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**THE RECOVERY OF SOLUTES RETAINED
ON ICE AFTER FREEZE CONCENTRATION
IN SALT SOLUTIONS**

**FINAL DEGREE PROJECT
FOOD ENGINEERING**

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Key words: desalination, freeze concentration, fractioned thawing, concentration index, falling-film cryoconcentrator.

ABSTRACT

Although there are different ways to desalinate water, freeze concentration is evaluated with the aim of characterize the process to compare the costs and it viability for the obtainment of potable water.

The effects of salt solutions on freeze concentration by freezing and posterior thawing were evaluated in this study. Fractioned thawing was studied as a method to recover solutes incorporated in the ice obtained by falling-film cryoconcentrator.

The ice layer used for the melting process was obtained by cryoconcentrated salt solutions, adjusting the temperature of cooling fluid to - 20 °C, in this case, ethylene glycol – water 50% (w/w). It had been worked with different concentrations such as 0.1%, 0.5 %, 1.5 %, 2.5%, 3.5%, 6 % and 8.5 %; 3 repetitions for each one.

Fractioned thawing was performed at 20°C, where were made 10 fractions, keeping a similar weight for the test samples.

Different parameters were studied to obtain the tracking of the process: concentration index, solute yield and thawing velocity.

The results obtained showed that in the first fractions, concentration index, had values > 1 and decreased through melting, therefore; concentrated extract was collected in the earlier fractions. It would be needed to thaw 40-50 % of the ice to recover the majority of retained solutes, thus; obtain pure water in the latest fractions. It is stated that thawing velocity increased along the increment of concentration.

Moreover there were attempts on working with concentration such as 11 %, 13.5 % and 18 % but it wasn't possible to get valid results.

Paraules clau: desalinització, crioconcentració, descongelació fraccionada, índex de concentració, crioconcentrador de pel·lícula descendent.

RESUM

Encara que hi hagi diferents maneres de desalinitzar l'aigua, s'avalua la concentració per congelació amb l'objectiu de caracteritzar el procés per tal de comparar els costos i la seva viabilitat per l'obtenció d'aigua potable.

Es van avaluar els efectes de solucions de sal en la crioconcentració a partir de la congelació i posterior desgel. La descongelació fraccionada ha sigut estudiada com a mètode per recuperar els soluts incorporats en el gel obtingut pel crioconcentrador de pel·lícula descendent.

La plaques de gel utilitzades en el procés de desgel es van obtenir a partir de solucions de sal crioconcentrades, ajustant la temperatura del fluid refrigerant a -20°C , en aquest cas, etilenglicol – aigua 50 % (p/p). Es va treballar amb diferents concentracions tal com 0.5 %, 1.5 %, 2.5%, 3.5%, 6 % i 8.5 %, amb 3 repeticions per cadascuna.

La descongelació fraccionada es va realitzar a 20°C , on es van fer 10 fraccions, mantenint un pes similar per les mostres d'assaig.

Es van estudiar diferents paràmetres per obtenir el seguiment del procés: índex de concentració, rendiment de soluts i la velocitat del desgel.

Els resultats obtinguts van mostrar que en les primeres fraccions, l'índex de concentració, tenia valors > 1 i va decréixer al llarg de la descongelació, per tant, l'extracte concentrat es va recollir en les fraccions inicials. Seria necessari descongelar 40 – 50 % del gel per recuperar la majoria del soluts retinguts i així obtenir aigua pura en les ultimes fraccions. Es constata que la velocitat del desgel creix a mesura que augmenta la concentració.

Per un altre part, es va intentar treballar amb concentracions com 11 %, 13.5 % i 18 % però no va ser possible obtenir resultats vàlids.

Palabras clave: desalinización, criconcentración, descongelación fraccionada, índice de concentración, criconcentrador de película descendente.

RESUMEN

Aunque haya diferentes maneras de desalinizar el agua, otras técnicas se evalúan, como la concentración por congelación, con el objetivo de caracterizar el proceso para comparar los costos y su viabilidad para la obtención de agua potable.

Se evaluaron los efectos de soluciones de sal en la criconcentración a partir de la congelación y posterior deshielo. La descongelación fraccionada ha sido estudiada como método para recuperar los solutos incorporados en el hielo obtenido por el criconcentrador de película descendente.

La placas de hielo utilizadas en el proceso de deshielo se obtuvieron a partir de soluciones de sal criconcentradas, ajustando la temperatura del fluido refrigerante a $-20\text{ }^{\circ}\text{C}$, en este caso, etilenglicol - agua 50% (p/p). Se trabajó con diferentes concentraciones tales como 0.5 %, 1.5 %, 2.5 %, 3.5 %, 6% and 8.5 %; 3 repeticiones para cada una.

La descongelación fraccionada se realizó a $20\text{ }^{\circ}\text{C}$, donde se hicieron 10 fracciones, manteniendo un peso similar para las muestras de ensayo. Se estudiaron diferentes parámetros para obtener el seguimiento del proceso: índice de concentración, rendimiento de solutos y la velocidad del deshielo.

Los resultados obtenidos mostraron que en las primeras fracciones, el índice de concentración, tenía valores > 1 y disminuyó a lo largo de la descongelación, por tanto, el extracto concentrado se recogió en las fracciones iniciales. Sería necesario descongelar 40 - 50 % del hielo para recuperar la mayoría de los solutos retenidos, así; obtener agua pura en las últimas fracciones. Se constata que la velocidad de deshielo crece a medida que el aumento de la concentración.

Por otra parte, se intentó trabajar con concentraciones como 11 %, 13.5 % and 18 % pero no fue posible obtener resultados válidos.

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NOMENCLATURE

w: weight (g)

p: peso/pes (g) (weight)

BOE: boletín oficial del estado (State official newsletter)

FM: freezing melting

FC: freeze concentration

IL: ice layers

FP: freezing point

FPD: freezing point depression

$\Delta\theta$: supercooling ($^{\circ}\text{C}$)

θ^* : equilibrium temperature ($^{\circ}\text{C}$)

θ : solution supercooling temperature ($^{\circ}\text{C}$)

FFFC: falling-film freeze concentration

CI: concentration index

Y: solute yield

K: thawing kinetic (g/min)

Q: thermal power (W)

X_{sliq} : concentration of each fraction (mS/cm)

X_{so} : concentration of original solution (mS/cm)

m_{sliq} : solute mass in the thawed liquid fraction (g)

m_{so} : initial solute mass (g)

m: mass of fractions with IC > 1 (g)

t_t : thawing time for fractions with IC > 1 (min)

K_t : thermal conductance (W/K·m²)

S: area (m²)

ΔT : $T_s - T_R$, where T_s is the solution temperature and T_R the refrigerant temperature (K)

1. INTRODUCTION

Why is needed assess new methods for water desalination?

Even if there are different ways to desalinate water, such as, reverse osmosis (RO), evaporation or electro dialysis (ED), other techniques are evaluated, as freeze concentration, with the aim of characterizing the process, to compare the costs and it viability for the obtainment of potable water.

Nowadays, new methodologies are being studied or blends of various methods could be the right choice, depending on the requirements in each case.

1.1 WATER SITUATION

In 2010, the United Nations declared the availability of drinking water as human right. But even so, UNICEF stated that about 748 million people lack of access to drinking-water in 2015 and it is estimated that 1.8 billion people use a source of drinking-water that is faecally contaminated. The lack of water in many countries is a reality that the world is facing. This has effect on the daily life of millions of people, especially in poor countries, where they suffer the consequences of a lot of illnesses because of water.

The burden of disease from inadequate water, sanitation, and hygiene totals 1.7 million deaths and results in the loss of at least 54 million healthy life years annually (Finlayson et al., 2005). Diarrhoeal diseases caused by dirty water intake and lack of adequate sanitation constituted the second reason of infantile mortality after pneumonia (UNICEF, 2015).

Moreover, in recent times, there has been a big change in water consumption, either by population growth (nowadays there are more than 7.000 million of people) or by increasing industrial and agricultural activities and the fresh water readily accessible for direct human use is very limited and the amount of such water is less than 0.01% of all water resources on Earth (Fujioka et al., 2013).

All this makes the demand for water even greater than what it was before, for this reason; studying new methods to desalinate water are needed.

Ultimately there are different procedures for desalination; however, the high cost complicates the use that can have.

Desalination is the method in where salty water is converted into potable water by the removal of salt content; it can be performed in different ways (Ghalavand et al., 2014).

1.1.1 Seawater

Seawater is a dissolution in water of different substances. The most common ions in seawater are: sodium (Na^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^+), chloride (Cl^-), bicarbonate (HCO_3^-), sulphate (SO_4^{-2}) and nitrate (NO_3^-). These ions are found in small amounts, that's why, their concentration usually is expressed by parts per million (ppm). The total quantity of dissolved ions is called total dissolved solids (TDS) and corresponds to the aggregate of the concentrations of the different ions in presence (IEA, 2009).

Chloride and sodium are the essential constituents of seawater being 55.1 % and 30.6 % respectively and they are found as sodium chloride or as it is commonly known "common salt". Other ions such as sulphate, magnesium, calcium and potassium are found in different proportions; 7.6 %, 3.7 %, 1.2 % and 1.1 % respectively. Different characteristics of seawater are shown in table 1.

Table 1: seawater characteristics.

Parameter	Value
Density (g/ml)	1.025
Concentration of dissolved mineral salt (%)	3.5
Freezing point (°C)	-2 – -2.6
pH	7.5 – 8.4

1.1.2 Potable water

In Spain water consumption is defined by Royal Decree 140/2003, of 7 February, where establishes the sanitary criteria of the water quality consumption.

Human consumption water is understood as all water either in its original state, either after treatment, intended for drinking, cooking, food preparation, personal hygiene and other domestic purposes, regardless of its origin and whether it is supplied to consumers through networks of public or private distribution, cisterns, public or private deposits. The regulation stated different parameters that have to be controlled, which indicated if the drinking water could be prejudicial for health, if the values are higher than the established. These parameters are biological, chemical or physical agents.

Indicators parameters: point the general quality of water, the efficiency of purification treatment and the possible acceptance of consumer (**Tab. 2**).

Radioactive parameters: indicate the possible natural or artificial contamination by radioactive elements (**Tab. 3**).

Chemical parameters: show chemical, agricultural, urban industrial pollution or for the proper treatment of purification performed inadequately (**Tab. 4**).

Microbiological parameters: show the danger of possible faecal pollution and derived risks (**Tab. 5**).

Table 2: indicators parameters of potable water. **Source:** BOE

Parameters	Parametric value
Coliform bacteria	0 CFUs in 100 ml
Counting bacteria	
- At output of the sewage treatment plant	100 CFUs in 1 ml
- Distribution network	Without anomaly changes
Aluminum	200 µg/l
Ammonium	0,50 mg/l
Total organic carbon	Without anomaly changes – mg/l
Residual combined chlorine	2,0 mg/l
Residual free chlorine	1,0 mg/l
Chloride	250 mg/l
Color	15 mg/l Pt/Co
Conductivity	2.500 µS/cm ⁻¹ a 20 °C
Iron	200 µg/l
Manganese	50 µg/l
Odor	3 a 25 °C – Dilution index
Oxidability	5,0 mg O ₂ /l
pH	
- Minimum	6,5
- Maximum	9,5
Savor	3 a 25 °C – Dilution index
Sodium	200 mg/l
Sulphate	250 mg/l
Turbidity	
- At output of the sewage treatment plant/deposit	1 FNU
- Distribution network	5 FNU

Table 2: radioactivity parameters of potable water. **Source:** BOE

Parameters	Parametric value
Total indicative dose	0,10 mSv/year
Tritium	100 Bq/l
Total activity α	0,1 Bq/l
Rest activity β	1 Bq/l

Table 4: Chemicals parameters of potable water. **Source:** BOE

Parameters	Parametric value
Antimony	5 µg/l
Arsenic	10 µg/l
Benzene	1 µg/l
Benzo (α) pyrene	0,010 µg/l
Boron	1 µg/l
Bromate	10 µg/l
Cadmium	5 µg/l
Cyanide	50 µg/l
Copper	2 µg/l
Chromium	50 µg/l
1,2 dichloroethane	3 µg/l
Fluorine	1,5 µg/l
polycyclic aromatic hydrocarbons	0,1 µg/l
Mercury	1,0 µg/l
Microcystin	1 µg/l
Nickel	20 µg/l
Nitrate	50 mg/l
Nitrites	
- Distribution network	0,5 mg/l
- At output of the sewage treatment plant/deposit	0,1 mg/l
Total pesticide	0,5 µg/l
Individual pesticide	0,1 µg/l
Except:	
- Aldrin	0,03 µg/l
- Dieldrin	0,03 µg/l
- Heptachlor	0,03 µg/l
- Heptachlor epoxide	0,03 µg/l
Lead	10 µg/l
Selenium	10 µg/l
Thrihalomethanes (THMs)	100 µg/l
Trichloroethane + tetrachlorethene	10 µg/l

Table 5: microbiological parameters of potable water. **Source:** BOE

Parameters	Parametric value
Escherichia coli	0 CFUs in 100 ml
Enterococci	0 CFUs in 100 ml
Clostridium perfringens	0 CFUs in 100 ml

1.2 DESALINATION

Desalination for water supply has grown steadily since the 1960s (Rahman et al., 2006). The seawater desalination process separates saline seawater into two streams: a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. This process requires some form of energy to desalinate, and utilizes several different technologies for separation (Khawaji et al., 2008).

The first desalination plant installed in Europe was in Spain in 1964 in Lanzarote. Spain is the fifth country in the world with the major number of desalination plants with a total of 900, such for example, Carboneras in Almeria, San Pedro de Pinatar in Murcia and Atabal in Malaga.

The different technologies for desalination can be classified by the different techniques according to the functioning system of the plant, depending on if a phase-change is included or not. There also other methods such as air dehydration, solvent extraction, ion exchange and hybrid systems as it can be seen in **Fig. 1** (Ghavaland et al, 2014).

In the current work is based on freezing melting process.

In a freezing melting (FM) process, first the solution is partially frozen, the ice crystals are physically separated from concentrated solution, and the ice is melted to form the product water (Rahman et al., 2014)

Some of the advantages of FM process are: (i) low energy requirement as compared to that of distillation processes, (ii) it has low operating temperature, (iii) requires no or little pretreatment. Whereas the disadvantages are: (i) higher capital and the operating costs, (ii) complexity of the unit operations in the freezing unit (Rahman et al., 2014).

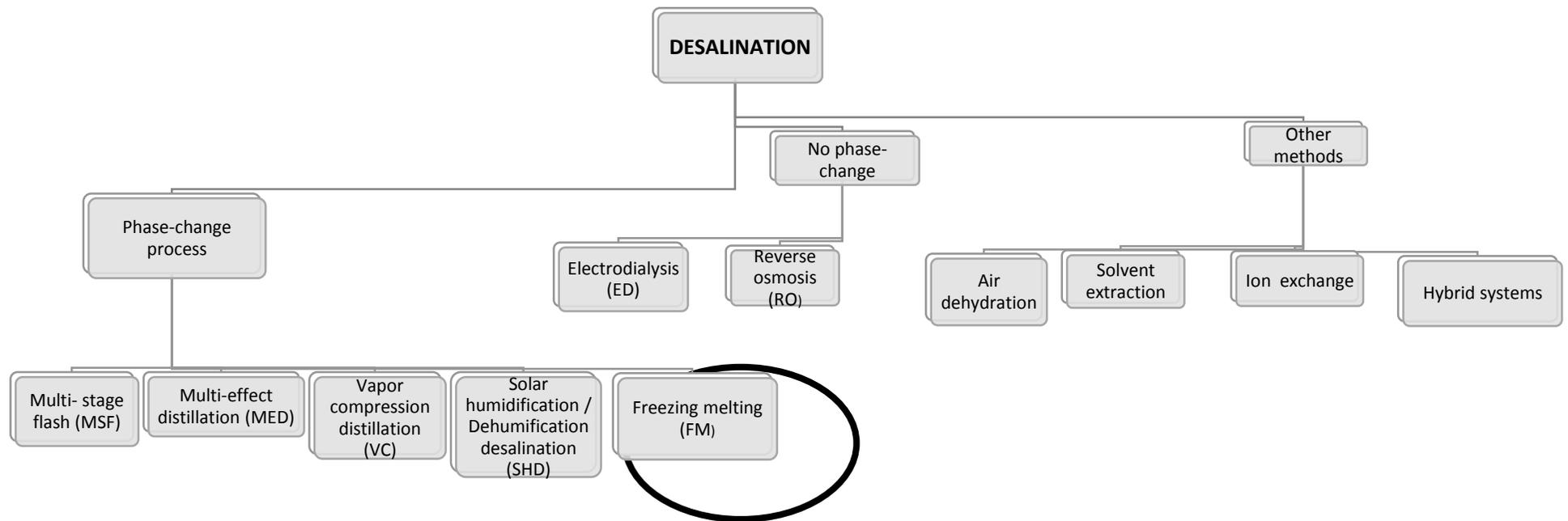


Figure 1: desalination techniques. **Source:** adapted from Ghavaland 2014.
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1.3 FREEZE CONCENTRATION

Freeze concentration (FC) involves the partial crystallization of water in the aqueous solution, after which the crystals are separated from the concentrate (Yee et al., 2003). Thus, it can be obtained ice crystal with high purity.

The crystallization is the formation of solid particles from a homogenous phase (Chen et al., 1998). It involves three parts: supercooling or supersaturation, crystal formation, which is called nucleation, and finally crystal growth.

1.3.1 Crystallization

1.3.1.1 Supercooling or supersaturation

The supercooling or supersaturation of a solution refers to a kinetic condition in which the solution is trapped in an apparently soluble state. It has been defined by Mullin (2009) as the difference of concentration between the solution in which the crystal is starting the growth and the solution in equilibrium with the crystal.

$$\Delta\theta = \theta^* - \theta \quad (1-1)$$

where:

$\Delta\theta$ = supercooling (°C)

θ^* = equilibrium temperature (°C)

θ = solution supercooling temperature (°C)

1.3.1.2 Nucleation

Nucleation is the generation of little particles stable capable of grow from a homogeneous phase.

The nucleuses are formed because the random vibrations of atoms are continuously forming tiny crystals of the new phase, and if the temperature is low enough, these crystals will be thermodynamically stable and grow (Ashby et al., 2009).

There are two types of nucleation.

Primary nucleation is where the origin of the new solid phase is not based or influenced by the presence of the solid phase that is originated (Grases et al., 2000). It is divided in two groups:

- Homogeneous: nucleation is induced in the bulk of a liquid in the absence of any solid surfaces.
- Heterogeneous: when a solid interface—whether a containing wall or a pre-existent crystal—is involved (Chow et al., 2003)

Secondary nucleation: production of new crystals in a solution already containing crystals (Chow et al., 2003).

As soon as the nucleus reaches to the critical radius, the process of the crystal growth starts. Then, the crystals particles grow to their final size depending on temperature conditions (Sánchez et al., 2009)

Freeze concentration is a process that has been applied in several industries within the food industry: dairy products, winery and distilling and for the concentration of dilute solutions of tea and coffee (Sánchez et al., 2009). It is used to remove water at low temperatures, preserving the quality of the original material.

It possesses several advantages (Yee et al., 2003):

- Low chemical deterioration due to low microbiological and enzymatic activity.
- No loss of volatile aroma components.
- Low product losses.

In FC when temperature of aqueous solution has been decreased below the freezing point, two phases are obtained: liquid and solid phase. The liquid phase is with higher solute concentration than the initial solution, and the solid one, is formed by pure ice in the ideal situation or ice with trapped solutes in the practical situation. This phenomenon is known as solute occlusion and it implies heat and mass transfer (Moreno, 2014), which is important, because they regulate the efficiency obtained in the separation of water.

1.3.2 Classification

According to the ice crystal growth, FC techniques can be classified in three groups: suspension, film and block freeze concentration (Moreno, 2014).

1.3.2.1 Suspension Freeze Concentration

Suspension FC is a technique that was developed by Niro Process Technology B.V. It is the most implemented technique at industries (Moreno, 2014).

This technique consists of three stages. First, takes place the crystallization. Second, individual ice crystals that were formed will enlarge in size by Ostwald ripening. Finally, the separation of ice crystals is by wash column (Sánchez et al., 2010; Moreno, 2014). The fact that for each part it has to be used the specific equipment makes this technique more expensive.

1.3.2.2 Film Freeze Concentration

Film freeze concentration has the characteristic that it is formed just one ice film. The crystal grows and remains adhered to the surfaces of the crystallizer during operation which facilitates the separation of the two phases. It has two different processes:

- **Progressive Freeze Concentration:** a large single ice crystal is formed and grown on the cooling surface in a crystallization vessel so that the separation between the ice crystal and the mother solution is very easy. Progressive cryoconcentration is one method of melt crystallization, which, has been applied mainly to purification of organic materials (Aider and De Halleux, 2008).

It can be classified depending on the equipment used. The first one is the vertical system, which is composed by a cylindrical agitated tank with a cooling jacket. The ice grows on the cooling wall and agitation is applied to reduce solute occlusion. The second is the tubular one and it is

constituted by two concentric tubes that are connected. The solution to be concentrated circulates through the inner and the refrigerant fluid by the external tube (Moreno, 2014).

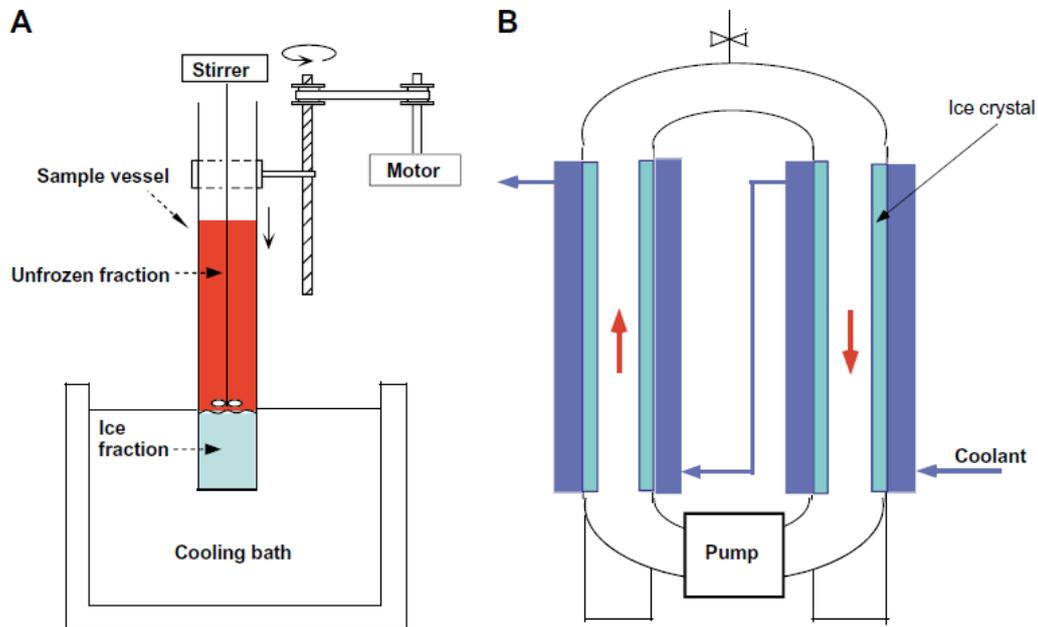


Figure 2: Apparatus for progressive freeze-concentration. (A) Vertical freezing test apparatus (B) Tubular ice system with circulating flow. **Source:** Miyawaki et al., 2012.

- **Falling-Film Freeze Concentration (FFFC):** is a simple method in which the solution to be concentrated is re-circulated on a cooled vertical plate. The fluid descends in a film, and an ice sheet is produced by freezing. The ice forms a single layer on the cold surface. The solution is collected and re-circulated continuously (Moreno, 2014). The separation of ice and concentrated solution occurs because the ice adheres to the surface, while the concentrated liquid flows down along the surface (Sánchez et al., 2011).

1.3.2.3 Block Freeze Concentration

Block FC is a technique also known as freeze-thaw concentration.

It includes three parts: freezing, thawing and separation of the concentrated liquid fraction.

There are two different ways to carry out this technique: total block FC and partial block FC.

At the first one, the food liquid solution is completely frozen and the temperature in the center of the product is largely below the freezing point. Then, all the frozen solution is thawed and the concentrated fraction is separated from the ice fraction.

However, in partial block FC, inside a crystallizer chamber, the solution is partially frozen from the center, where it is introduced a pipe in which the cooling agent circulates (Sánchez et al., 2011).

In the next figure, is shown the experimental set-up for block FC (**Fig. 3**)

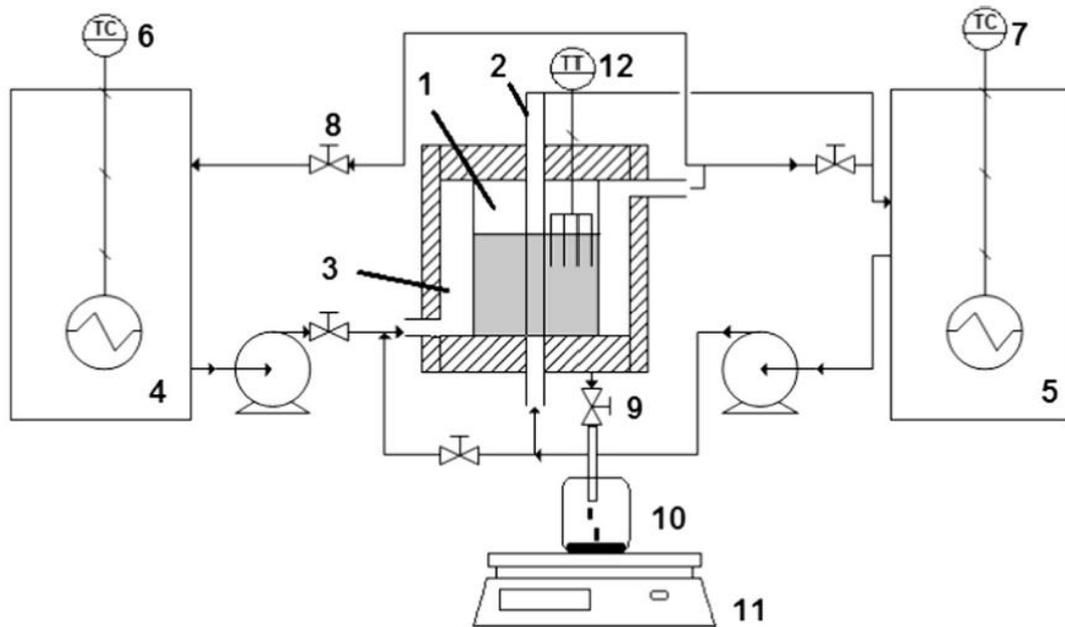


Figure 3: experimental set up for Block FC. (1) Cylindrical container; (2) internal jacket; (3) cooling plate; (4) & (5) circulated baths; (6) & (7) temperature controller; (8) valve; (9) exit valve; (10) collector vessel; (11) scale. **Source:** Moreno 2014

1.3.3 Parameters influencing the freeze concentration

To design an equipment or the posterior control, is important to know which are the properties that affect the solution.

There are several properties that can influence a solution, but in this case, is particularly important in the process: freezing point (FP) – freezing point depression (FPD) and viscosity.

1.3.3.1 Freezing Point (FP) –Freezing Point Depression (FPD)

FP is defined as the temperature, at which a substance changes from liquid to solid state when the liquid cools. The most widely used method to measure freezing point is the temperature curve method, because of its accuracy and simplicity (James et al., 2005).

The design of a freeze concentration system has to take into account the freezing point of the solution to be cryoconcentrated (Gulfo, 2014).

The freezing point is influenced by the mole fraction existent in the solution and not by the total mass (Gulfo, 2014)

The depression of freezing point is influenced by the solution, which depends on the concentration and the type of solid that forms the solution.

The higher the concentration, the more decreases the freezing point reaching the minimum FPD at the eutectic point (for each solute) where the solid fraction and the liquid have the same composition.

The knowledge of the precise FPD of aqueous solution such as sodium chloride is important to the study of fluid inclusions (Potter et al., 1978).

1.3.3.2 Viscosity

When the concentration of a solution increases, so does the viscosity; which is influenced by the decrease of temperature and augmentation of concentration. It is important control the viscosity in function of temperature, pressure and the concentration due to the inefficiency of freeze concentration when the fluid converts to highly viscous (Gulfo, 2014).

An augmentation of viscosity determines a maximum limit of concentration during the cryoconcentration; therefore, the capacity to separate the ice crystals decreases.

1.4 FRACTIONED THAWING

One of the drawbacks of freeze concentration (and in this case of FFFC) is that the ice layer obtained can have a large amount of occluded solutes. A strategy for the recovery of these solutes is the fractioned thawing.

Fractioned thawing consists of slowly heating the ice-layer obtained from the freeze concentrator and collecting the liquid that is formed in various fractions (Gulfo et al., 2014). Several authors such as Yee et al., (2003) and Miyawaki et al., (2012) reported that it increase the efficiency of recovery.

But even though, this method should be studied in more depth due to lack of literature and information with the aim of achieving an accurate method.

In next table, are shown different studies related with freeze concentration (**Tab. 6**).

Table 6: some articles related with freeze concentration.

TITLE, AUTHORS, PLACE & YEAR	OBJECTIVES	MATERIALS & METHODS	RESULTS
<p>Effects of Single Food Components on Freeze Concentration by Freezing and Thawing Technique</p> <p>Phang Lai YEE, Minato WAKISAKA, Yoshihito SHIRAI and Mohd Ali HASSAN.</p> <p>Fukuoka, JAPAN; Serdang Selangor, MALAYSIA. 2003</p>	<p>The objective of this study was to evaluate the effects of individual food components on freeze concentration after being treated by freezing and thawing. The relative importance of the initial concentration of liquid food is described with respect to treatment performance.</p>	<p>The substances and chemicals used were purchased from Wako Pure Chemical Industries, Ltd. (Osaka, Japan). Aqueous solutions were prepared by dissolving the chemicals in distilled water: sodium chloride → 1 %, 5 %, 10 % and 20 % (w/w); glucose → 1 %, 5 %, 10 % and 20 % (w/w); fructose → 1 %, 5 %, 10 % and 20 % (w/w); sucrose → 1 %, 5 %, 10 % and 20 % (w/w); lactose → 1 %, 5 % and 10 % (w/w); dextrin → 1 %, 5 % and 10 % (w/w). Freezing and thawing method were used.</p> <p>A sample solution of 200 g was used to produce ice cubes by freezing at -18 ° C more than 12 h. 20% solutions were frozen at -80 ° C.</p> <p>A 1 liter glass vessel containing 300 ml of sample solution was cooled by the coolant of the ethylene glycol at -15 ° C to determinate freezing point.</p>	<p>Sodium chloride and some sugar solutions can be successfully concentrated by freezing and thawing.</p> <p>The initial concentration affected the freeze concentration of the single food component. Most of the concentrated food components were in the fractions no. 1, 2 and 3. The freezing point depression affects the freeze concentration of the aqueous solutions by freezing and thawing.</p> <p>The thawing rate increased with increasing concentration of food components, irrespective of the type of the food components.</p>
<p>Freeze concentration of must in a pilot plant falling film cryoconcentrator</p> <p>E. Hernández, M. Raventós, J.M. Auleda, A. Ibarz</p> <p>Barcelona & Lleida; SPAIN. 2010</p>	<p>The main aim of the current work is to study the process of freeze concentration of grape juice must using a multi-plate device.</p>	<p>The white must from Macabeo variety grapes with 16.4 ° Brix was provided by INCAVI (Institut Català de la Vinya i el Vi).</p> <p>The equipment comprises a freezer unit, a freezing system, a hydraulic system and an electric system. The refrigerant was R-404A.</p> <p>The levels of sugars were determined using High Performance Liquid Chromatography. Concentration was measured in ° Brix. 45 L of grape juice were used to freeze concentrate and the duration of the test was determined by a constant average flow of 0.8 ±0.1 L/s.</p> <p>Concentration index and thawing rate were determined</p>	<p>It was observed as the content of soluble solids in the must increases, the efficiency decreases, which is corroborated by the negative slope of the straight line fit.</p> <p>An average concentration rate of 1.38 °Brix/h was obtained with semi-industrial equipment working at flow rates of around 0.8 L/s.</p> <p>The concentration attained was 29.5 ° Brix and ice production ranged from 1.32 to 1.05 g·m⁻²·s⁻¹ as the concentration of the fluid increased. Estimate energy consumption varied between 0.58 and 1 kWh/kg of ice.</p>



TITLE, AUTHORS, PLACE & YEAR	OBJECTIVES	MATERIALS & METHODS	RESULTS
<p>Sea water desalination by dynamic layer melt crystallization: Parametric study of the freezing and sweating steps</p> <p>Anouar Rich, Youssef Mandri, Denis Mangin, Alain Rivoire, Souad Abderafi, Christine Beron ; Naoual Semlali, Jean-Paul Klein, Tijani Bounahmidi, Ahmed Bouhaouss, Stéphane Veessler</p> <p>Rabat, MOROCCO; Marseille, FRANCE. 2012</p>	<p>This work aims at developing a dynamic layer crystallizer operated batchwise, for freezing desalination of sea water.</p>	<p>This work deals with indirect freezing desalination operated batchwise. The technique is part of layer melt crystallization.</p> <p>The operation is conducted in two main steps: the freezing step and sweating step.</p> <p>The crystallizer is composed of a stainless steel tube immersed inside a cylindrical glass tank equipped with a double jacket. The solution was introduced into the glass tank and agitated by air bubbling.</p> <p>NaCl/water solutions and sea waters from Rabat, Marseille and Nice were used for the experiments.</p>	<p>The ice layer formed in the freezing step is contaminated by liquid inclusions containing the impurities. Its purity is dependent on the initial temperature, on the growth rate and on the solution concentration.</p> <p>The salinity reached was too high to satisfy the drinking water standards.</p> <p>However, the sweating step is able to efficiently complete the purification, which can lead to salinities lower than 0.5 g/kg satisfying the drinking water standards and the whole process can drop in only 8 h.</p>
<p>Freeze desalination: An assessment of an ice maker machine for desalting brines.</p> <p>P.M Williams, M. Ahmad, B.S Connolly.</p> <p>Swansea, UNITED KINGDOM. 2013</p>	<p>The principle aim of this study is to investigate the potential of an ice maker for desalting several types of process feed brines including sodium chloride solutions, Arabian Gulf seawater and reverse osmosis brines.</p>	<p>Feed samples (NaCl), Arabian Gulf (AG) seawater and brine from reverse osmosis (RO) were used to the experiment.</p> <p>An ice maker machine was considered and tested in the study, but in order to use and examine it for saline water applications were carried out several modifications.</p> <p>The crystallization process was effectuated for a pre-determined time and then separated the ice slab. This was achieved by switching the mode of operating of the ice maker. After the separation of ice slab, the melting process was performed and later the physiochemical analyses.</p>	<p>The results show that the process was useful in concentrating reverse osmosis brine and producing a recycle stream for further processing by membrane plant.</p> <p>The feed concentration has a significant influence upon the salt rejection and water recovery ratios. NaCl solutions of 0.5, 3.5 and 7 wt% consumed: 0.43, 0.45 and 0.51 kWh/kg respectively, whereas AG seawater and RO brine: 0.47 and 0.51 kWh/kg respectively.</p>



TITLE, AUTHORS, PLACE & YEAR	OBJECTIVES	MATERIALS & METHODS	RESULTS
<p>Behaviour of falling-film freeze concentration of coffee extract</p> <p>F.L. Moreno, M. Raventós, E. Hernández, Y. Ruiz</p> <p>Cudinamarca, COLOMBIA; Barcelona, SPAIN. 2014</p>	<p>The objective of this study was to evaluate the behavior of coffee extract during falling-film freeze concentration at different coffee mass fractions, ice growth rates and film velocities on the plate and to obtain the parameters for average distribution coefficient modeling.</p>	<p>Coffee extract was prepared from soluble coffee by Buencafé Liofilizado de Colombia.</p> <p>The coffee was added to distilled water at 35 ° C and mixed for 20 min. Samples were stored at 4 ° C for 12 h.</p> <p>Four different coffee mass fractions were tested within the typical interval for freeze-concentration. Three plate temperatures were tested to achieve different ice growth rates and three fluid fluxes were adjusted to obtain different film velocities of fluid falling on the ice sheet.</p> <p>The experiment was carried out with 800 ml of coffee extract.</p>	<p>The mass fraction of solids and the ratio of the average growth rate of the freezing front to the velocity of the fluid film affected significantly the average distribution coefficient of the ice produced.</p> <p>A logistic model was adjusted to predict the behavior of successive stages of falling-film freeze concentration. In successive stages of falling-film freeze concentration, the coffee mass fractions tend to 35% at the studied conditions.</p>
<p>Calculation process for the recovery of solutes retained in the ice in a multi-plate freeze concentrator: Time and concentration</p> <p>R. Gulfo, J.M Auleda, M. Raventós, E. Hernández.</p> <p>Barcelona, SPAIN. 2014</p>	<p>The aim of this paper is to study fractioned thawing as a method to recover the solutes incorporated in the ice layer formed in a falling-film freeze concentrator.</p>	<p>Ice sheets used for the thawing process were obtained by cryoconcentrated sugars solutions and simulated at initial concentration of 5 to 20 ° Brix.</p> <p>Due to the large size of the ice layers, there were taken small test samples.</p> <p>For the thawing, it was used a cubical oven programmed at 20, 25 and 30 ° C.</p> <p>Different ration and parameters were used to describe the results, i.e.; concentration index, accumulated index and accumulated time.</p>	<p>At constant temperature, the thawing times and the concentration indices for solutions of the basic sugars at equal solute mass fraction in the ice and equal form factor are identical, independent of the type of the sugar.</p> <p>The thawing time decreased with the concentration (in ° Brix) and is inversely proportional to the form factor, being more sensitive to variation in the form factor than to variation in the concentration.</p> <p>By fractioned thawing more than 60% of the solutes retained in the ice was recovered in 34% of the total of thawing time.</p>



2 OBJECTIVES

General objective

The main objective of the current study was to evaluate the recovery of solutes retained on ice after falling-film freeze concentration and fractioned thawing technique in salt solution at different concentrations: 0.1%, 0.5%, 1.5%, 2.5%, 3.5%, 6% and 8.5% in the pilot plant ESAB.

Specific objectives

1. Determine the principle parameters of the fractioned thawing such as concentration index and solute yield in each sample of the 10 fractions.
2. Explore the combination of FFFC with fractioned thawing to obtain potable water.
3. Assess the power consumption of the falling-film FC process.

3 SOLUTE DETERMINATION

Falling-film freeze concentration is a technique which still being studied either in an industrial manner as to pilot plant level.

It should be underscored that there is difference between freezing and thawing and traditional freeze concentration, which is that aqueous solution is completely frozen in the former process and then thawed under controlled condition, in particular at low thawing rate (Yee et al., 2003).

3.1 BASIS

Draw from the premise of fractioned thawing; quantify the solutes content in each sample obtained in freeze concentration for the three repetitions of each concentration.

3.2 MATERIAL

Falling- film cryoconcentrator

Falling-film cryoconcentrator is the equipment used for the ice layers obtainment. It comprises a thermostatic bath, peristaltic pump and speed shifter (**Fig. 4**).

A power meter was integrated to measure the energy consumption.

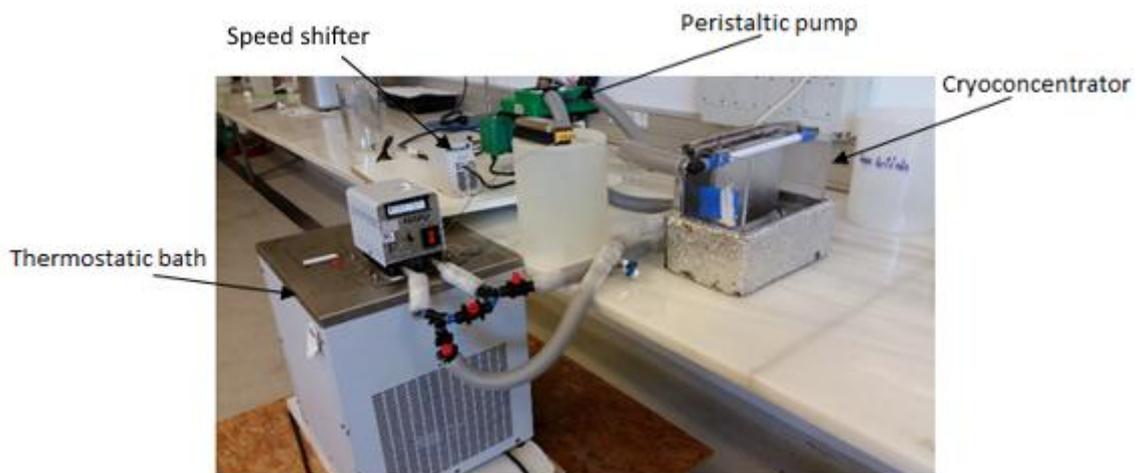


Figure 4: falling-film cryoconcentrator.

Ice layers to analyze

Ice layers (IL) to thaw were obtained from freeze concentration process with falling film technique at the pilot plant of ESAB (**Fig. 5**).



Figure 5: ice layers.

Salt solutions had been used to this process. The salt used was “Sal Costa Clásica 1 kg” from a local market. A range of 7 different concentrations was studied (**Tab.7**). For example, in the first stage, 0.1 % solution means that 1 g of salt was dissolved in 999 g of water.

Table 7: different concentration worked with.

Stage	Concentration (%)
1	0.1
2	0.5
3	1.5
4	2.5
5	3.5
6	6
7	8.5

Melting chamber

The melting chamber has built-in incandescent bulb, metallic mesh, plastic funnel and wire. It is a square-shaped metallic support that only can be opened from the front part, this way is easier to maintain the internal temperature (**Fig. 6**).



Figure 6: melting chamber.

Precision balance KERN Model KB 1200-2N (Fig. 7)

Maximum weight: 1210 g
Accuracy: 0.01 g



Figure 7: precision balance.

Refractometer ATAGO Model PAL-3 (Fig. 8)

Measurement range: Brix 0.0 to 93.0 % - Temperature 10.0 to 100.0 °C
Measurement accuracy: Brix ± 0.1 %
Resolution: °Brix 0.1 %
Ambient temperature: 10 to 40 °C
Calibration: distilled water
Measurement time: 3 seconds
Sample volume: 0.3 ml



Figure 8: refractometer.

Conductivity meter (Fig. 9)

Resolution: 0.1°C between -99.9 to 199.99 °C
Conductivity: $\leq 0.5\%$ v.w.
Salinity: $\leq 2\%$ v.w.
Reference temperature: 20 – 25 °C, with automatic temperature compensation
Calibration: standard solutions



Figure 9: conductivity meter.

Power meter REVALCO single-phase 1RCEM1 (Fig. 10)

Nominal current (I_n): 5 A

Maximum current ($I_{m\acute{a}x}$): 30 A

Operating frequency: 50-60 Hz



Figure 10: power meter.

3.3 METHOD

Once obtained the ice layers of different concentrations, the central part is cut into a rectangle, weighed and then placed in the melting chamber in order to obtain 10 fractions approximately same weight. The camera is programmed so that the temperature is $20\pm 1^\circ\text{C}$.

When the liquid fractions were obtained, it took place the measure of salinity (mg/l) and conductivity (mS/cm)

As for each concentration was prepared three solutions to obtain a representative result and due to they are 7 different concentrations, 21 different samples are obtained.

3.3.1 Sample acquisition

Ice layers were obtained from a freeze concentrator with falling-film technique. The equipment used is cryoconcentrator (**Fig. 11**).

The solution to be concentrated had 800 g.

The salt solution flows in a descending film over the cooling plates and it was collected in a collector tank (6) and re-circulated by a peristaltic pump (7).

The cooling fluid circulated continuously inside the cooling plate (3), in this case, ethylene glycol – water 50 % (w/w). The temperature of the fluid was controlled by the thermostatic bath adjusted to -20°C (2).

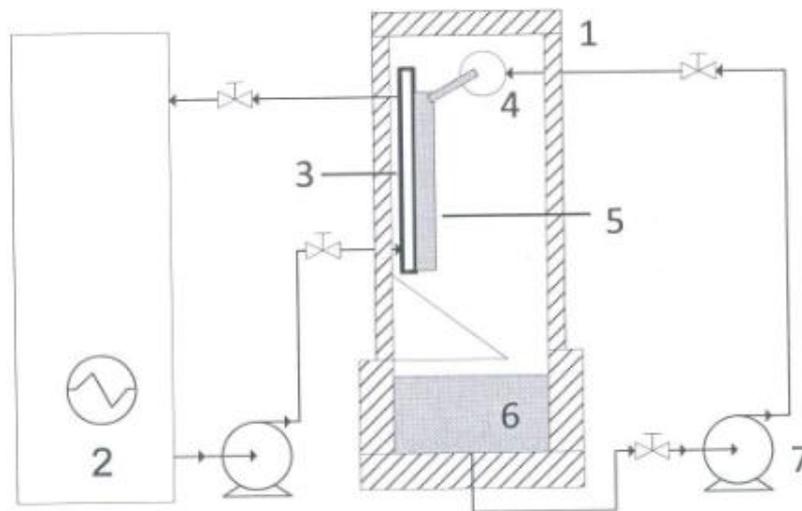


Figure 11: diagram of the falling film cryoconcentrator. (1) Chamber; (2) cooling bath; (3) cooling plate; (4) distribution duct; (5) ice layer; (6) collector vessel; (7) pump. **Source:** Moreno 2014

Due to the large size of ice layers, there was a need to take small test samples from the IL. The samples for the fractioned thawing were taken from the IL. They were manually operated and cut into shape rectangle from the center of the layer as it is shown in **Fig. 12**. As an average, the samples to thaw weighed 90 g, but the weight wasn't constant for each repetition; thus, every time it was divided the total weight into 10 to get an equal weight in each fraction.



Figure 12: obtaining of the test sample to thaw.

The reason why small test samples were taken is because it was not feasible to perform the thawing with the whole ice layer because when it was removed from the surface of the cryoconcentrator, it breaks.

3.3.2 Solutes recovery by fractioned thawing

Fractioned thawing is performed with the small test of ice layers obtained with the falling-film cryoconcentrator.

The thawing is carried out following the method described by Gulfo (2014) in the melting chamber (**Fig. 13**).

Melting chamber is a cubic box of 0.48 m of edge and a temperature system control (Pie Electro Dit, model 11 551 0-300 W). The thawing temperature was 20 ± 1 °C.

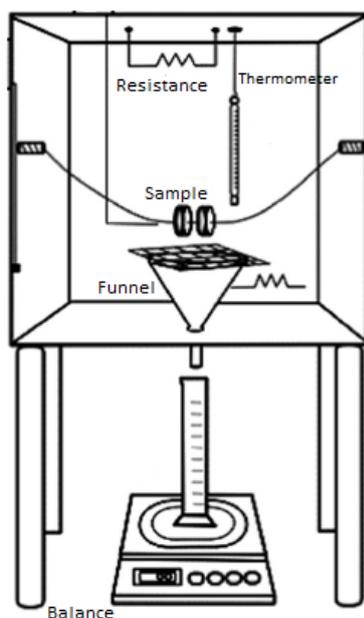


Figure 13: experimental design of fractional thawing. **Source:** Adapted from Gulfo 2014.

The sample to be thawed is placed on the top of the mesh, where it connects directly with the plastic funnel through which pass the melted drops. These are collected in a beaker which is put above the balance to control the weight of each fraction. The procedure is shown in **Fig. 14**.

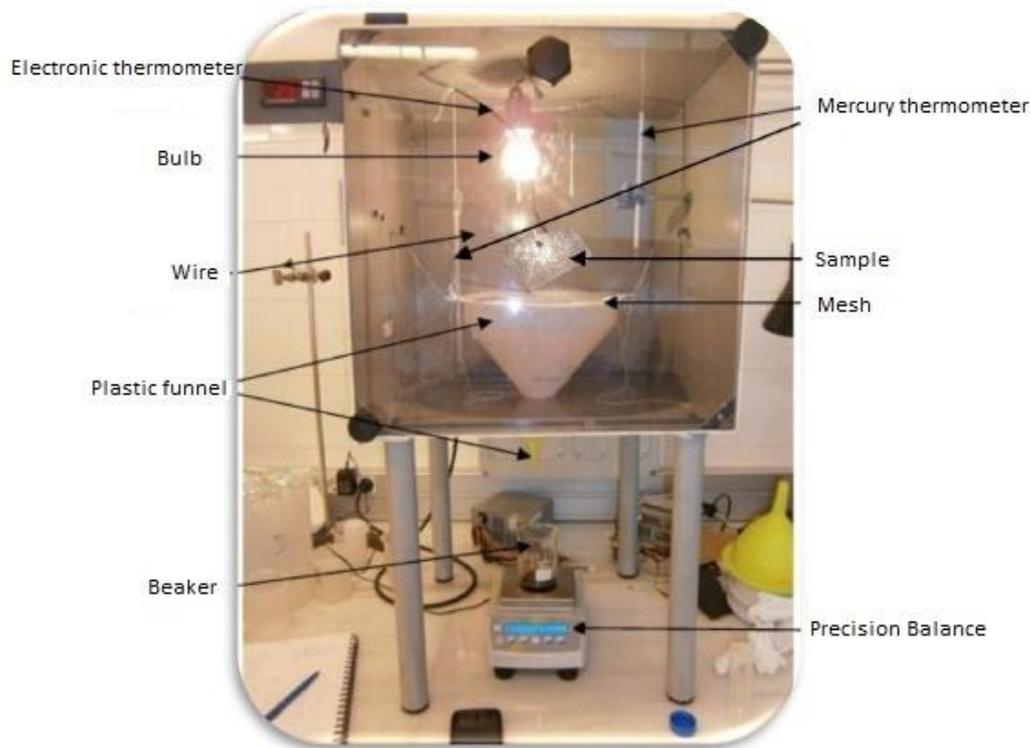


Figure 14: melting chamber and melted drops collection. **Source:** Adapted from Font 2013.

3.3.3 Calibration curves

Calibration is defined by ISO 25 as: “set of operations that establish, under certain experimental conditions the relationship between the values indicated by the measuring device or measuring system, or values represented by a material measure, with the values obtained in the measurement of a known value”.

To elaborate the calibration curve, they were prepared different solutions of salt and water at concentrations such as 0.1%, 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 8.5%, 13.5%, where were measured salinity and conductivity with the aim of obtaining the curve, that subsequently is used to determine the mass of the solution after thawing.

The curves obtained refer to salinity and conductivity versus the salt concentration. They are used to determine later the concentration of salt that are in the thawed fraction (**Fig. 15**).

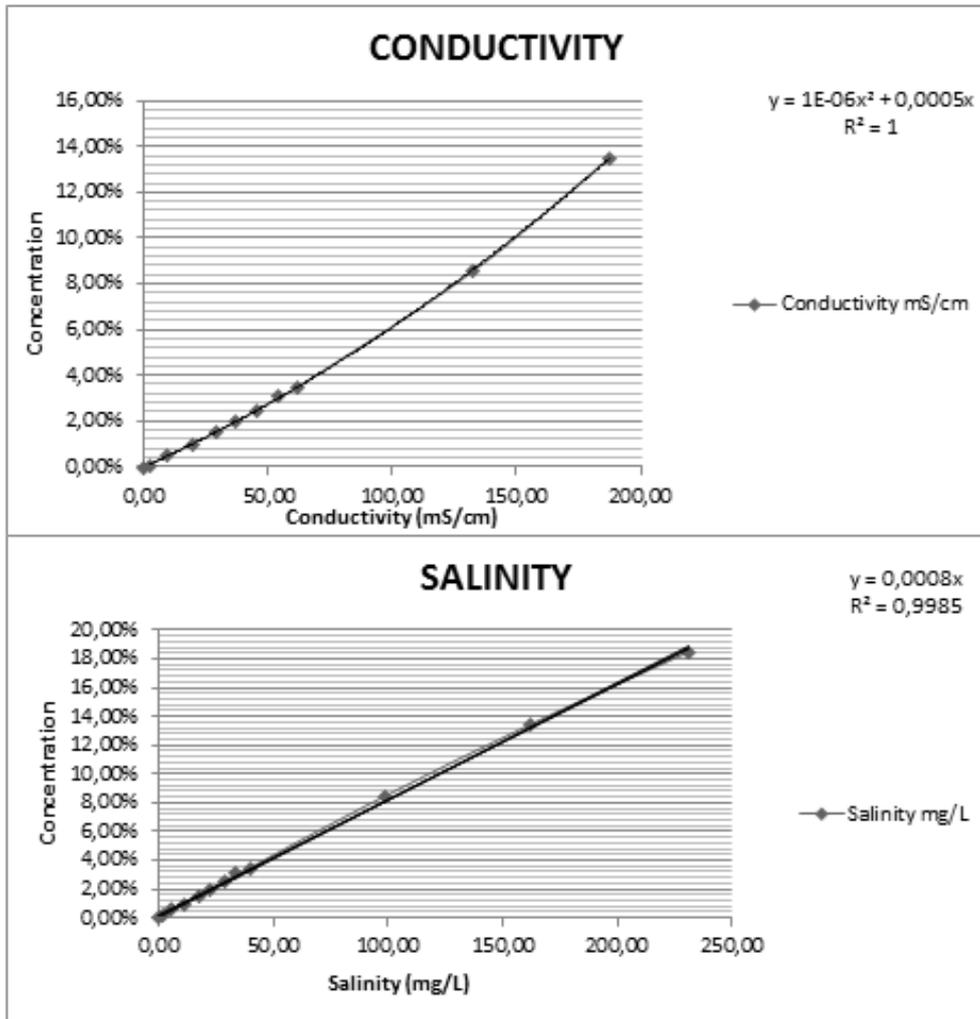


Figure 15: calibration curve of conductivity and salinity.

3.4 DATA ANALYSIS

The different parameters analyzed are:

Concentration Index (CI): relationship between the solid concentration in the thawed liquid fraction and the solid concentration in the initial solution.

$$CI = \frac{X_{slq}}{X_{so}} \quad (3-1)$$

where:

CI: concentration index

X_{slq} : conductivity of each fraction (mS/cm)

X_{so} : conductivity of original solution (concentrated liquid) (mS/cm)

Solute Yield (Y): relationship between mass of the solute present in the separated liquid and the mass of solute present initially in the original solution.

$$Y = \frac{m_{slq}}{m_{so}} \quad (3-2)$$

where:

Y: solute yield

m_{slq} : solute mass in the thawed liquid fraction (g)

m_{so} : initial solute mass (g)

Thawing kinetic (K): ratio between the mass of fractions that are concentrated between the times that take to thaw.

$$K = \frac{\sum m}{\sum t_t} \quad (3-3)$$

where:

V: thawing velocity

$\sum m$: sum of the mass of fractions with IC > 1 (g)

$\sum t_t$: sum of the thawing time of fractions with IC > 1 (min)

4 RESULTS AND DISCUSSION

4.1 Concentration Index

The concentration index expresses concentration of solutes reached after the FC process. In such way, it can be known the scope of the recovery.

IC lower than 1 indicated the obtainment of a diluted fraction, which means, that can reach a complete recovery.

It was calculated with equation 3-1.

The results of the second concentration, 0.5 % in this case, were discarded due to the high values of conductivity and salinity which are considered unfavorable results and for this reason, in all parameters are not taken into account the second stage.

The behavior of the first stage, 0.1 %, is shown in **Fig. 16**.

At the 0.1 % solution is presented a strange case. In the first fifth fractions, the concentration index had a different development being higher than 1 in the fraction 1, 3 and 5, and lower in fraction 2 and 4. From the sixth fraction the IC was established being < 1 .

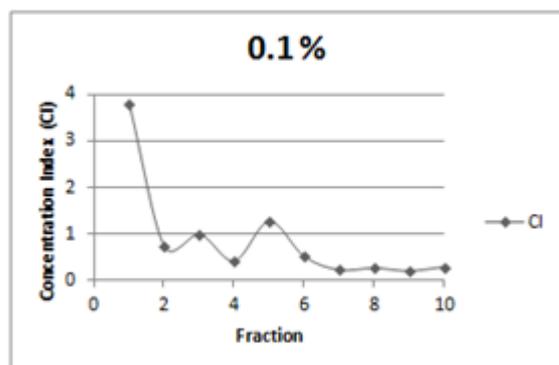


Figure 16: profile of concentration index in salt solution of 0.1 % .

Results of 1.5 % and 2.5 % concentration can be seen in **Fig. 17**.

Both stages are pretty similar. The concentration index started being < 1 in the fraction 5; therefore there was freeze concentration until the fourth fraction.

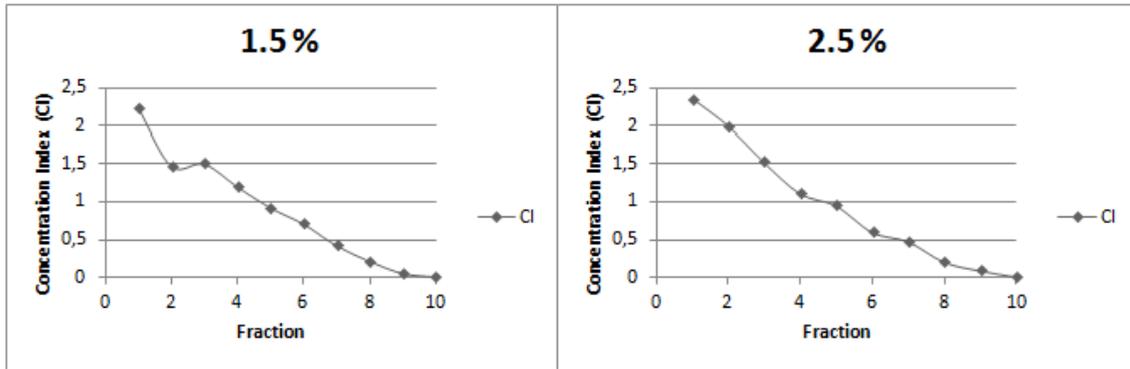


Figure 17: profile of concentration index in salt solution of 1.5 % and 2.5 %.

The results of the concentration 3.5 % (Fig. 18) show that CI decreased during the thawing process. Until the fifth fraction there was freeze concentration of the 50% of the total mass because $CI > 1$ until the fraction 5. This stage is especially important because is considered that seawater has a concentration of 3.5 % of dissolved minerals salts, therefore, results can indicate an approximate conduct of seawater in the process of freeze concentration by a falling-film technique.

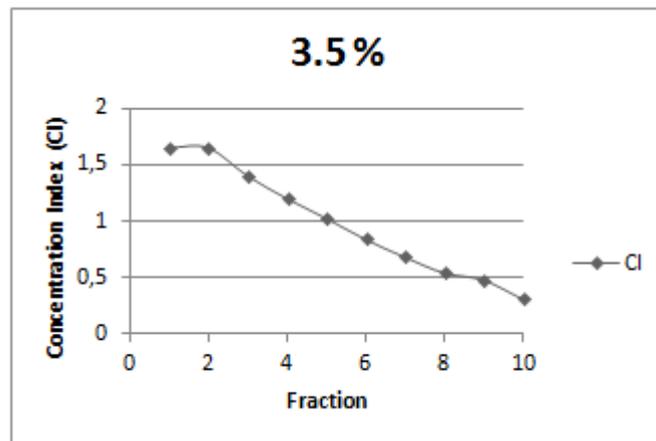


Figure 18: profile of concentration index in salt solution of 3.5 %.

6 % and 8.5 % concentration (Fig. 19) had a related conduct along the thawing process. The CI is < 1 from the fifth fraction, which means even if the initial concentration has increased; the behavior went on the same way and it would be needed thawing around the 40 % of the ice to recover the majority of the retained solutes.

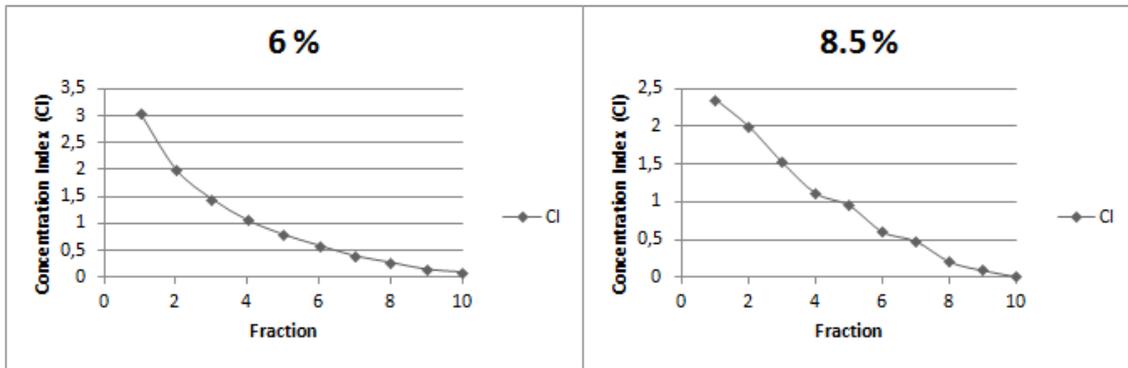


Figure 19: profile of concentration index in salt solution of 6 % and 8.5 %.

The effect of different concentrations of salt in a generic way is shown in **Fig. 20**.

The CI at the first fractions had values higher than 1 and decreased through the melting, which implies, that concentrated extract was compiled in the earlier fractions, as reported similar conduct Moreno et al. (2014); Miyawaki et al. (2012) and Yee et al. (2003) in previous studies. There is no clear trend in the values obtained in relation to the concentration index and the initial concentration of the solution, besides that in the first fractions, is where are the highest quantity of retained solutes.

In the first fraction of 0.1 % solution, it could be obtained more than 3.5 times concentrated salt solution. Yee et al., (2003), stated similar behavior in sodium chloride solution.

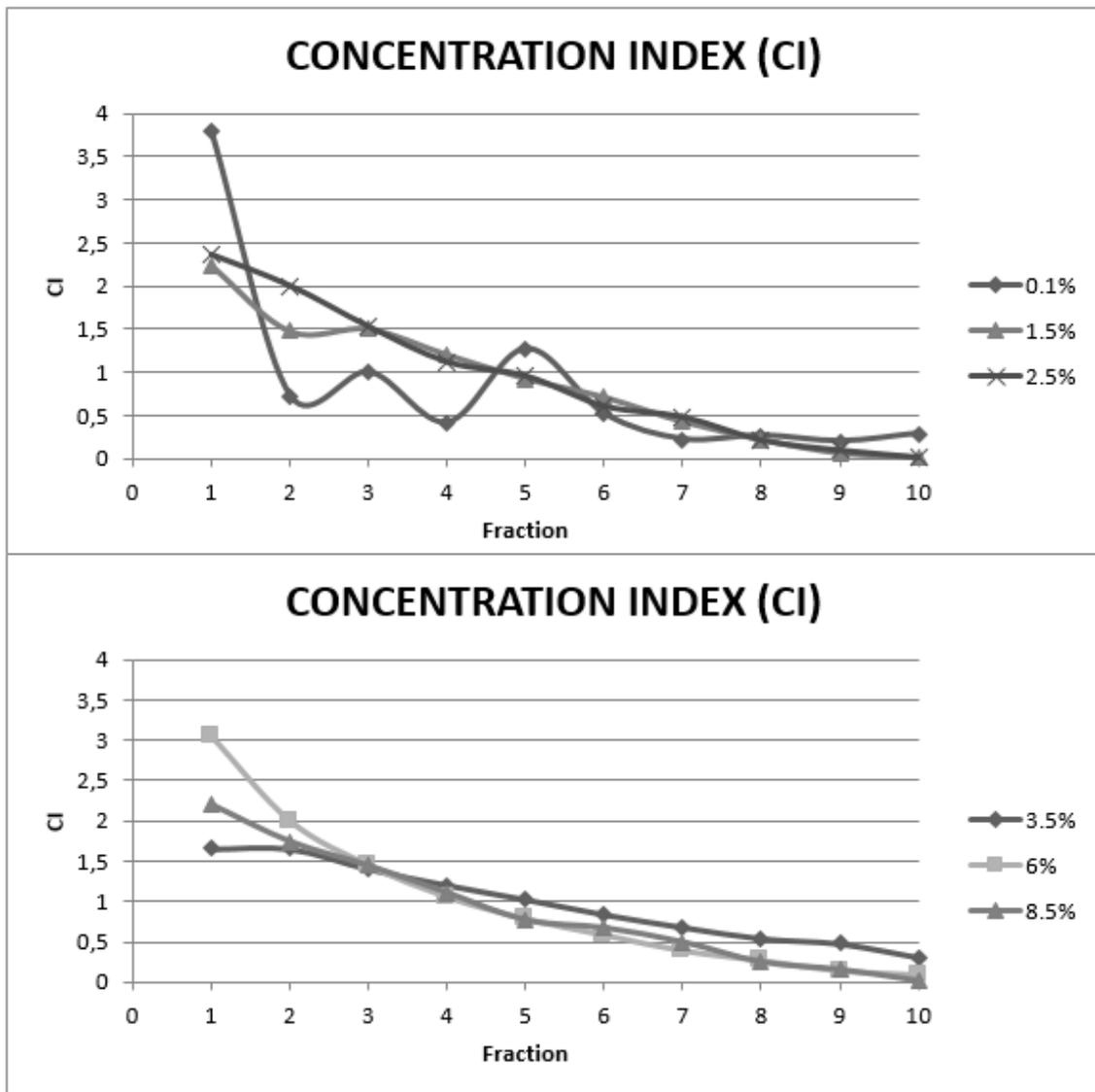


Figure 20: profile of concentration index after freezing and thawing different concentration of salt solution.

The fact that solid concentration in the earlier concentrations was higher than the others probably would be due to two occurrences; on one hand, the external faces in contact with the cold surface had a higher quantity of retained solutes as a consequence of the supercooling temperatures (Scholz et al., 1993; Moreno et al., 2014); and the faces in contact with the solution, the effect is due to the contact between ice-solution as is illustrated in **Fig. 21**. Supercooling effect can be reduced by planting seed crystal; however, to diminish the occlusion in the face in contact with the solution, it could be washed with pure water or the same solution.

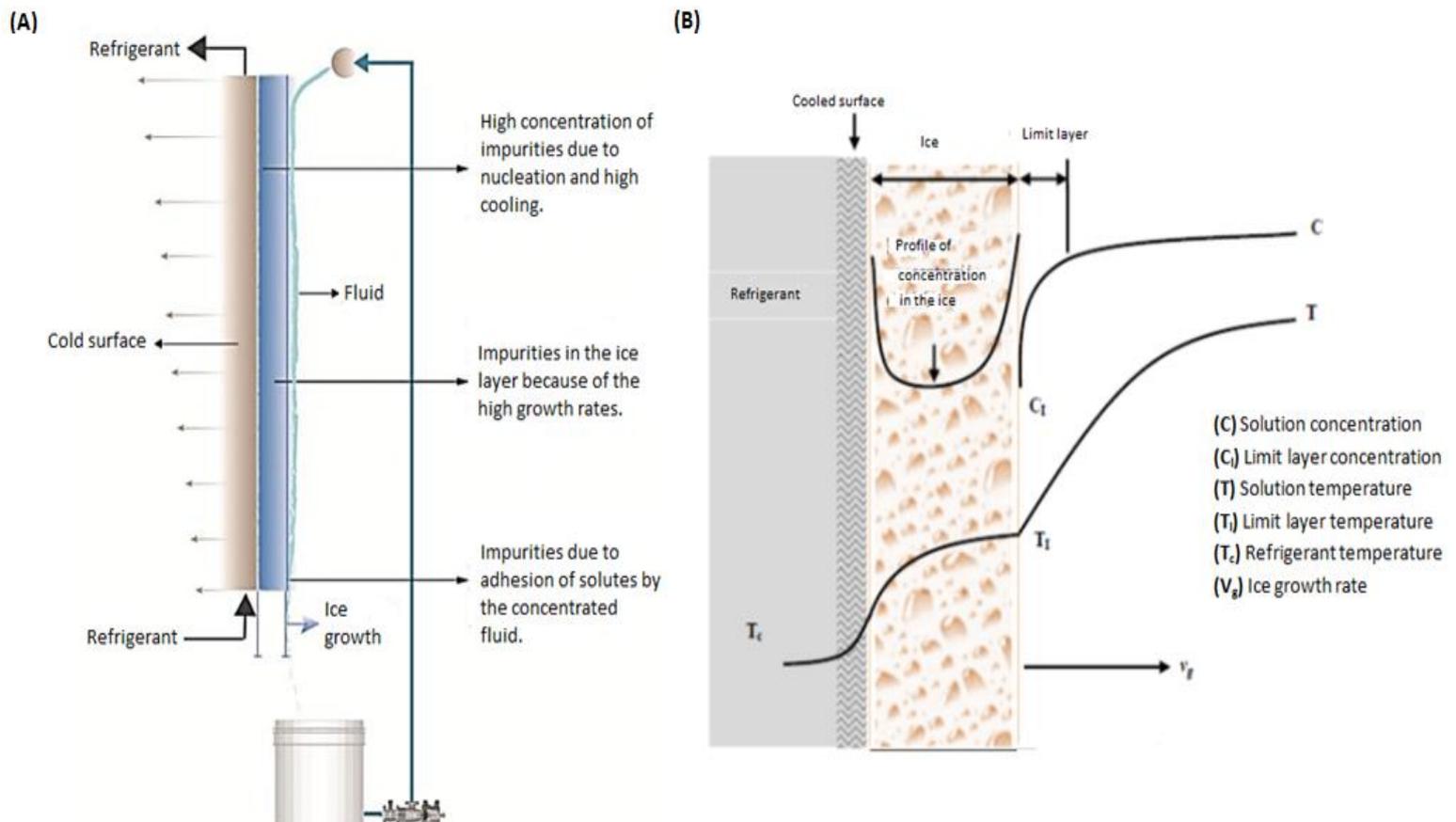


Figure 21: (A) Solutes inclusion in the ice. (B) Temperature and concentration in the ice layer profiles. **Source:** adapted from Gulfo 2014.

On the other hand, there was diffusion of solutes occluded in the ice to the thawed drops (Nakagawa et al., 2009; Moreno et al., 2014). The concentrated fraction that rest trapped in the ice crystals can move in freeway and get separated when the ice is partially thawed. This phenomenon is called sweating, which involves, heating the solid layer without contact with the melt up to temperatures lower than the thawing temperature of the solid for a desired time (Guardani et al., 2001; Moreno et al., 2014).

4.2 Solute yield

Solute yield is a parameter useful to analyze the solute recovery. It represents the recovered quantity of salt of the original solution.

The solute yield throughout the thawing at the different concentrations is shown in **Fig. 22**. The results range between 0 and 1, where, results of 1 mean that the effectiveness of the process is complete.

Solute yield indicated a similar behavior at the different stages, where at the last fractions values were close to 1, which means that, at the final fractions, pure water was recovered and as the majority of occluded solutes were at first fractions, the solute yield was lower for these. As it can be seen in the results, it can be said that almost there is no relation between the initial solution and the solute yield.

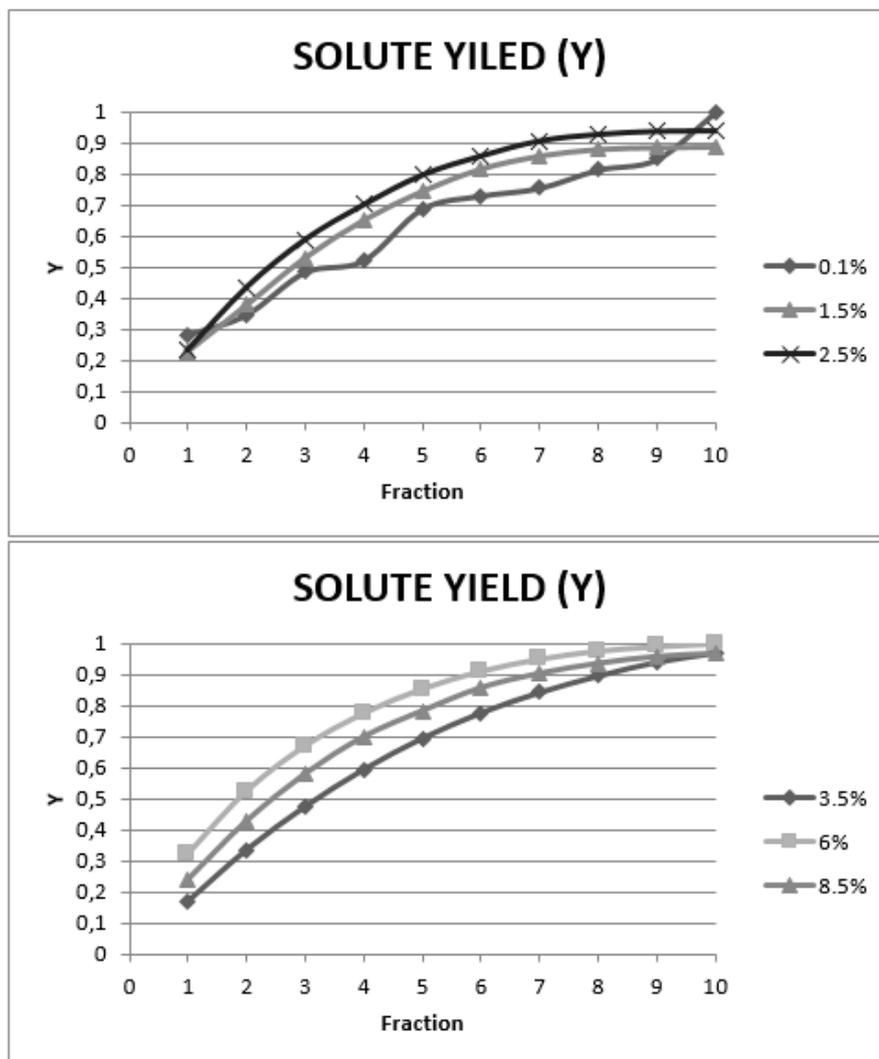


Figure 22: profile of solute yield after freezing and thawing different concentration of salt solution.

4.3 Thawing kinetic

Thawing kinetic is a parameter that expresses what is being concentrated along the time, which means, those fractions where the concentration index was higher than 1.

The results obtained are shown in **Fig. 23**.

The results of 0.1 % solution were not taken into account because the value was too low and as in other parameters the results were unexpected.

The velocity increased from concentration 1.5 % to 6 %.

So, as a general trend, velocity increased as there was an augmentation in the initial concentration. Yee et al., (2003) stated that the thawing rate, which was expressed in ml/min, was determined by the slope ($\Delta X/\Delta Y$) of the plot for sample cumulative volume versus time, where were determined the same behavior of the augmentation as long as the concentration. A higher initial concentration means a greater occlusion of solutes in the ice and a less rigid structure of the ice. Solute prevent water molecules interact with each other.

However, at the 8.5 % solution, kinetic decreased and it is a consequence of the increment of viscosity of the fluid and the decrease of the freezing point, and taking into account that at higher levels of concentration it wasn't possible to obtain results. There was attempt on working with concentration such as 11 %, 13.5 % and 18 %. For the first two, the formation of the ice sheet took more much time than the previous ones and even though the results weren't good enough due to the thickness of the layer and there was no way to perform the melting process. On the other hand, at 18.5 % even if the freeze concentration process took long time there wasn't a formation of the ice layer.

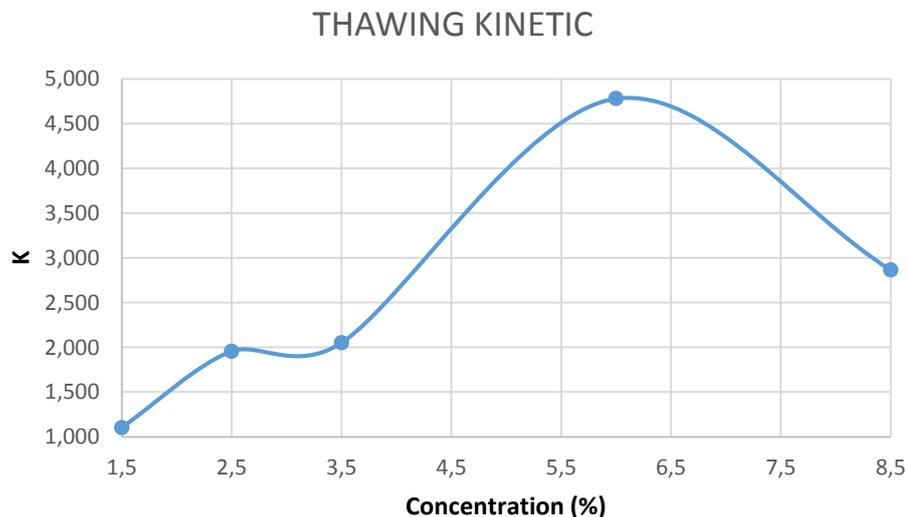


Figure 23: thawing kinetic of different concentration of salt solutions.

4.4 Power consumption

Power consumption was measured for the three repetitions of each stage, taking into account the consumption of the thermostatic bath and peristaltic pump in kilowatts-hours by kilogram of ice formed (kWh/ kg ice).

The power consumption augmented as the initial concentration increased.

The increment between the second and the fourth stage is small due to little difference of the concentrations, however in the last two concentrations is seen a notorious increase because of the time that took the formation of ice sheet was twice as long.

In reference to the first concentration, 0.1 %, the consumption was 1.11 kWh/ kg ice formed, which means, higher than the 0.5 %. This is because as with other parameters, results of the first concentration were strange not as it was expected.

In **Tab. 8** are shown the results.

Table 8: power consumption of freeze concentration.

Initial concentration (%)	Power consumption (kWh/ kg ice)	Time (min)
0.1	1.11	40
0.5	0.99	40
1.5	1.08	40
2.5	1.20	40
3.5	1.22	40
6	2.97	80
8.5	3.85	80

An increase of power consumption is highly probable because of two phenomena. First, the recirculation of the fluid implies the increase of viscosity and the head loss which mainly affect the mass transfer so, therefore an increment of consumption, and secondly, the high level of concentration involves the decrease of the freezing point, which impact on heat transfer.

The heat transfer in the plate in a steady regime is governed by an application of Fourier's law, defined by the following equation:

$$Q = k \cdot S \cdot \Delta T \quad (4-1)$$

where:

Q: thermal power (W)

K_t : thermal conductance (W/K·m²)

S: area (m²)

ΔT : $T_s - T_R$, where T_s is the solution temperature and T_R the refrigerant temperature (K)

When the freeze concentration process progresses, the solution temperature and the freezing point decreased; considering that the T_R , K and S are constant, ΔT decreased and therefore also the thermal power (Q).

335 kJ/kg is the thermal energy (E) required to form 1 kg of ice.

As the thermal energy is the product of thermal power (Q) per time, if Q decreases, the time have to augment, which means, that ice formation will require more time and subsequently there is an increase in electric energy consumption.

Williams et al., (2013) reported similar behavior in NaCl solutions, whereas the concentration increases so does the energy consumption. For concentrations such as 0.5 %, 3.5 % and 7 % of NaCl solutions, the results were 0.43, 0.45 and 0.51 kWh/kg respectively.

Comparing the results of 0.5 % and 3.5 %, Williams et al., presented values lower than the obtained in the current study.

5 CONCLUSIONS

1. The results of the first concentration, 0.1 % solution, had an unexpected behavior compared with the bibliography consulted due to the equipment start-up and the tempering. Also, the 0.5 % solution, had higher values than expected.
2. Concentration index, determined that was freeze concentration of retained solutes during the thawing of 40 – 50 % of the total mass, which means, that concentrated extract was collected in the earlier fractions.
3. Solute Yield, had values ≈ 1 at last fractions of thawing, thus, pure water was recovered.
4. Thawing kinetic at the initial concentrations, between 1.5 % and 6 %, increased as a consequence of the increment of initial concentration. Although at 8.5 % diminished because of the augmentation of viscosity of the fluid and the decrease of the freezing point.
5. Power consumption increased as there was an augmentation in the initial concentration, where from 0.5 % to 3.5% solution increased from 0.99 to 1.22 kWh/kg ice, however; the change was more noticeable when there was an augmentation in time too, as in the case of the last two fractions; 6 % and 8.5 %, where were obtained values of 2.97 and 3.85 kWh/kg ice respectively.

6 RECOMMENDATIONS

1. Improve the part of the melted drops collection with the aim of being more rigorous.
2. Establish a relation between the data obtained with refractometer and the concentration of salt.
3. Determine an efficient way to obtain the small test samples of ice layer to avoid losses.
4. Study the energetic costs and the economic viability of the process.
5. Statistical analysis of the data obtained to verify the accuracy of the results.



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ANNEXES.

EXPERIMENTAL DATA



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NOMENCLATURE

Con: conductivity (mS/cm)

CI: concentration index

Desv CI: standard deviation of concentration index

Y: solute yield

DesvSt: standard deviation

R1: repetition 1

R2: repetition 2

R3: repetition 3

V: thawing kinetic (g/min)

f: thawing fraction

m_{liq}: liquid mass of the ice (g)

m_{so}: initial mass of the solution (g)

CONCENTRATION INDEX

0.1 %									
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		Desv. CI
	Cond	CI	Cond	CI	Cond	CI	Cond	CI	
0	0.265	-	0.124	-	47.800	-	16.063	-	-
1	2.090	7.887	0.093	0.747	0.388	2.730	0.857	3.788	3.686
2	0.124	0.466	0.034	0.128	19.760	1.587	6.639	0.727	0.764
3	0.037	0.139	0.495	1.868	15.750	1.005	5.427	1.004	0.865
4	0.069	0.261	0.017	0.063	12.180	0.930	4.089	0.418	0.454
5	0.023	0.085	0.742	2.800	6.630	0.935	2.465	1.273	1.389
6	0.038	0.144	0.102	0.386	8.220	1.017	2.787	0.516	0.451
7	0.032	0.120	0.008	0.030	9.390	0.524	3.143	0.225	0.263
8	0.037	0.139	0.018	0.066	23.800	0.600	7.952	0.268	0.290
9	0.032	0.121	0.055	0.209	9.350	0.277	3.146	0.202	0.078
10	0.102	0.386	0.072	0.272	49.500	0.219	16.558	0.292	0.085

0.5 %									
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		Desv. CI
	Cond	CI	Cond	CI	Cond	CI	Cond	CI	
0	143.800	-	128.400	-	218.000	-	163.400	-	-
1	247.000	1.727	234.000	1.764	584.000	2.730	355.000	2.074	0.790
2	186.400	1.299	210.000	1.580	335.000	1.587	243.800	1.489	0.299
3	179.300	1.273	173.900	1.291	215.000	1.005	189.400	1.190	0.287
4	180.500	1.258	157.100	1.159	196.200	0.930	177.933	1.116	0.346
5	192.200	1.341	147.400	1.075	203.000	0.935	180.867	1.117	0.429
6	178.700	1.245	138.000	1.004	222.000	1.017	179.567	1.089	0.431
7	114.700	0.795	128.400	0.784	115.300	0.524	119.467	0.701	0.302
8	70.100	0.485	234.000	0.514	131.700	0.600	145.267	0.533	0.363
9	38.200	0.263	210.000	0.483	60.400	0.277	102.867	0.341	0.219
10	23.200	0.159	173.900	0.346	47.900	0.219	81.667	0.241	0.253



1.5 %									
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		Desv. IC
	Cond	CI	Cond	CI	Cond	CI	Cond	CI	
0	8.090	-	8.730	-	9.510	-	8.777	-	-
1	14.620	1.807	22.300	2.554	22.500	2.366	19.807	2.243	0.389
2	14.970	1.850	13.500	1.546	9.850	1.036	12.773	1.478	0.412
3	13.440	1.661	11.070	1.268	15.070	1.585	13.193	1.505	0.208
4	12.190	1.507	11.050	1.266	8.000	0.841	10.413	1.205	0.337
5	8.000	0.989	6.540	0.749	9.910	1.042	8.150	0.927	0.156
6	6.300	0.779	4.570	0.523	7.920	0.833	6.263	0.712	0.165
7	3.260	0.403	2.720	0.312	5.350	0.563	3.777	0.426	0.127
8	1.471	0.182	1.092	0.125	3.340	0.351	1.968	0.219	0.118
9	0.045	0.006	0.319	0.037	1.348	0.142	0.571	0.061	0.071
10	0.166	0.020	0.033	0.004	0.153	0.016	0.117	0.013	0.009

2.5 %									
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		Desv. CI
	Cond	CI	Con	CI	Cond	CI	Cond	CI	
0	15.210	-	16.890	-	18.310	-	16.803	-	-
1	29.300	2.059	34.700	2.162	47.300	2.860	37.100	2.360	0.436
2	30.300	2.138	32.300	1.983	32.400	1.879	31.667	2.000	0.130
3	22.800	1.557	30.400	1.860	21.100	1.168	24.767	1.528	0.347
4	8.130	0.514	28.100	1.701	20.600	1.138	18.943	1.118	0.594
5	13.330	0.868	18.390	1.043	17.610	0.958	16.443	0.956	0.088
6	10.580	0.681	10.510	0.549	11.240	0.592	10.777	0.607	0.067
7	7.770	0.491	3.030	0.554	7.830	0.403	6.210	0.482	0.076
8	4.310	0.264	3.560	0.137	4.670	0.235	4.180	0.212	0.066
9	1.456	0.085	1.173	0.006	3.950	0.196	2.193	0.096	0.095
10	0.088	0.005	0.102	0.005	0.706	0.033	0.299	0.014	0.016

3.5 %									
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		Desv. CI
	Cond	CI	Cond	CI	Cond	CI	Cond	CI	CI
0	24.500	-	22.500	-	21.300	-	22.767	-	-
1	39.500	1.612	35.900	1.596	36.300	1.753	37.233	1.654	0.087
2	42.200	1.722	34.500	1.533	35.400	1.707	37.367	1.654	0.105
3	34.300	1.400	31.800	1.413	29.400	1.402	31.833	1.405	0.007
4	28.100	1.147	26.900	1.196	26.800	1.271	27.267	1.205	0.063
5	23.900	0.976	22.300	0.991	23.700	1.118	23.300	1.028	0.078
6	20.100	0.820	18.220	0.810	19.150	0.895	19.157	0.842	0.047
7	16.480	0.673	15.300	0.680	15.070	0.699	15.617	0.684	0.014
8	12.710	0.519	11.380	0.506	13.230	0.612	12.440	0.545	0.058
9	10.370	0.423	9.370	0.416	12.980	0.600	10.907	0.480	0.104
10	6.140	0.251	6.150	0.273	8.950	0.410	7.080	0.311	0.086

6 %									
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		Desv. CI
	Cond	CI	Cond	CI	Cond	CI	Cond	CI	CI
0	17.490	-	28.400	-	26.300	-	24.063	-	-
1	92.200	3.487	95.900	3.377	62.900	2.309	83.667	3.058	0.651
2	63.400	2.281	55.500	1.954	47.900	1.775	55.600	2.004	0.256
3	42.300	1.465	40.300	1.419	39.100	1.474	40.567	1.453	0.030
4	32.800	1.116	30.300	1.067	24.300	0.989	29.133	1.057	0.064
5	20.800	0.692	21.100	0.743	22.300	0.925	21.400	0.787	0.123
6	14.920	0.491	14.010	0.493	17.400	0.771	15.443	0.585	0.161
7	9.330	0.303	8.290	0.292	11.070	0.576	9.563	0.390	0.161
8	4.790	0.154	4.770	0.168	8.040	0.484	5.867	0.269	0.187
9	0.174	0.006	1.565	0.055	4.060	0.366	1.933	0.142	0.195
10	0.052	0.002	0.059	0.002	0.766	0.269	0.292	0.091	0.154



8.5 %									
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		Desv. CI
	Cond	CI	Cond	CI	Cond	CI	Cond	CI	CI
0	6.980	-	37.300	-	44.800	-	29.693	-	-
1	19.030	2.726	76.600	1.627	99.900	2.230	65.177	2.195	0.550
2	15.230	2.182	60.700	1.316	77.000	1.719	50.977	1.739	0.433
3	11.090	1.589	49.100	1.155	70.900	1.583	43.697	1.442	0.248
4	8.600	1.232	43.100	0.944	51.400	1.147	34.367	1.108	0.148
5	6.950	0.996	35.200	0.753	25.200	0.563	22.450	0.771	0.217
6	4.910	0.703	28.100	0.558	34.300	0.766	22.437	0.676	0.107
7	3.610	0.517	20.800	0.657	14.580	0.325	12.997	0.500	0.166
8	0.044	0.006	24.500	0.431	14.530	0.324	13.025	0.254	0.221
9	0.023	0.003	16.060	0.268	9.670	0.216	8.584	0.162	0.140
10	0.013	0.002	10.000	0.000	2.810	0.063	4.274	0.022	0.036

INDEX CONCENTRATION (mean)							
Fraction	Concentration						
	0.1 %	0.5 %	1.5 %	2.5 %	3.5 %	6 %	8.5%
1	3.788	2.074	2.243	2.360	1.654	3.058	2.195
2	0.727	1.489	1.478	2.000	1.654	2.004	1.739
3	1.004	1.190	1.505	1.528	1.405	1.453	1.442
4	0.418	1.116	1.205	1.118	1.205	1.057	1.108
5	1.273	1.117	0.927	0.956	1.028	0.787	0.771
6	0.516	1.089	0.712	0.607	0.842	0.585	0.676
7	0.225	0.701	0.426	0.482	0.684	0.390	0.500
8	0.268	0.533	0.219	0.212	0.545	0.269	0.254
9	0.202	0.341	0.061	0.096	0.480	0.142	0.162
10	0.292	0.241	0.013	0.014	0.311	0.091	0.022

SOLUTE YIELD

0.1 %										
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		DesvSt.	DesvSt.
	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y
0	0.012	0.000	0.007	0.000	0.008	0.000	0.009	0.000	0.003	0.000
1	0.010	0.792	0.000	0.056	0.000	0.002	0.003	0.283	0.006	0.441
2	0.001	0.838	0.000	0.077	0.001	0.127	0.001	0.347	0.000	0.426
3	0.000	0.852	0.002	0.376	0.001	0.225	0.001	0.484	0.001	0.327
4	0.000	0.878	0.000	0.387	0.001	0.301	0.000	0.522	0.000	0.312
5	0.000	0.887	0.003	0.836	0.000	0.341	0.001	0.688	0.002	0.301
6	0.000	0.901	0.000	0.898	0.000	0.392	0.000	0.730	0.000	0.293
7	0.000	0.913	0.000	0.903	0.000	0.450	0.000	0.755	0.000	0.265
8	0.000	0.927	0.000	0.914	0.001	0.601	0.000	0.814	0.001	0.185
9	0.000	0.939	0.000	0.947	0.000	0.658	0.000	0.848	0.000	0.164
10	0.000	0.978	0.000	0.991	0.003	0.988	0.001	1.000	0.001	0.007

0.5 %										
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		DesvSt.	DesvSt.
	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y
0	0.572	0.000	0.774	0.000	0.625	0.000	6.570	0.000	0.105	0.000
1	0.099	0.173	0.142	0.176	0.171	0.273	1.370	0.207	0.036	0.079
2	0.074	0.303	0.128	0.334	0.099	0.432	1.003	0.356	0.027	0.109
3	0.073	0.430	0.105	0.464	0.063	0.532	0.802	0.475	0.022	0.124
4	0.072	0.556	0.095	0.579	0.058	0.625	0.750	0.587	0.019	0.147
5	0.077	0.690	0.088	0.687	0.058	0.719	0.745	0.698	0.015	0.181
6	0.071	0.814	0.083	0.787	0.064	0.820	0.725	0.807	0.010	0.222
7	0.045	0.894	0.066	0.866	0.033	0.873	0.480	0.877	0.017	0.250
8	0.028	0.942	0.045	0.917	0.038	0.933	0.367	0.931	0.009	0.285
9	0.015	0.969	0.043	0.965	0.017	0.961	0.249	0.965	0.015	0.307
10	0.009	0.984	0.032	1.000	0.014	0.982	0.018	0.989	0.012	0.332



1.5 %										
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		DesvSt.	DesvSt.
	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y
0	0.385	0.000	0.444	0.000	0.503	0.000	3.726	0.000	0.059	0.000
1	0.070	0.183	0.116	0.262	0.122	0.243	9.929	0.229	0.028	0.389
2	0.072	0.371	0.069	0.418	0.052	0.346	6.530	0.378	0.011	0.412
3	0.065	0.538	0.057	0.546	0.081	0.506	4.070	0.530	0.012	0.208
4	0.058	0.690	0.056	0.673	0.042	0.590	3.965	0.651	0.009	0.337
5	0.038	0.789	0.033	0.747	0.052	0.695	3.330	0.744	0.010	0.156
6	0.030	0.867	0.023	0.799	0.042	0.778	2.061	0.815	0.009	0.165
7	0.015	0.907	0.014	0.830	0.028	0.833	1.400	0.857	0.008	0.127
8	0.007	0.925	0.005	0.843	0.017	0.868	0.814	0.878	0.007	0.118
9	0.000	0.925	0.002	0.846	0.007	0.882	0.677	0.884	0.004	0.071
10	0.001	0.927	0.000	0.846	0.001	0.884	0.001	0.886	0.000	0.009

2.5 %										
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		DesvSt.	DesvSt.
	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y
0	0.604	0.000	0.723	0.000	0.838	0.000	9.427	0.000	0.117	0.000
1	0.124	0.206	0.156	0.216	0.240	0.286	22.499	0.236	0.059	0.436
2	0.129	0.420	0.143	0.414	0.157	0.474	18.772	0.436	0.014	0.130
3	0.094	0.575	0.134	0.601	0.098	0.591	14.292	0.589	0.022	0.347
4	0.031	0.627	0.123	0.771	0.095	0.705	10.745	0.701	0.047	0.594
5	0.052	0.714	0.075	0.875	0.080	0.800	9.045	0.796	0.015	0.088
6	0.041	0.782	0.040	0.930	0.050	0.860	5.695	0.857	0.005	0.067
7	0.030	0.831	0.040	0.985	0.034	0.900	4.522	0.905	0.005	0.076
8	0.016	0.857	0.010	0.999	0.020	0.923	1.987	0.926	0.005	0.066
9	0.005	0.866	0.000	0.999	0.016	0.943	0.937	0.936	0.008	0.095
10	0.000	0.866	0.000	1.000	0.003	0.946	0.001	0.937	0.001	0.016

3.5 %										
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		DesvSt.	DesvSt.
	1.206	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y
0	0.200	0.000	1.009	0.000	0.854	0.000	1.023	0.000	0.176	0.000
1	0.215	0.166	0.165	0.164	0.150	0.171	0.172	0.167	0.026	0.087
2	0.172	0.344	0.158	0.321	0.146	0.337	0.173	0.334	0.037	0.105
3	0.139	0.487	0.145	0.464	0.120	0.472	0.146	0.474	0.026	0.007
4	0.118	0.602	0.122	0.585	0.109	0.595	0.123	0.594	0.015	0.063
5	0.098	0.699	0.100	0.684	0.095	0.702	0.104	0.695	0.012	0.078
6	0.080	0.781	0.081	0.764	0.076	0.787	0.085	0.777	0.011	0.047
7	0.061	0.847	0.068	0.831	0.060	0.852	0.069	0.843	0.010	0.014
8	0.050	0.898	0.050	0.881	0.052	0.908	0.054	0.896	0.006	0.058
9	0.029	0.939	0.041	0.921	0.051	0.964	0.047	0.941	0.006	0.104
10	1.206	0.963	0.027	0.948	0.035	1.000	0.030	0.970	0.004	0.086

6 %										
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		DesvSt.	DesvSt.
	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y
0	0.751	0.000	1.319	0.000	1.217	0.000	1.096	0.000	0.303	0.000
1	0.453	0.349	0.502	0.380	0.251	0.231	0.402	0.320	0.133	0.651
2	0.297	0.577	0.271	0.584	0.186	0.408	0.251	0.523	0.058	0.256
3	0.190	0.723	0.191	0.728	0.149	0.556	0.177	0.669	0.024	0.030
4	0.145	0.835	0.141	0.834	0.090	0.655	0.126	0.775	0.031	0.064
5	0.090	0.904	0.097	0.907	0.083	0.747	0.090	0.853	0.007	0.123
6	0.064	0.953	0.063	0.954	0.064	0.824	0.064	0.910	0.000	0.161
7	0.039	0.983	0.037	0.981	0.040	0.882	0.039	0.949	0.002	0.161
8	0.020	0.999	0.021	0.996	0.029	0.930	0.023	0.975	0.005	0.187
9	0.001	0.999	0.007	1.000	0.015	0.967	0.007	0.989	0.007	0.195
10	0.000	1.000	0.000	1.000	0.003	0.994	0.001	0.998	0.001	0.154

8.5 %										
Fraction	Repetition 1		Repetition 2		Repetition 3		Mean		DesvSt.	DesvSt.
	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y	mass (g)	Y
0	0.171	0.000	1.081	0.000	1.305	0.000	0.852	0.000	0.600	0.000
1	0.047	0.273	0.238	0.220	0.300	0.230	0.195	0.241	0.132	0.550
2	0.037	0.491	0.184	0.390	0.230	0.406	0.150	0.429	0.100	0.433
3	0.027	0.650	0.145	0.525	0.211	0.568	0.128	0.581	0.093	0.248
4	0.021	0.773	0.126	0.642	0.152	0.685	0.100	0.700	0.069	0.148
5	0.017	0.872	0.102	0.736	0.074	0.742	0.064	0.783	0.043	0.217
6	0.012	0.942	0.080	0.810	0.101	0.819	0.064	0.857	0.046	0.107
7	0.009	0.994	0.058	0.864	0.043	0.852	0.037	0.903	0.025	0.166
8	0.000	0.995	0.069	0.928	0.042	0.884	0.037	0.935	0.035	0.221
9	0.000	0.995	0.045	0.969	0.028	0.906	0.024	0.957	0.023	0.140
10	0.000	0.995	0.027	0.995	0.008	0.912	0.012	0.967	0.014	0.036

SOLUTE YIELD (mean)							
Fraction	Concentration						
	0.1 %	0.5 %	1.5 %	2.5 %	3.5 %	6 %	8.5%
1	0.283	0.207	0.229	0.236	0.167	0.320	0.241
2	0.347	0.356	0.378	0.436	0.334	0.523	0.429
3	0.484	0.475	0.530	0.589	0.474	0.669	0.581
4	0.522	0.587	0.651	0.701	0.594	0.775	0.700
5	0.688	0.698	0.744	0.796	0.695	0.853	0.783
6	0.730	0.807	0.815	0.857	0.777	0.910	0.857
7	0.755	0.877	0.857	0.905	0.843	0.949	0.903
8	0.814	0.931	0.878	0.926	0.896	0.975	0.935
9	0.848	0.965	0.884	0.936	0.941	0.989	0.957
10	1.000	0.989	0.886	0.937	0.970	0.998	0.967

TIME

0.1 %			
Fraction	Repetition 1	Repetition 2	Repetition 3
	time	time	time
0	21:27:00	12:00:00	14:30:00
1	21:33:00	12:07:00	14:34:00
2	21:38:00	12:13:00	14:39:00
3	21:45:00	12:19:00	14:45:00
4	21:50:00	12:26:00	14:49:00
5	21:56:00	12:30:00	14:55:00
6	22:03:00	12:35:00	15:01:00
7	22:10:00	12:43:00	15:09:00
8	22:18:00	12:51:00	15:18:00
9	22:29:00	12:57:00	15:29:00
10	22:41:00	13:30:00	15:50:00
Total (min)	74	90	80

0.5 %			
Fraction	Repetition 1	Repetition 2	Repetition 3
	time	time	time
0	15:35:00	18:03:00	19:54:00
1	15:42:00	18:09:00	20:04:00
2	15:49:00	18:15:00	20:07:00
3	15:55:00	18:21:00	20:12:00
4	16:01:00	18:27:00	20:16:00
5	14:08:00	18:33:00	20:22:00
6	14:15:00	18:39:00	20:26:00
7	14:22:00	18:45:00	20:32:00
8	14:29:00	18:51:00	20:38:00
9	14:39:00	18:57:00	20:44:00
10	14:50:00	19:04:00	20:50:00
Total (min)	75	61	56

1.5 %			
Fraction	Repetition 1	Repetition 2	Repetition 3
	time	time	time
0	12:34:00	14:46:00	17:08:00
1	12:43:00	14:57:00	17:17:00
2	12:51:00	15:02:00	17:25:00
3	12:54:00	15:06:00	17:31:00
4	12:59:00	15:10:00	17:37:00
5	13:03:00	15:14:00	17:43:00
6	13:07:00	15:18:00	17:47:00
7	13:10:00	15:23:00	17:51:00
8	13:15:00	15:30:00	17:57:00
9	13:21:00	15:37:00	18:04:00
10	13:38:00	15:47:00	18:04:00
Total (min)	56	61	56

2.5 %			
Fraction	Repetition 1	Repetition 2	Repetition 3
	time	time	time
0	16:46:00	18:59:00	13:51:00
1	16:58:00	19:08:00	14:07:00
2	17:01:00	19:13:00	14:14:00
3	17:06:00	19:17:00	14:19:00
4	17:10:00	19:21:00	14:23:00
5	17:14:00	19:25:00	14:28:00
6	17:20:00	19:29:00	14:32:00
7	17:24:00	19:32:00	14:37:00
8	17:31:00	19:36:00	14:43:00
9	17:41:00	19:43:00	14:47:00
10	17:46:00	19:57:00	13:51:00
Total (min)	60	58	56

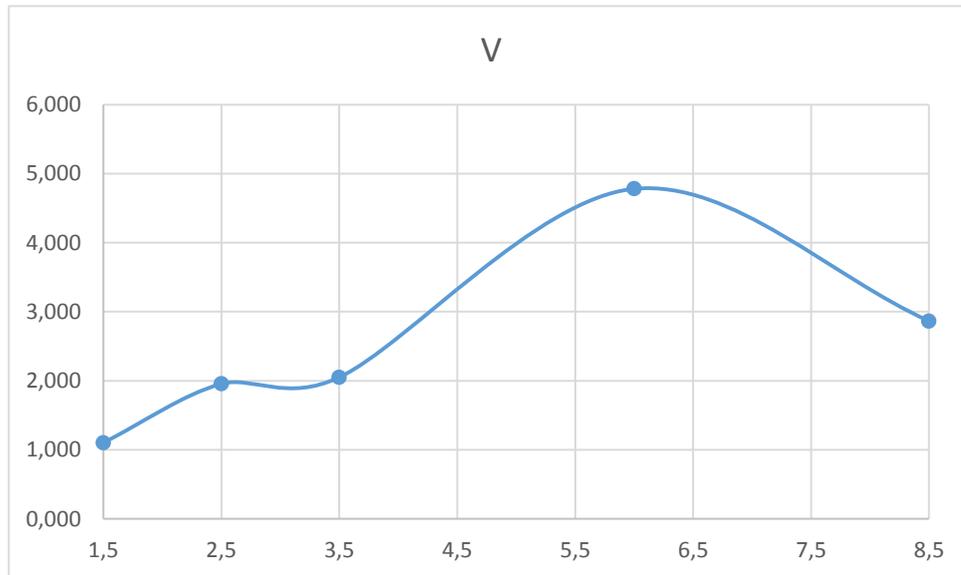
3.5 %			
Fraction	Repetition 1	Repetition 2	Repetition 3
	time	time	time
0	-	15:07:00	14:55
1	13:17:00	15:14:00	15:11
2	13:32:00	15:25:00	15:15
3	13:40:00	15:32:00	15:20
4	13:48:00	15:37:00	15:25
5	13:54:00	15:41:00	15:29
6	13:59:00	15:46:00	15:33
7	14:08:00	15:50:00	15:37
8	14:17:00	15:55:00	15:41
9	14:25:00	16:04:00	15:47
10	15:04:00	16:16:00	15:55
Total (min)	107	69	60

6 %			
Fraction	Repetition 1	Repetition 2	Repetition 3
	time	time	time
0	14:20:00	17:27:00	20:48:00
1	14:29:00	17:37:00	20:54:00
2	14:23:00	17:42:00	20:57:00
3	14:32:00	17:46:00	21:02:00
4	14:40:00	17:50:00	21:05:00
5	14:44:00	17:54:00	21:08:00
6	14:47:00	17:57:00	21:11:00
7	14:50:00	18:02:00	21:14:00
8	14:55:00	18:07:00	21:19:00
9	15:01:00	18:13:00	21:25:00
10	15:16:00	18:24:00	21:30:00
Total (min)	56	57	42

8.5 %			
Fraction	Repetition 1	Repetition 2	Repetition 3
	time	time	time
0	16:15:00	19:09:00	17:16:00
1	16:22:00	19:20:00	17:22:00
2	16:29:00	19:25:00	17:26:00
3	16:32:00	19:28:00	17:30:00
4	16:35:00	19:31:00	17:34:00
5	16:38:00	19:33:00	17:37:00
6	16:41:00	19:36:00	17:40:00
7	16:44:00	19:39:00	17:40:00
8	16:48:00	19:44:00	17:49:00
9	16:52:00	19:49:00	17:52:00
10	17:59:00	19:56:00	17:57:00
Total (min)	44	47	41

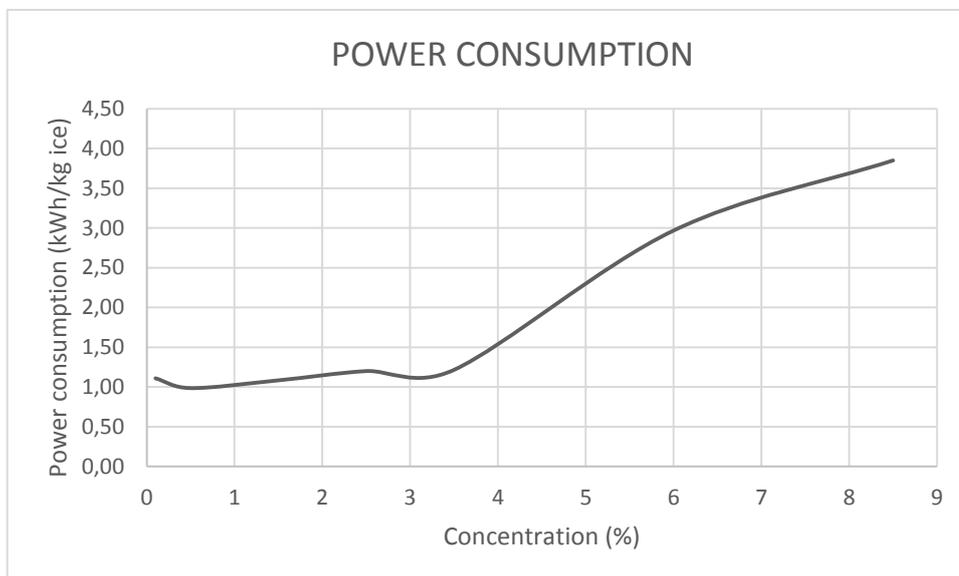
THAWING KINETIC

Fraction	time (h)				mass (g)				K (g/min)
	R1	R2	R3	Mean	R1	R2	R3	mean	
0.1 %	0.29	0.30	0.25	0.28	0.01	0,006	0.003	0.007	0.02
0.5 %	0.40	0.36	0.30	0.35	0.47	0.64	0.51	0.54	1.53
1.5 %	0.25	0.24	0.29	0.26	0.27	0.30	0.30	0.29	1.10
2.5 %	0.24	0.22	0.32	0.26	0.38	0.56	0.59	0.51	1.96
3.5 %	0.37	0.34	0.34	0.35	0.84	0.69	0.62	0.72	2.05
6 %	0.2	0.23	0.17	0.20	1.09	1.11	0.68	0.96	4.78
8.5%	0.2	0.22	0.18	0.20	0.13	0.69	0.89	0.57	2.87



POWER CONSUMPTION

Initial concentration (%)	Power consumption (kWh/ kg ice)	Time (min)
0.1	1.11	40
0.5	0.99	40
1.5	1.08	40
2.5	1.20	40
3.5	1.22	40
6	2.97	80
8.5	3.85	80



THAWING FRACTION

Thawing fraction (f): ratio between the thawed mass and the mass of the original solution. Thawing fraction is a way to follow the development of the melting process.

$$f = \frac{m_{liq}}{m_{s0}}$$

where:

m_{liq} : liquid mass of the ice.

m_{s0} : initial mass of the solution.

	0.1 %	0.5 %	1.5 %	2.5 %	3.5 %	6%	8.5 %
f1	0.36	0.39	0.35	0.34	0.36	0.33	0.25
f2	0.39	0.44	0.35	0.36	0.33	0.33	0.20
f3	0.36	0.30	0.39	0.36	0.32	0.20	0.30
mean	0.37	0.41	0.36	0.35	0.33	0.33	0.25
%	37.00	41.50	36.33	35.33	33.67	33.00	25.00