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# Sea ice desalination under gravity using microwave heating

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## ABSTRACT

Gravitational desalination is an important sea ice desalination method. It essentially makes use of the different freezing points of a brine and pure water to promote the separation of the brine and fresh water ice crystals. The ambient temperature influences the ice temperature, which leads to a long desalination cycle and a low production efficiency. Aiming to solve the above-mentioned problems, experiments were designed considering different microwave powers, salinities, and sea ice masses and the physical properties of sea ice and microwave heating characteristics. The results show that the desalination rate of sea ice is the highest after 2–4 min; the desalination rate reaches up to 90% at a loss rate of < 40% when sea ice with a salinity of 5‰ is heated for 8 min in a 600 W microwave. Heavier sea ices need more time to completely desalinate. At lower microwave energies, sea ice can melt brines with higher salinities.

## 1. Introduction

Sea ice desalination is an important method of seawater desalination and has been studied since the 1960s[1–3]. Sea ice discharges most of the salts in the formation process; hence, the overall salinity of sea ice is lower than that of the original seawater. Residual sea ice salts exist in the form of “brine pockets”. Current sea ice desalination methods include gravity desalination, centrifugal desalination, extrusion desalination, controlled temperature freeze–thaw desalination, soaking desalination, and spray freezing desalination. These methods can be divided into two categories based on different salt melting processes. One method is slight melting under external heat conduction. The basic principle of this method is that brine pockets are heated up to melt ice crystals at ambient temperature. The gravity effect leads to the formation of vertical “drainage channels” among the pockets and to the discharge of salt through the channels[4,5]. However, this method generally requires a desalination cycle of one to two months[6] and its continuous production is poor. The other method is based on a mechanical process causing the direct exposure of the brine pockets. Centrifugation[7], soaking[8], and other associated processes are then used to achieve the separation of brines and fresh water ice crystals. However, most of the brine pockets are very small; the method therefore requires a high degree of sea ice crushing. In addition, there are also higher requirements with respect to the power of equipment and apertures of filter meshes. However, this desalination process is characterized by relatively higher energy consumption and lower actual production. The long desalination cycle and low production efficiency limit the actual production and application of sea ice desalination. Therefore, it is key to identify a rapid and efficient desalination method to promote the industrialization of sea ice desalination. Microwave heating technology has many advantages and can theoretically solve the above-mentioned problems.

Microwave heating technology utilizes microwaves to produce a high-frequency electromagnetic field, which initiates polar molecule vibrations at high speeds, resulting in molecular levels of friction producing a lot of heat[9]. The microwave heating technology is characterized by a high heating speed, selective heating, and strong penetration ability[10]. Based on these characteristics, it is applied in the food industry[11,12], material synthesis[13,14], and ceramic calcination[15–17]. In theory, differences in dielectric properties exist between the components of sea ice; sea ice is heat selective[18]. The dielectric constant of freshwater ice crystals is low. They almost absorb no microwave energy, manifested as strong penetrability of microwaves. However, the brine pockets have a high dielectric constant and high absorption capacity with respect to the microwave energy[19]. Under microwave heating, brines rapidly warm up to melt the cell wall and

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**Table 1**
Experimental apparatus.

| Name | Model/specification | Accuracy |
|---|---|---|
| Digital salinity meter | HI931100 | 0.01 g/kg |
| Electronic balance | YP6001N | 0.01 g |
| Microwave desalination device | ML06S-5/2450 MHz | 100 W, 1 min |
| Measuring cylinder | 100 ml, 300 ml | 0.1 ml |

accelerate the formation of saline channels. This study aims to explore the effects of the sea ice salinity, microwave power, and sea ice mass on the sea ice desalination efficiency.

## 2. Experiment design

Four factors (microwave power, heating time, original sea ice salinity, and sea ice weight) were considered for the experiments. Single-factor experiments were conducted. Thus, there are four parallel experiments for each single experimental condition.

### 2.1. Experimental materials

Ice samples were taken from the Cangzhou City Port Economic and Technological Development Zone of the Hebei Province (longitude 117°20′, latitude 36°21′) on January 20, 2016. The original salinities of the experimental ice samples are 2.7‰, 5.0‰, 8.8‰, and 16.4‰ and their thickness is ~14.5 cm. The sea ices were cut into rectangular shapes with a specific size (their cross sections are square) and were kept in cold storage in their natural growth direction.

The experimental apparatus is shown below (Table 1).

### 2.2. Microwave desalination device

The diagram of the microwave heating sea ice desalination experimental device is shown in Fig. 1. The microwave power source (left) can be used to set the microwave power and heating time; the rotating tray is placed into the reaction chamber (right).

### 2.3. Experiment procedure

The microwave power and heating time of the desalination test device were set in advance; the heating time was 2 min. One of the sea ices, which have been cut into rectangular shapes, was placed into the device for heating. After the heating process (2 min), molten ice water was removed and experimental data were recorded. The remaining part of the sea ice was then returned to the desalination apparatus for the next heating cycle. The cumulative heating time at different microwave powers was 10 min. The residual unthawed part of the sea ice was weighed and its salinity was measured after it melted naturally.

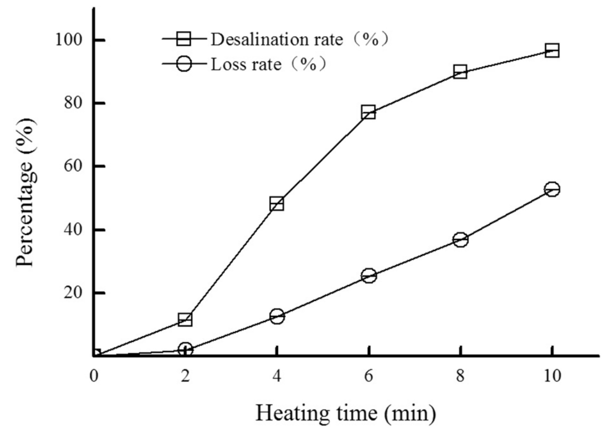


**Fig. 2.** Variation of the desalination and loss rates (sea ice with a salinity of 5.0‰, microwave power of 600 W, ice weight of 950 ± 70 g).

### 2.4. Method and equation

In this paper, the loss rate is a ratio of molten water weight to the total sea ice. The desalination rate is defined by the ratio of the amount of molten salt after microwave heated to the total salt of the initial sea ice, which was calculated using the following equation:

$$\text{Desalination rate} = \frac{C_j * m_j}{C_0 * m_0} * 100\% \tag{1}$$

where $C_j$ is the concentration of the molten water (g/kg); $C_0$ is the concentration of the initial sea ice (g/kg); $m_j$ is the weight of the molten water (g); $m_0$ is the weight of the initial sea ice (g).

## 3. Results and discussion

### 3.1. Microwave heating sea ice desalination

Fig. 2 shows that the desalination and loss rates of the raw sea ice with a salinity of 5.0‰ notably increased with increasing heating time in the 600 W microwave. The desalination rate increased by 65.6% in the 2–6 min period. The loss rate increased by 23.3%. In the period of 6–10 min, the desalination rate increased by 20.0% and the loss rate increased by 17.3%. After 8 min of microwave heating, the desalination and loss rates were 89.7% and 36.8%, respectively. Compared with the traditional sea ice gravity desalination experiment in Table 2, microwave heating sea ice desalination can greatly shorten the time to achieve the same desalination rate.

### 3.2. Changes of the desalination and period loss rates at different microwave powers

Changes in the desalination rates during microwave heating can reflect the formation degree of drainage channels. If the desalination


**Fig. 1.** Microwave sea ice desalination experimental device.