再結晶缶を用いたスラリーアイスの氷粒子径コントロールに関する研究

Study on control of ice particle size in slurry ice by utilizing recrystallizer module

Intelligent Mechanical Systems Engineering Course

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1. Introduction

In the food industries, freeze concentration was used to increase the concentration of liquid food while maintaining its characteristic aromas and flavors that is susceptible to heat degradation [1]. This process partially freezes the water contents in the liquid into ice particles of pure water. The slurry consisting of ice particles and the product were then separated in a centrifugal machine resulting in a much more concentrated product (Fig. 1).

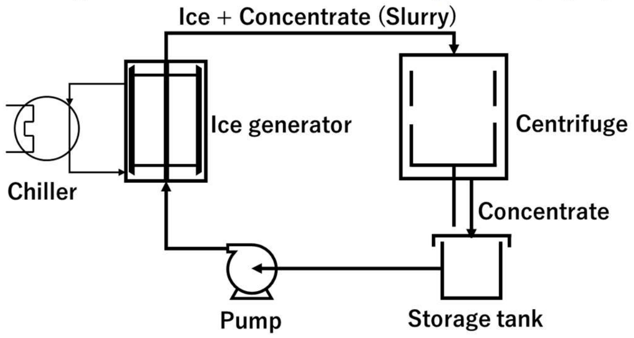

Fig. 1 Freeze concentration process

In doing this there tends to be some residue liquid attached to the surface of the ice particles, the smaller the ice particles the more liquid is loss through this process and vice versa (Fig. 2).

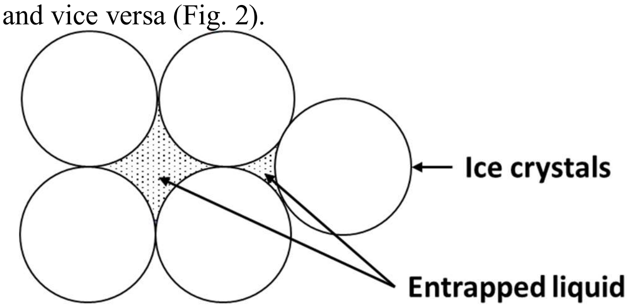

Fig. 2 Liquid loss

By increasing the size of the ice, this loss can be mitigated. To give the ice particles time to grow and to make controlling possible a recrystallizer module is utilized. In this module agitation is essential in preventing the ice particles from coagulating and causing the fluid pumping to come to a halt.

This research studies on the agitation effects on ice particles growth characteristics within the recrystallizer module and mechanisms involved with a heavy emphasis on the Ostwald ripening mechanism.

1.1. Ice particle growth

Freeze concentration process have an issue during the solid-liquid separation step, where in the waste ice there still has product left in it. This lower the efficiency of the process. A way to do increase the efficiency is to increase the overall particle size of the ice before separation by Ostwald ripening (Fig. 3).

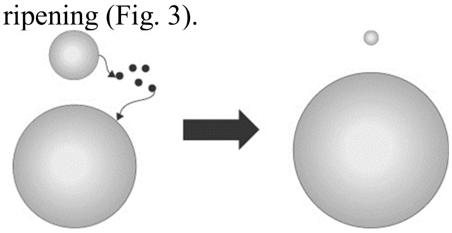

Fig. 3 Ostwald ripening

Lifshitz and Slyozov (1961) [2], and Wagner (1961) [3] made the model describing the growth characteristics of ice particle from the effect of Ostwald ripening independently. Which was then consolidated into the LSW theory.

$$R_t^3 - R_0^3 = K_D t$$

R_t : particle size at time t; R_0 : initial particle size

K_D : diffusive ripening constant

2. Ostwald ripening control experiment

Confirming that Ostwald ripening can occur to ice particles in slurry ice is necessary and to see the general results of what could be expected in the main experiment of this study.

Solution for ice generation was prepared at 1%wt NaCl solution and filled into the 140 liters propylene storage tank (Kaisuimaren Co.Ltd., MH-140) lined with thermal insulation sheet. The ice was generated in the slurry ice generator (Izui iron works Co.Ltd., Shakittomini) and transferred to the storage tank. The slurry was kept in suspension by agitating at 300 RPM using motorized agitator (HANWAKAKOKI Co.Ltd., KP-4001A). The particle size was measured by using a microscope (KEYENCE, VHX-500F) to photograph the ice particle every 15 minutes starting from when ice starts to appears in the storage tank. Feret diameter [4] was used to measure in this experiment (Fig. 4).

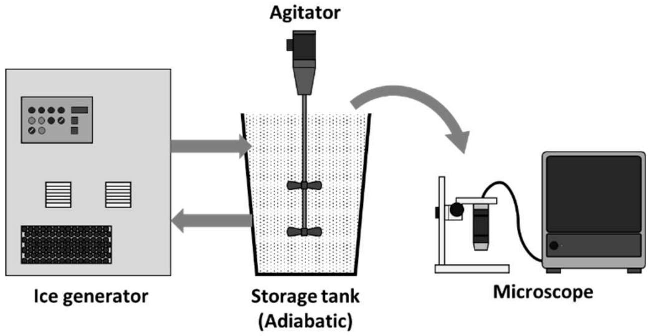

Fig. 4 Equipment and setup

2.1. Ostwald Results

The ice particle size growth rate characteristics can be seen in Fig. 5. An estimated growth model results at $r_t = 16.292\ t^{0.5775}$, with a R-square value of 0.9862 which represents a good correlation of the model. The obtained result better corresponds to Ratke and Thieringer findings in 1985 [5] where the diffusion is not the limiting factor, as shown in the model below.

$$R_t^2 - R_0^2 = Kt$$

K : ripening constant

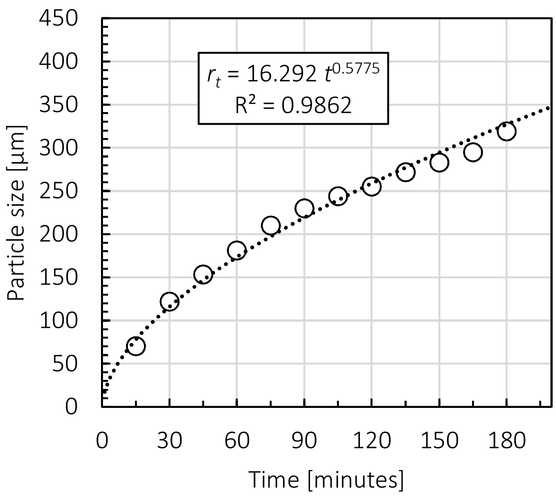

Fig. 5 Particle size curve

During the run, super large ice particles were seen from 75 minutes after the initial ice generation (Fig. 6). The super large ice particle measured to be at around 1mm wide. Considering that this process is adiabatic, no mass was added or removed from the system this crystal growth can be said to be the effect of Ostwald ripening.

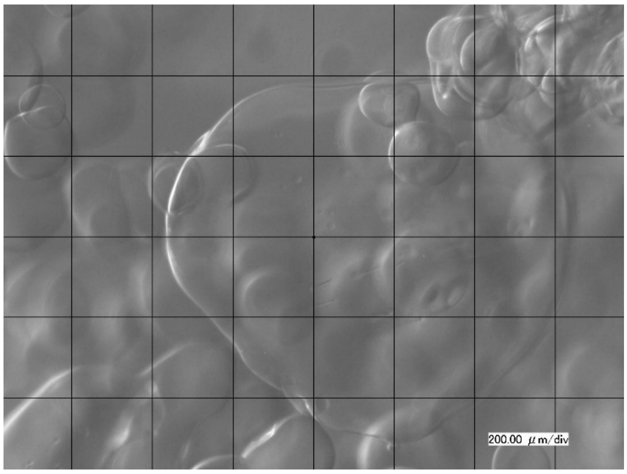

Fig. 6 Super large ice particle (200 µm/div)

3. Recrystallizer experiment

In suspension freeze concentration each module has its own dedicated job. The generator module, a scraped surface heat exchanger (SSHE), produce ice crystals. The recrystallizer facilitates ice crystal growth by providing suitable ripening temperature and homogeneous mixing. These two modules have its own optimum operating conditions so it cannot be combined into one single module (Fig. 7).

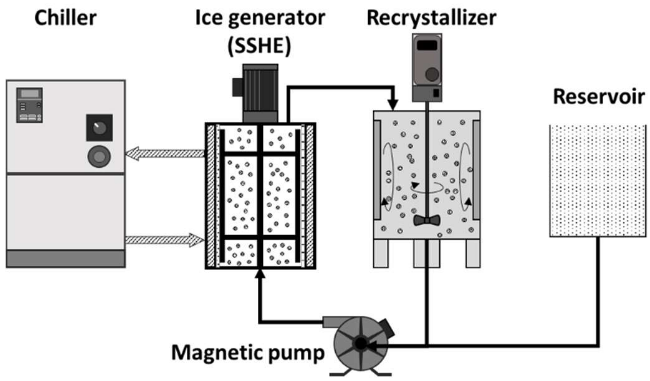

Fig. 7 Equipment and setup

The operating room was held at the lowest, stable temperature of 15ºC. The SSHE coolant was set at -12ºC during the first 30 minutes of ice generation and increased to -2.7ºC during cold storage. The recrystallizer agitation speed used in the experiment was calculated from rotational Reynolds number ranging from 10,000 to 45,000 Re_r (5,000 Re_r increments). Particle size data was measured every 15 minutes after the holding temperature was changed to -2.7ºC.

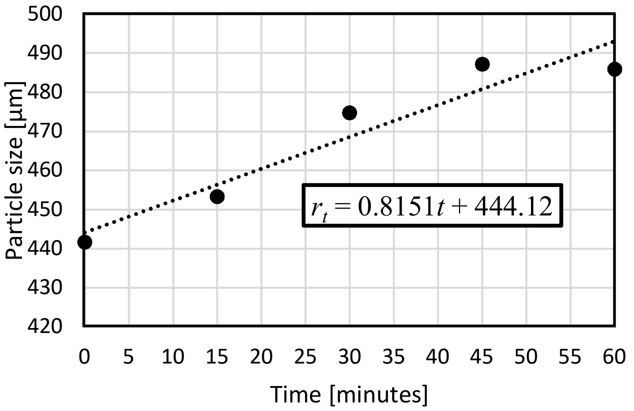

Fig. 8 Re_r 30,000 particle size growth

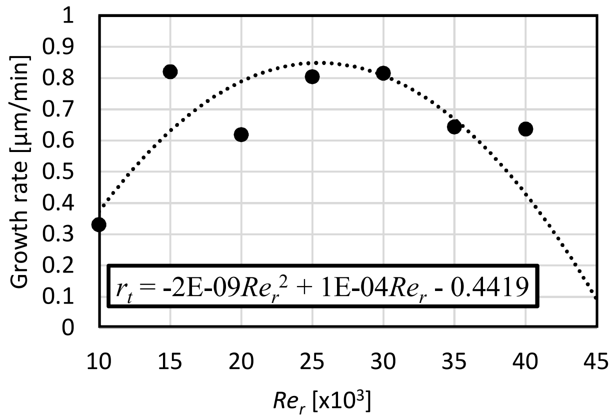

Fig. 9 Growth rate and Re_r relationship

3.1. Recrystallizer results and discussion

A relationship curve between the growth rate of each Re_r were consolidated from all available data. Second-degree polynomial curve can be seen in this relationship. Particle growth by Ostwald ripening needs good agitation to quicken the mass diffusion limitation, but applying too much agitation leads to the decrease in growth rate. During high agitation micro-bubbles were found in the system, this cause the solution temperature to raise from heat transfer beyond its boundaries. In addition to the boundary heat transfer, agitation at such degree causes heat to be generated in the solution which hinders the growth rate. The maximum growth rate was found to be in the region where the power just enough to achieve homogeneous mixing of the solution.

4. Conclusion

Agitation in the cold storage tank of continuous freeze concentration process have a direct effect on the ice particle size. Using low agitation, the ice particles grows at a slow rate, but applying too much agitation will cause the ice to melt. A suitable agitation power where it is enough to achieve homogeneous mixing is desirable for maximum ice particle growth. Proceeding beyond that point proves to be unbeneficial.

5. References

[1] A. Omran and C. King, "Kinetics of Ice Crystallization in Sugar Solutions and Fruit Juices," *AlChe, Vol.* 20, No. 4, pp. 795-803, 1974.

[2] I. Lifshitz and V. Slyozov, "THE KINETICS OF PRECIPITATION FROM," *Journal of Physics and Chemistry of Solids,* Vol. 19, pp. 35-50, 1961.

[3] C. Wagner, "Theory of the aging of precipitates by dissolution-reprecipitation (Ostwald ripening)," *Zeitschrift für Elektrochemie,* Vol. 65, pp. 581-591, 1961.

[4] H. G. Merkus, "Particle Size Measurements: Fundamentals, Practice, Quality," p. 15, 2009

[5] L. Ratke and W. Thieringer, "The Influence of Particle Motion on Ostwald ripening in liquids," *Acta Metallurgica,* Vol. 33, No. 10, pp. 1793-1802, 1985.

[6] L. Ratke and P. W. Voorhes, in *Growth and Coarsening: Ostwald Ripening in Material Processing*, Springer, pp. 117-118, 2002