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Pressure effect on the release of supercooled water with dissolved air

Donggyu Lee [a], Chunwan Park [a], Sujin Jeong [a], Chaedong Kang [b,*]

[a] Graduate School of Mechanical Engineering, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju 561-756, Republic of Korea

[b] Department of Mechanical Engineering, Chonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju 561-756, Republic of Korea

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ABSTRACT

It is proposed that vapor has been elucidated to having relation to the release of supercooled water.

In this study, considering that the vapor has a relation to dissolved air, a supercooling experiment is performed to test tubes of pure water with three patterns of initial dissolved oxygen ($DO_i = 4.1$, 7.5, and 12.6 mg L^{-1}), i.e. dissolved air. The initial DO in each test tube is kept to the value as constant as possible during supercooling. And the pressure effect on supercooling release of pure water is observed by measuring supercooling degree and by visualizing bubbles enclosed to the ice after full crystallization of the pure water.

From this study, it appeared that the factors such as cooling rate, initial DO and pressure of pure water are related to the release of supercooling (supercooling degree and supercooling time). Moreover, the initial DO was confirmed to the confined bubble in fully frozen ice of pure water.

Effet de la pression sur l'échappement d'eau sur-refroidie avec l'air dissous

Mots clés : Surrefroidissement ; Oxygène dissous ; pressurisation ; Micro-bulles ; Tube à essais

1. Introduction

Ice slurry obtained when the water or aqueous solution with supercooled state is released forcedly or naturally, is well-known for the fluidity, high energy density, high heat transfer rate, safety, and chemical reliability (Saito, 2002).

The ice slurry with their merits has been widely applied to human life, such as cold thermal energy storage (CTES) as building HVAC, food processing, cold chain, medical surgery, cleaning, and so on (Bellas and Tassou, 2005; Kauffeld et al., 2010).

In supercooling type CTES, water is supercooled first below freezing point, and then, turns into ice slurry by the release of supercooling which forms forcedly neuclei in supercooled water. However, the supercooled water often releases naturally at the heat exchanger which supercools water. Sometimes, the

* *Corresponding author*. Tel.: +82 63 270 2318; fax: +82 63 270 2315.
E-mail address: ckang@jbnu.ac.kr (C. Kang).

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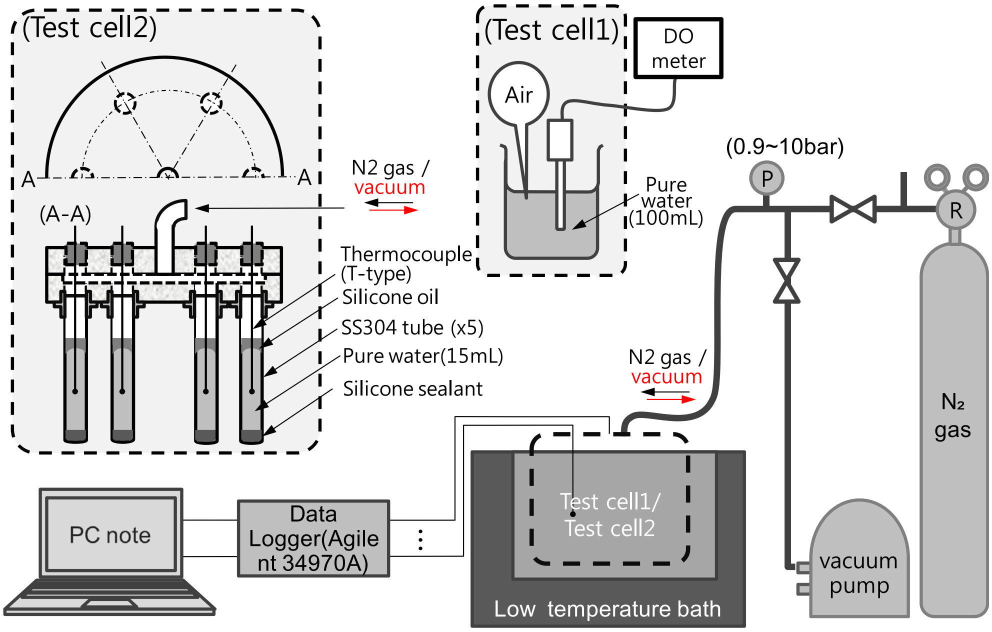

Fig. 1 – Schematic of pure water cooling apparatus.

release of supercooling may cause ice blockage due to ice adhesion and growth in the heat exchanger for supercooling.

Different researchers have studied the effect on the release of supercooling to various parameters; Cooling rate (Okawa et al., 2002), the bubble size and its rising velocity in supercooled water (Hozumi et al., 2002a,b), existence of bubble (Heneghan and Haymet, 2003), solid particles (Okawa et al., 2001), applying ultrasonic wave(Trinh and Ohsaka, 1998; Tanino et al., 2000; Inada and Zhang et al., 2001; Hozumi et al., 2002).

In detail, the supercooling release relates to the amount of bubbles obtained from the water applying ultrasonic wave with a certain intensities (Inada and Zhang et al., 2001). And the bubble formed from vacuumized distilled water contributes to the release of supercooling.

On the contrary, the increased supercooling degree occurs at the pressurized distilled water because the generated bubble was dissolved again in the water (Hozumi et al., 2002). Similarly, smaller supercooling degree presents to the water with a bubble than that without bubble (Heneghan and Haymet, 2003).

In addition, the supercooling for an aqueous solution was investigated to the pressure effect. Active freezing using by electrolyte was performed to NaCl solution (Petersen et al., 2006; Kang et al., 2009). Kang et al. (2009) showed the supercooling degree is proportional to the pressure of ethylene glycol aqueous solution. Homogenous nucleation temperature was shown to acting pressure with aqueous glycerol solutions (Miyata et al., 2012).

From the previous study for the supercooling release, the enhancement or retardation of the bubble formation from dissolved air in supercooled water or solution was elucidated to influence to release the supercooling.

However, the bubble or air existed visible before supercooling release.

Then again, there were reported to the supercooling of water with a certain dissolved oxygen (DO). Scheiber and Gutmann (1993) showed DO in water droplet increased to -7 °C using by amperometric needle sensor. And the density of water in supercooled state decreases as the temperature of the water decreases from 0 to lower than -30 °C (Hare and Sorensen, 1986). From those findings, the dissolved air (DA) in pure water under supercooled state can be predicted to increase the volume of water.

In previous studies, the bubble affected to the release of supercooled water. Additionally, it is necessary to the research to the effect on the release of supercooled water to DO and pressure of water.

In this work, we want to observe experimentally the effect on the release of supercooling to each cooling rate, dissolved air, i.e. oxygen (DO) and pressure in pure water. In detail, the formed and enclosed bubble when supercooled water with each initial DO was released to until full ice was evaluated. And the result is helpful to the study for ice slurry making.

2. Experimental setup

2.1. *Experimental apparatus for cooling*

Fig. 1 showed the experimental apparatus, which consisted of low temperature bath with brine, test module, nitrogen gas pressure vessel and data acquisition system. Pure water was provided from purifier (Pure Power I, 18 MΩ-cm, Human Sci. Co., Korea). Firstly, the pure water of 200 mL in glass beaker (Pyrex) was prepared with test cell 1, which was adjusted dissolved oxygen (DO) of the pure water by aerator and purifier. Then each pure water of 15 mL was put into six test tubes (ϕ20 × 100 mm, 2 t, 0.8 μm Ra, SS304) in test cell 2. Each tube was dipped separately into low temperature bath so that the water surface in each tube was lower than free surface of brine.

All the pure water was initially set to near 5 °C and cooled by brine of -10 °C in the low temperature bath. And the cooling rate of pure water in test tube regards as constant