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Experimental of Seawater Desalination Using Thermosolar Energy

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Abstract
Desalination of seawater or brackish water is a proven technology for more than 50 years which provides fresh water to millions of people living in areas of water scarcity, whether for drinking or other uses, such as hygiene and even agricultural, helping these communities not only to survive, but to achieve their economic, technological and environmental development. Unfortunately, current commercial desalination requires a large amount of energy, either caloric or electric and mostly covered by conventional sources, increasing both costs and environmental pollution. Freezing desalination can theoretically achieve up to 70 % less energy use than thermal technologies, with other advantages such as that it does not need pre-treatment and low corrosion in the system. The present work shows the results obtained during the experimentation in a prototype of desalination plant of sea water by freezing, coupled to a solar cooling system, managing to increase water production for each energy unit used and it is presented an analysis of salt percent obtained in water produced.

1. Introduction

The shortage of water on the planet and the excessive consumption of energy are two priority problems for all governments and the scientific community in the world.
Water is an irreplaceable element to achieve social, economic and technological development as has occurred throughout history. Its shortage is the cause of millions of deaths and diseases, especially of people at an early age, (UNESCO, 2015; water.org, 2018; WWAP, 2003) and, on the other hand, the excessive use of energy has increased greenhouse effect gases emissions, the main cause of climate change, representing a series of serious threats to the human security of existing and future populations, as well as to the integrity and survival of ecosystems (Arreguín Cortés, López Pérez, Rodríguez López, & Montero Martínez, 2015; Moss & Unesco., 2012).
Unfortunately, water supply and energy production are strongly linked, water is necessary for cooling of thermal and nuclear plants, production of bioenergy or hydroelectric plants, and wells pumping, transportation and purification of water, such as water desalination, require high energy consumption (ONU, 2014).
Given the shortage of fresh water in the world, water desalination has become a viable technique in many countries for more than 50 years (American Membrane Technology Association (AMTA), 2000; Fischetti, 2007; Youssef, Al-Dadah, & Mahmoud, 2014) and

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currently, around 44 Mm^3 of water is desalinated every day, (IDA Desalination, 2017), but is an intensive energy consumption process (Erlbeck et al., 2017), with a high environmental impact (Guevara & Stabridis, 2008).

Freezing desalination has the advantage of being the most energy efficient process, being able to save up to 70%, with respect to the most used thermal techniques (Ahmad & Williams, 2011; Mtombeni, T., Maree, J.P., Zvinowanda, C, 2013), (Thermal desalination provide 62% of seawater desalted), in addition to other advantages, such as low corrosion, does not need pre-treatment (as reverse osmosis, which desalinates the largest amount of water in the world), and its high separation rate. (Johnson, 1979; Mandri et al., 2011; Rahman, Ahmed, & Chen, 2007).

Freezing desalination is a natural process, given the insolubility of salts in solid water, therefore during the freezing process, saline ions are expelled towards to the warmer zones. The technique produces purer ice by controlling the freezing velocities, (progressive freezing), in such a way that saline ions are allowed to "escape" from the interface, before being "trapped" in the ice (Fujioka, Wang, Dodbiba, & Fujita, 2013). This progressive cooling is very compatible with solar cooling systems, which do not use fossil fuels and there are several technologies that achieve a sufficiently low temperature to achieve freezing of seawater or brackish water.

There is an antecedent of a freezing desalination plant which was installed in Saudi Arabia consisting of 43,800 m^2 of solar collectors. It operated with absorption using lithium bromide-ammonia to freeze. The capacity of the system was between 48-178 m^3/d with an energy consumption of 108 kWh/m^3 (Khoshaim, 1985), the plant closed in 1989, given the lack of interest then in low energy consumption because of low hydrocarbon costs by then and the lesser concern of environmental contamination.

The seawater freezing process can be carried out by different refrigeration technologies, using mechanical cycles such as vapor compression, thermomechanical such as ejection-compression and physical-chemical sorption, using liquid-vapor, solid-vapor absorption cycles (thermochemical) and adsorption with solid-vapor equilibria, allowing a great variety of arrangements with solar renewable energies, depending on the level of temperature required, such as biomass, solids (wood, agricultural waste, etc.), gaseous (biogas) or liquid (biodiesel), use the geothermal reservoirs and use the residual heat of the geothermal flows such as steam, brines, as well as the heat contained in the exhaust combustion gases, low residual pressure steam and thermal effluents from industrial processes and finally the energy thermosolar in its different technologies and temperature levels in a domain between 85 and 200 ^{o}C, which are those required for the operation of most thermochemical refrigeration systems. Among these technologies are the flat plate solar collectors, (80 to 90 ^{o}C) evacuated tubes (75 and 150 ^{o}C) with and without heat pipes (75 and 95^{o}C), composite parabolic concentrators (75 and 120 ºC) and parabolic trough concentrators (200 and 300 ^{o}C) (Best & Ortega, 1999). In most cases, the operating conditions will depend on the properties of the refrigerant fluid in its relation to the temperature and in certain cycles also of the concentration (sorption). In previous technologies, the level of freezing is feasible, however in the case of water, the system must operate at very low pressures to achieve its freezing. The industrial production of ice is carried out in most cases using pure ammonia in steam compression cycles, operating at pressures above ambient pressure, since its boiling

point at normal pressure is -33 °C, what makes it suitable for this application. Many of the refrigeration cycles to produce ice, based on sorption, use ammonia as a cooling fluid, which is absorbed in water, in aqueous solutions, in salts such as lithium nitrate, in alkali and alkali halides. earth, such as calcium chlorides, strontium, magnesium, barium, etc., or adsorbed on active carbons, silica gel, zeolites, etc. (Kim & Infante Ferreira, 2008; Wang & Oliveira, 2006).
In this work, the experimental results are shown in two solar cooling systems for the desalination of sea water by the progressive freezing method.

2. Experimental Design

The study was carried out on the solar platform of the Institute de Energías Renovables de la Universidad Nacional Autónoma de México, located at 18 º 51 ' N and 99 º14 ' LO, with dry warm climate, with an average of 50% annual humidity and average maximum temperatures of 27 ºC and minimum average of 16 ºC, average solar irradiance of 950 W/m². The tests were carried out in Temixco, Morelos, with maximum solar radiation, in July 2017. Experimentation consists in the synthetic preparation of salt water, in the same proportion as it contains seawater (34.5 g/l) but using, in substitution of the different salts contained in seawater, sodium chloride to simplify the operation, but keep a close approximation to the behaviour of seawater, since NaCl is the main salt contained (around 70%), and its values of density, dynamic viscosity and specific heat have similar values to those of seawater, according to literature (Melinder & Ignatowicz, 2015). In addition to the measurement equipment used only shows the measurements of NaCl solutions.
Subsequently this saline solution is introduced, according to the operating conditions of each solar cooling system already instrumented to follow the necessary temperatures and pressures during the process.
Once the process was finished, measurements of salinities were made of the sections of the ice formed, as well as its weight.
The first equipment tested, is a prototype of a one-phase intermittent thermochemical solar cooling system, with Barium chloride (as an absorbent) and Ammonia (as a refrigerant), ($BaCl_2$, $8NH_3$), with temperatures of generation between 54 and 69 ºC, where 6.65 L of desorbed ammonia are obtained and taken to the reactor, to evaluate the operation (Martínez-Tejeda et al., 2018).
The other equipment is an intermittent solar cooling system that operates with (Lithium Nitrate, as absorbent and Ammonia as refrigerant (NH_3–$LiNO_3$), capable of producing up to 8 kg of ice/day (Huicochea, Rivera, Martínez, Siqueiros, & Cadenas, 2013).

3. Results

As can be seen in Figure 1, in the results obtained in the Barium-Ammonia Chloride equipment, the minimum temperatures reached in the evaporator, were able to lower the temperature of the saline solution up to 1 ºC, for a couple of hours, through what the freezing was not achieved.

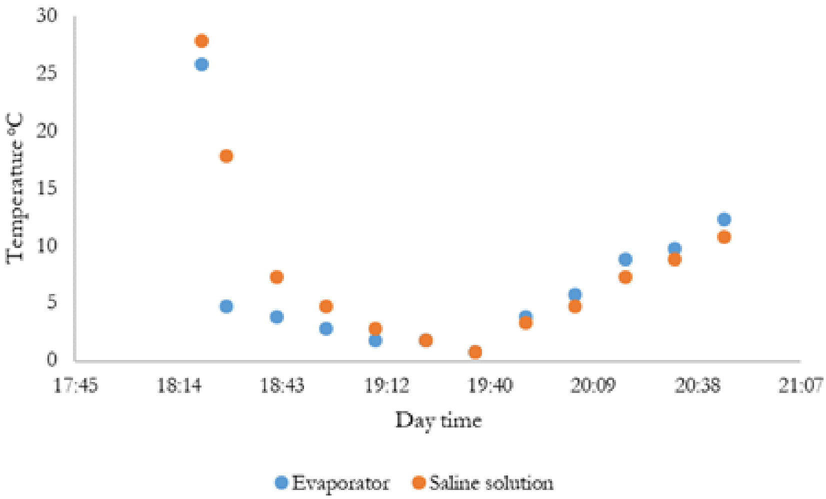


Figure 1: Evaporator temperatures and saline solution in solar cooling with BaCl2, 8NH3

In the thermal evolution obtained in the equipment with Lithium-Ammonia Nitrate, shown in Figure 2 can be observed that the temperature in evaporator reached temperatures under -3 oC for seven hours approximately and saline solution reach around -2 ºC, for about five hours.

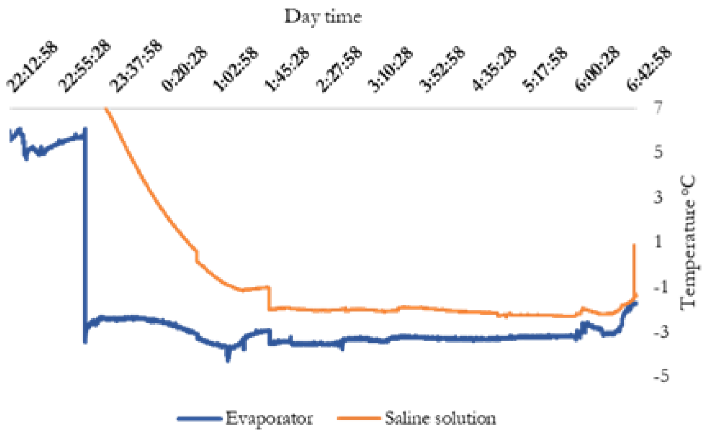


Figure 2: Evaporator temperatures and saline solution in solar cooling with NH3-LiNO3

As can be seen in Figure 3, the ice generated in the evaporator, despite the low temperatures reached, did not freeze completely, since inside the 16 pistons contained in the evaporator, liquid solution was found, with a thick layer that the system was able to freeze. The total ice generated was approximately 30% of the total introduced, (2.4 kg of solution).

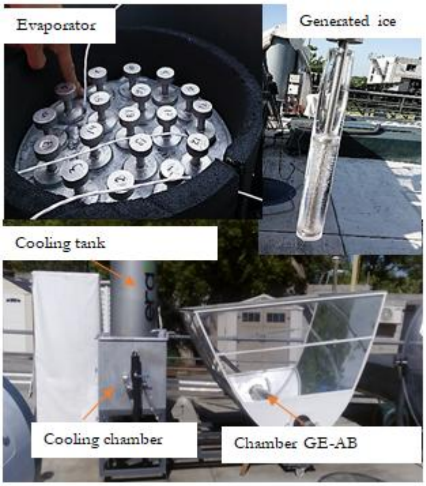
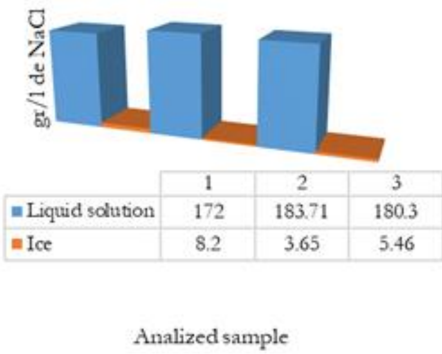


Figure 3: NH3-LiNO3 System and ice sample

The salinity analysis of the samples is shown in Figure 4. It can be observed saline migration towards the liquid part of up to 90% in sample 2.



	1	2	3
Liquid solution	172	183.71	180.3
Ice	8.2	3.65	5.46

Figure 4: Salinity analysis on samples

4. Discussion

Even though saline migration was achieved in large percentage, the power of the solar cooler using Lithium-Ammonia Nitrate, with which better results were obtained, was not enough to freeze the volume total capacity of the system of synthetic seawater. One of the colligative properties of the diluted solution is the lowering of freezing point when concentration rises. Once seawater start freezing, saline migration process starts from the freezing portion, to liquid remaining, which increase its concentration progressively and thus, lowering its freezing point at the same time. Although, at the beginning of the process, the freezing point is -1.9 ºC, it decreases when the concentration in the brine increases, for example, for a salinity of 40 gr/l, the freezing point reaches up to -2.58 ºC (Fofonoff & Millard, 1983).

5. Conclusions

A desalination prototype has been tested by the freezing method, using solar cooling. It was possible to desalt the synthetic seawater prepared with up to 90% saline migration, without the use of conventional energies, through an intermittent solar cooling system that operates with (Lithium Nitrate, as absorbent and Ammonia as refrigerant (NH_3-$LiNO_3$). The power of the solar refrigerator managed to freeze about 30% of the volume capacity that is the evaporator, so it is necessary to modify the dimensions of the evaporator or to generate an increased amount of ammonia to prolong the experiment and achieve lower temperatures.

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