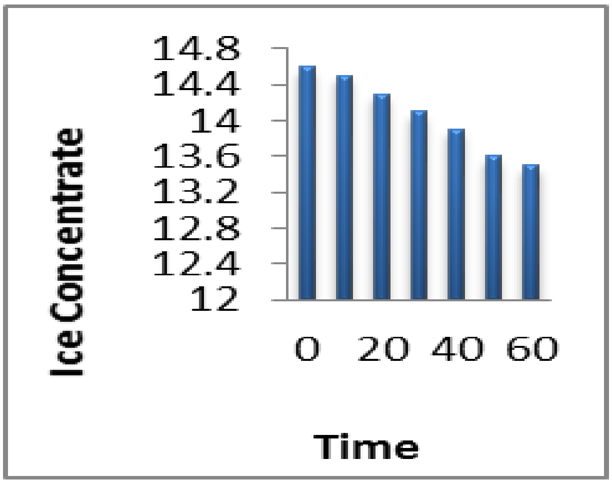
We have applied the cooling load on evaporator from the storage tank. The temperature and brix concentration of food sample and current and voltage to compressor were observed. The readings were taken at an interval of 10mins. The evaporator plate angle was varied for every reading and the angle with effective freeze concentration was selected.

IV. RESULTS AND DISCUSSION

Table – 1 Result table for evaporator plate angle 20 degree

Sr. No.	Time in minutes (T)	Brix in	
		Concentrated Sample	Ice Concentrate
1	0	14.6	14.6
2	10	14.7	14.5
3	20	14.8	14.3
4	30	15	14.1
5	40	15.3	13.9
6	50	15.5	13.6
7	60	15.7	13.5

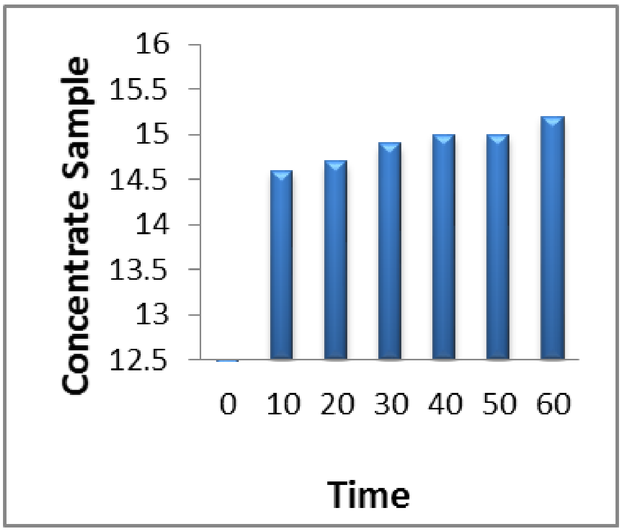


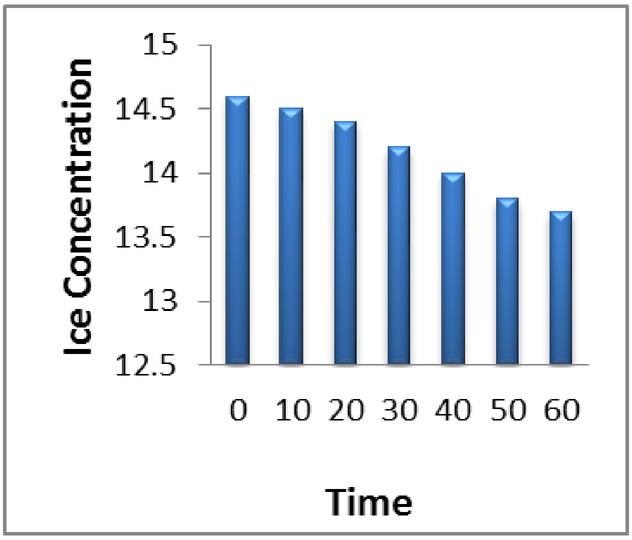


At 20 degree plate angle an orange juice of 0.5 liter's quantity can be successfully concentrated from 14.6 to 15.7 Brix in batch process.

Table – 2 *Result table for evaporator plate angle 30 degree*

Sr. No.	Time in minutes T	Brix in	
		Concentrated Sample	Ice Concentrate
1	0	14.6	14.6
2	10	14.6	14.5
3	20	14.7	14.4
4	30	14.9	14.2
5	40	15	14
6	50	15	13.8
7	60	15.2	13.7

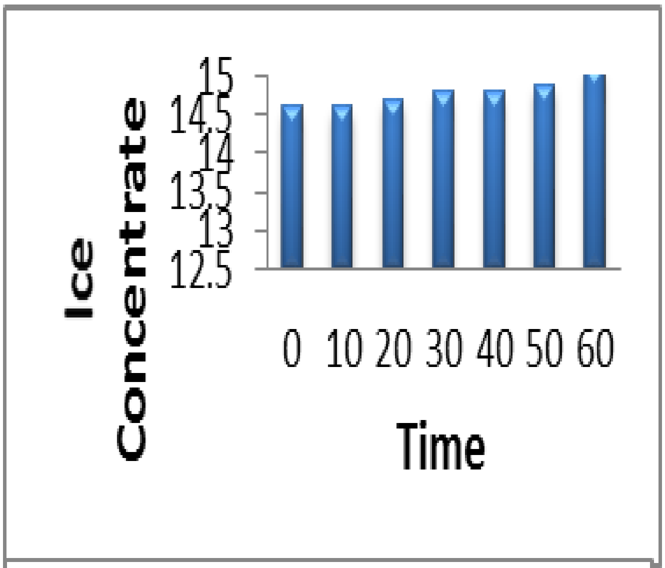


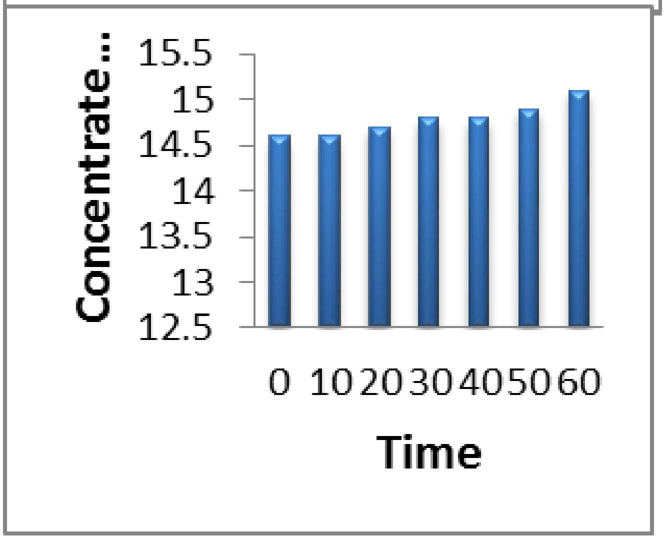


At 30 degree plate angle an orange juice of 0.5 liters' quantity can be successfully concentrated from 14.6 to 15.2 Brix in batch process.

Table – 3 Result table for evaporator plate angle 45 degree

Sr. No.	Time in minutes T	Brix in	
		Concentrated Sample	Ice Concentrate
1	0	14.6	14.6
2	10	14.6	14.5
3	20	14.7	14.4
4	30	14.8	14.3
5	40	14.8	14.1
6	50	14.9	13.9
7	60	15.1	13.8





At 45 degree plate angle an orange juice of 0.5 liters quantity can be successfully concentrated from 14.6 to 15.1 Brix in batch process.

Table – 4 Result table for evaporator plate angle 60 degree

Sr. No.	Time in minutes T	Brix in	
		Concentrated Sample	Ice Concentrate
1	0	14.6	14.6
2	10	14.6	14.6
3	20	14.7	14.5
4	30	14.7	14.3
5	40	14.8	14.1
6	50	14.9	14
7	60	15	13.9

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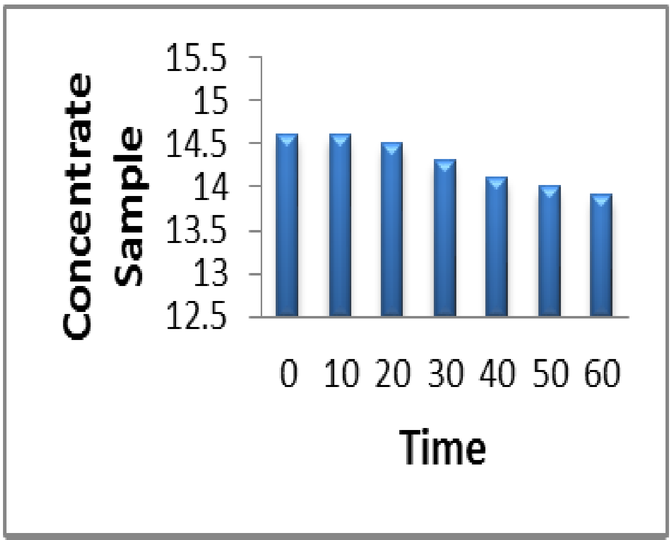
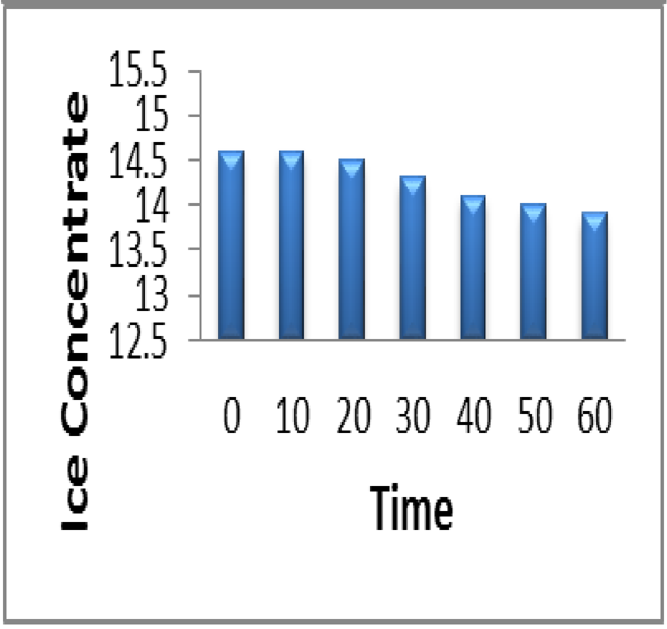
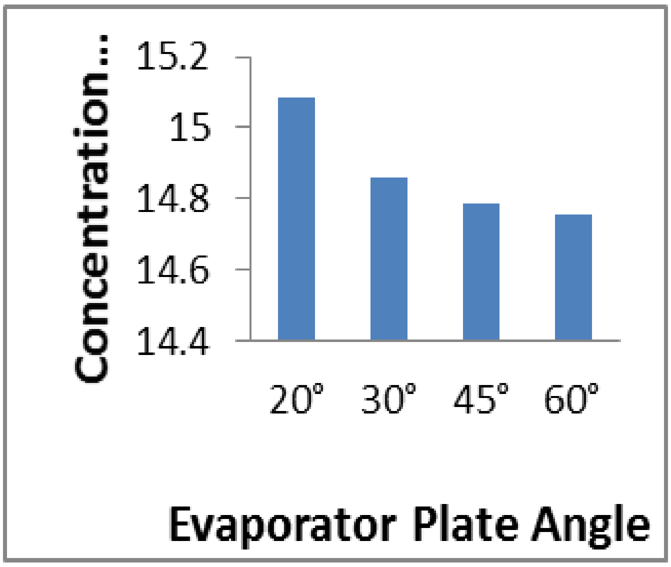




At 60 degree plate angle an orange juice of 0.5 liters quantity can be successfully concentrated from 14.6 to 15 Brix in batch process.

Table – 5 Result table for evaporator plate angles

Sr No.	Evaporator Plate Angle	Concentration Rate
1	20	15.08571
2	30	14.85714
3	45	14.7857
4	60	14.7571429



From the above fig it can be seen that as evaporator plate angle increases the concentration rate decreases.

V. CONCLUSION

PFC was proved to be effective for the concentration of solute for the solution with a low osmotic pressure.

By varying the evaporator plate angle an orange juice of 0.5 liters quantity was successfully concentrated with semi industrial equipment, in batch process.

At 20 degree plate angle an orange juice can be concentrated from 14.6 to 15.7 brix in batch process.

At 30 degree plate angle an orange juice can be concentrated from 14.6 to 15.2 brix in batch process.

At 45 degree plate angle an orange juice can be concentrated from 14.6 to 15.1 brix in batch process.

At 60 degree plate angle an orange juice can be concentrated from 14.6 to 15 brix in batch process.

It can be seen that as evaporator plate angle increases juice flow rate also increases and because of which juice concentration rate decreases. So the evaporator plate angle is kept less than 45 degree for effective freeze concentration.

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