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Investigation on concentration characteristics of ozone micro-bubbles fixed in ice and ozone gas released from ice

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ABSTRACT

Ice formed from water in which ozone gas is dissolved is promising for the cold storage of foods because of the ozone's sterilization and deodorization capabilities. However, effective dissolution of ozone gas in water and taking ozone gas into ice are not easy. Furthermore, the decomposition rate of the ozone itself is usually very fast, regardless of its phase. Thus, to effectively take ozone gas into ice, the authors have developed ice containing ozone micro-bubbles. In this paper, ice containing ozone micro-bubbles formed by adding surfactant was kept for a desired time at a desired constant temperature without melting of the ice. The concentration of ozone micro-bubbles fixed in ice and the ozone gas concentration released from ice by melting were measured to investigate the ozone decomposition rate due to fixation in ice and the characteristics of the released concentration. Furthermore, the influences of surfactant on both concentrations were examined.

Etude des caractéristiques de concentration de micro-bulles de gaz d'ozone fixées dans la glace et émises de la glace

Mots clés : Glace contenant des micro-bulles ; Sterilization et deodorization ; Agent tensio-actif ; Concentration de gaz d'ozone ; Fixation ; Fusion

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1. Introduction

Use of ozone to prolong the freshness of perishable food has gradually increased because of its sterilization and deodorization capabilities (Ikeda et al., 1998 (in Japanese); Mohammad et al., 2009). The effects of sterilization and deodorization are caused by the strong oxidizability of ozone. However, taking ozone gas into ice and the effective dissolution of ozone gas in water are not easy because of Henry's law. Furthermore, regardless of the liquid or gas phase, the decomposition rate of ozone is usually very fast, and the decomposed ozone gas is harmless. In one report, the lifetime of ozone in water is several tens of minutes (Sugimitsu, 1996 (in Japanese), Park et al., 2001); therefore, it is very difficult to prolong the freshness of food due to the ozone in water. Next, the use of ice formed by water, in which ozone gas was dissolved, was proposed for the cold storage of foods, but a pressure vessel was necessary for the first successful attempt of dissolution of ozone gas in water; therefore, high cost and the increase in equipment size are problems (Yoshimura et al., 2007 (in Japanese)).

Recently, ice in which ozone micro-bubbles were trapped was considered for the cold storage of foods. Inada et al. investigated how micro-bubbles were trapped in ice when water containing micro-bubbles was frozen in a copper cylinder (Inada et al., 2009). However, investigation on effective trapping of micro-bubbles in ice was insufficient. Thus, in the previous report, it was clarified that the optimal inclination angle of the cooling surface to effectively trap oxygen micro-bubbles in ice could be spread to 45° by addition of surfactant, after which the correlations among the average diameter and diameters distribution of oxygen micro-bubbles trapped in ice, the ice formation rate and the oxygen micro-bubbles content in ice, and influence of surfactant addition were clarified, using oxygen gas in place of ozone gas (Matsumoto et al., 2013).

In this paper, to suppress decomposition rate of ozone gas trapped in ice, the validity of fixing ozone micro-bubbles instead of ozone gas in ice and the influence of surfactant on the fixation are investigated. Moreover, the concentration of ozone gas released from ice due to melting and the influence of surfactant on the released concentration are also examined.

2. Experiment

Since the experimental apparatus to form ice containing micro-bubbles was fully explained in their previous report (Matsumoto et al., 2013), the authors briefly explain the apparatus here.

2.1. *Experimental apparatus to form ice containing ozone micro-bubbles*

As shown in Fig. 1, an ice formation component with an inner volume of 192 cm^3 is a box structure with walls constructed of acrylic resin and the bottom face made of copper plate with dimensions 80 mm × 80 mm × 10 mm. And the component is

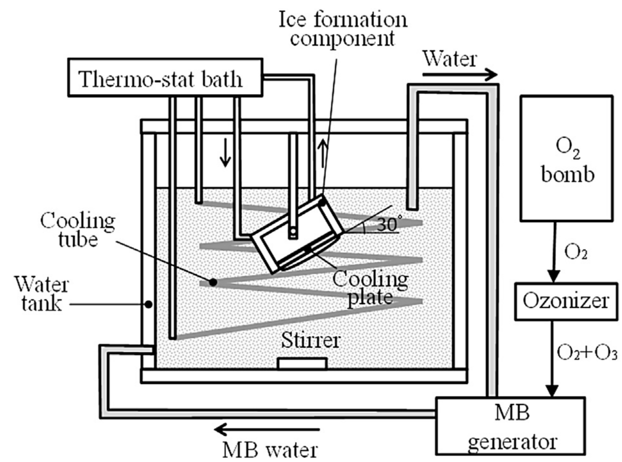

Fig. 1 – Experimental apparatus for formation of ice containing ozone micro-bubbles (Matsumoto et al., 2013).

set at an incident angle of 30° in an acryl resin water tank of dimensions 350 mm × 300 mm × 250 mm. A stainless steel coil is set in the tank and water in the tank is pre-cooled by circulating cold brine into the coil. Ice is formed on the copper plate by circulating the cold brine into the ice formation component. Electroless nickel plating is deposited on the surface of the copper plate because of the presence of ozone. The experimental apparatus is placed in a room with a temperature below 0 °C. Ozone micro-bubbles are generated by passing through a micro-bubble generator (pressing dissolution method) after supplying oxygen gas at 0.45 L min^{-1} to the ozonizer (silent discharge method). Approximately 7.5% of the supplied oxygen gas changes into ozone micro-bubbles.

The surface temperature of the copper plate is defined as the temporal average value of temperatures measured at the inflow and outflow sides of the cold brine onto the copper plate.

2.2. *Measurement method*

From the useful information obtained from the previous report (Matsumoto et al., 2013), a non-silicon surfactant, which is a food additive with defoaming property, is used at a concentration of 1 ppm. The product name of the surfactant is "awabureku L-01" and made by Taiyo Kagaku, Co., Ltd., in Japan. Similar measurements are carried out under the conditions with and without the addition of surfactant. For each condition measurements of ozone concentration are carried out four times, and the average value among four measurements is estimated.

2.2.1. *Ozone in water concentration*

The concentration of ozone in water is measured by the KI method (Sugimitsu, 1996 (in Japanese), Rachmat, et al., 2012). As shown in Fig. 2, in the KI method, iodine is isolated by the reaction of ozone in water and potassium iodide. The concentration of ozone in water can be obtained by titration of $Na_2S_2O_3$ in the acidic state.

Ozone concentrations in water immediately after the start and the finish of ice formation are measured by the KI method,