# PRODUCTION OF ICE SLURRY WITH HIGH FLUIDITY FOR COLD HEAT STORAGE AND TRANSFORMATION


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## ABSTRACT

Ice cold storage and transport system are being developed for electric load leveling. Agglomeration of ice slurry, however, is still a big problem. Then, appropriate additives such as bio-surfactant are needed for agglomeration prevention of the ice slurry.

In this study, to prevent the agglomeration, some surfactants were selected. As the results, it became clear that adding of the surfactants could prevent the agglomeration and product the ice slurry with high fluidity


## INTRODUCTION

The development of new high-efficient cool heat storage and transport system using the ice slurry is desired from the viewpoint of the effective utilization of electric power in nighttime. In this system, however, ice particles often cohere and agglomerate together during long storage, and there is a danger that agglomeration may cause inferior situations (blockage of piping, superfluous load of power etc.).

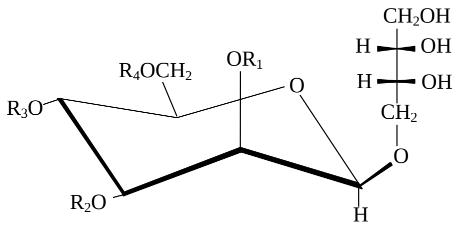
Adding of the anti-freeze protein (Grandum *et al.*, 1997, Inada *et al.*, 2000, Yang *et al.*, 1988), or silan-coupling agents (Inada *et al.*, 2000) prevented the agglomeration of ice crystals. Synthesis surfactant Sorbon T-81 as a synthesized surfactant showed good prevention effect of agglomeration of ice slurry in the addition of the low concentration (Akiya *et al.*, 2000). However, it was seemed that the quantity of these additives was large for the viewpoint of wastewater treatments.

In this study, bio-surfactant MEL-A (Mannosylerythritol lipid - A) was selected as an additive, and agglomeration prevention effect of MEL-A was confirmed under the concentration of 2.5mg/l~500mg/l. And it became clear that adding of the bio-surfactant could prevent the agglomeration of the ice slurry, and the fluidity of the ice slurry was kept by adding of bio-surfactant 100mg/l, even if the ice-packing factor (IPF) of the ice was 38%. Time change of the ice crystal size distribution under storage of the ice slurry was also discussed.

## EXPERIMENTAL

### Bio-surfactant

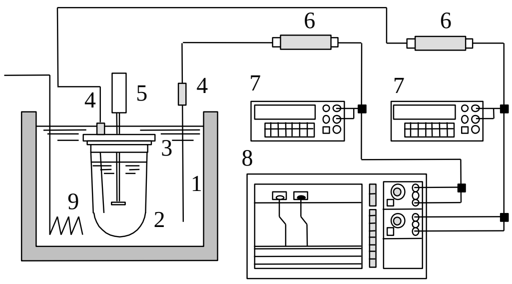
MEL-A was prepared and purified as reported previously (Kitamoto *et al.*, 1992). The obtained MEL-A was shown in Figure 1 and was used in the following experiments.




MEL-A : $R_1$-$R_4$=2xAc, 2xFatty acid

Figure 1. Structure of MEL-A

Schematic diagram of experimental apparatus was shown in Figure 2.




1: Temperature controlled water bath
2: Glass cell
3: Flange
4: Platinum resistance thermometer
5: Stirrer
6: Amplifier
7: Digital voltage meter
8: Recorder
9: Cooler and heater

Figure 2. Schematic diagram of experimental apparatus

As shown in Figure 2, the apparatus used for ice crystallization consists of a glass cell with a volume of $1.3x10^{-3}m^3$ (2), a cooler and a heater (9), a stirrer (5), a temperature controlled bath (1), a platinum resistance thermometer (4), two digital voltage meters (7) and a recorder (8).

### Experimental Procedure

The bio-surfactant was perfectly dissolved in 0.3mol/l aqueous solution of sodium chloride so that the concentration of bio-surfactant was 2.5mg/l~500mg/l. The reason for the addition of sodium chloride is that the quantity of ice crystal is moderately adjusted, which indicates that decision of agglomeration and flocculation of ice crystal particles can be experimentally carried out easily. The solution was collected in the glass cell. Then the cell was set in the temperature-controlled bath. The solution was kept at 293K and stirred at $600min^{-1}$ for one hour. Then the solution was cooled down till the nucleation of ice crystal was occurred with a constant cooling rate. After moderate quantity of ice crystal was deposited, the temperature of the bath was reset at a specific temperature range (271.2~271.6K at 0.1K intervals) and the solution kept without stirring for 8 hours. Then the aqueous solution was taken from the cell and the concentration of sodium chloride was measured. Furthermore, the ice slurry was quickly put in the thermostat schale and taken in photograph by use of the microscope.

## RESULTS AND DISCUSSIONS

### Ice Slurry Formation

Typical example of the ice slurry, which was kept at fixed temperature for 8 hours after ice slurry was formed, was shown in Figure 3. Figure 3(a) showed that no agglomeration of ice slurry was observed. Figure 3(b) showed that the ice slurry was deposited on the inside surface of the glass cell. But the ice crystal layer was torn off easily by use of a small spoon and the crystal layer returned again by short agitation. In this case, we defined that agglomeration prevention effect of bio-surfactant was not observed and this state was called “Partial agglomeration”. Figure 3(c) showed the typical example in which the crystal aggregated and the fluidity of the ice slurry could not be observed

(a) No agglomeration (IPF=29%, MEL-A=2mg/l)    (b) Partial agglomeration (IPF=32%, MEL-A=2mg/l)    (c) Agglomeration (IPF=35%, MEL-A=2mg/l)

Figure 3. Photograph of ice slurry

### Time change of crystal size distribution of ice crystal in the slurry

Example of photomicrography of the ice slurry generation post-eight hours was shown in Figure 4.

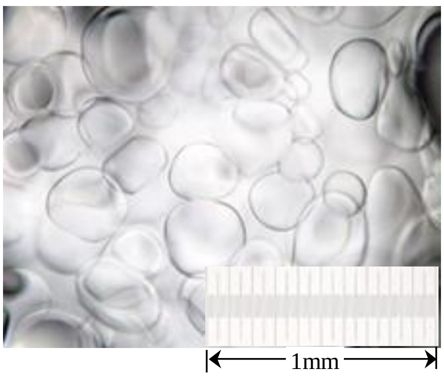



Figure 4. Example of the photomicrography of the ice slurry

It was found that there was no agglomeration of ice crystal from Figure 4. The crystal size distribution of the ice crystal using the photomicrograph such as Figure 4 was obtained. And time change of the crystal size distribution was shown in Figure 5. The crystal size distribution obtained from post-one hour after nucleation of ice crystal showed comparatively sharp distribution. However, the tendency in which the distribution was extended was shown with time. From these results, it was found that ice crystal grew in spite of the temperature of the slurry was kept at constant and the largest size of the crystal was under 1,000$\mu$m. From the portion of the crystal which size was over 1,000$\mu$m was not observed, it was seemed to no problem for the transportation of the ice slurry.

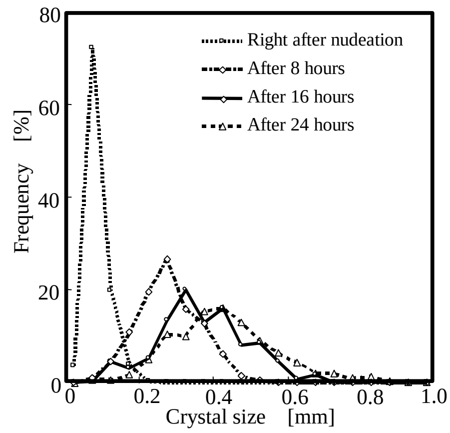



Figure 5. Time change of the ice crystal size distribution

**Additive Effect of Bio-Surfactant**

As shown in Figure 3, the agglomeration prevention effect of bio-surfactant was obtained by visual observation. The experimental results of the relation between concentration of bio-surfactant and ice packing factor was shown in Figure 6. IPF was obtained from Equation (1).

$$IPF(\%) = (C_f - C_i)/C_f \times 100 \quad (1)$$

Where, $C_i$ and $C_f$ were concentrations of sodium chloride before and after the ice crystallization

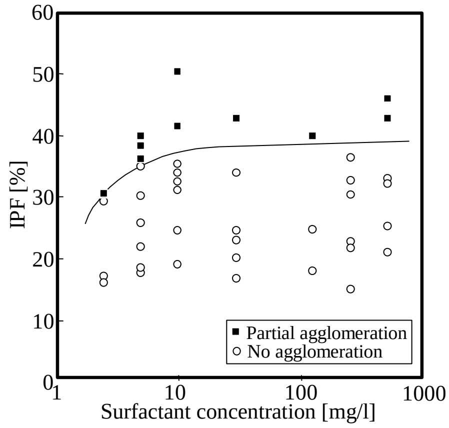



Figure 6. The relationship between the IPF and the concentration of Bi-surfactant

In Figure 6, the open circle represented the case when no agglomeration was observed, while the closed square represented the case when partial agglomeration was occurred, in other words, ice crystal deposited around the inside wall of the cell. Even when partial agglomeration was occurred, there was little problem with stirring of the slurry. The deposited ice crystal was easily detached from the inside wall of the cell by scratching with a spoon and returned to the slurry with good fluidity. Detailed mechanism of prevention of agglomeration using bio-surfactant is under investigation. It is considered that the agglomeration of ice crystals may be suppressed by configuration of the surfactant molecules in the ice/water interface vicinity.

**Dynamic Ice Generation and Transportation**

Figure 7 showed the dynamic ice generation system. The system mainly composed of a brine-chilling unit, cold and warm brine tanks, heat exchangers, storage tanks and a transportation system.

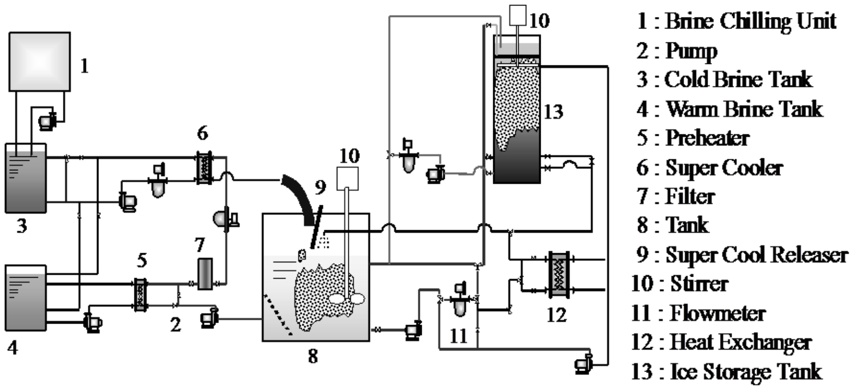



Figure 7. Schematic diagram of the ice generation system.

An aqueous solution containing 100mg/l of bio-surfactant is pumped from ice tank (8) through pre-heater (5), filter (7) to the super cooler (6). In the super cooler, the water solution is super cooled to about -1.5K, using brine cooled by chilling unit (1), before its delivered to the super cool releaser where slurry ice is formed. The slurry ice is temporarily stored in ice tank (8) and stirred before being transported to storage tank (13) through mass flow meter where the transported IPF is measured.

Table 1 showed the relationship between transported IPF and stored IPF and it was found that the transportation of ice slurry was performed without any trouble such as agglomeration of ice crystals. From these experimental results, it was found that the addition of bio-surfactant is effective to prevent agglomeration of ice slurry for developing the novel cool heat and transport system.

Table 1. Relationship between transported IPF and stored IPF

| Stored IPF [%] | Transported IPF [%] |
|---|---|
| 8 | 2 |
| 17 | 4 |
| 25 | 5 |

**CONCLUSION**

In order to develop the novel cool heat storage and transport system using ice slurry, agglomeration prevention of ice slurry was studied using some additives.

Bio-surfactant MEL-A (Mannosylerythritol lipid - A) was selected as an additive, and agglomeration prevention effect of MEL-A was confirmed under the concentration of 2.5mg/l~500mg/l.

ACNOLESEMENNT

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