INTERNATIONAL JOURNAL OF REFRIGERATION 32 (2009) 394–401

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Vacuum freezing type ice slurry production using ethanol solution 2nd report: Investigation on evaporation characteristics of ice slurry in ice production

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ARTICLE INFO

Article history:
Received 6 October 2007
Received in revised form
12 September 2008
Accepted 13 September 2008
Published online 2 October 2008

Keywords:
Production
Ice slurry
Vacuum - ethanol
Aqueous solution
Measurement
Concentration
Evaporation
COP - sublimation

ABSTRACT

In this study, an original method for production of ice slurry from ethanol solution without using a refrigerator is proposed. As was introduced in the first report, this system has advantages compared with similar existing systems using materials other than ethanol solution. In this paper, the process of producing ice slurry using this method was observed, and the relationship between ethanol concentration of the solution and that of the vapor, which evaporated from the ice-solution mixture, was measured. It was found that the ethanol concentration of vapor was lower than that in the condition that did not produce ice. The composition of vapor was found to be affected by the sublimation of the ice produced. Finally, the COP of this system was estimated and the effect of sublimation of ice was investigated.

Production de coulis de glace à l'aide d'une solution d'éthanol et d'un processus de refroidissement sous vide. 2e rapport : étude sur les caractéristiques d'évaporation du coulis de glace lors de la production de glace

Mots clés : procédé ; fabrication ; coulis de glace ; vide- éthanol ; solution aqueuse ; mesure ; concentration ; évaporation ; COP - sublimation

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0140-7007/$ – see front matter © 2008 Elsevier Ltd and IIR.
doi:10.1016/j.ijrefrig.2008.09.004

Nomenclature

c_p	specific heat of solution, J kg^{-1} K^{-1}
COP	coefficient of performance
L^e	latent heat of evaporation, J kg^{-1}
L^f	latent heat of fusion, J kg^{-1}
m_{cyc}	mass of vapor circulated in the system, kg
m_{ice}	mass of ice, kg
m_{sol}	mass of solution, kg
m_v	mass of vapor, kg
M	mass of vapor per mol, kg mol^{-1}
P	pressure, Pa
Q_{ice}	cooling energy generated in evaporator, J
Q_{fin}	cooling energy generated by the end of the experiment, J
q_m	heat of mixing per unit mass of solute, J kg^{-1}
R	universal gas constant, J mol^{-1} K^{-1}
T	temperature, K
V	volume of vapor, m^3
W_{pump}	work for transporting vapor, J
X	ethanol mass concentration of liquid phase, wt%
Y	ethanol mass concentration of vapor phase, wt%
γ	specific heat ratio
θ	temperature, °C

subscript

1	evaporator
2	condenser
i	initial condition
cond	condenser
cool	cooled period
evp	evaporator
ET	ethanol
fin	condition at finish of experiment
H_2O	water
stab	stabilized period

1. Introduction

Recently, dynamic type ice storage systems using ice slurry have been the subject of a number of studies (Saito, 2002). Ice slurry is very suitable both as a refrigerant and as a thermal storage material, since it has many advantageous properties, such as its high fluidity and heat transferability.

The main interests for researchers can be classified as the "production", "storage", and "transfer and melting" of ice slurry. For "storage", Pronk et al. (2005) have investigated the variation of the characteristics of ice particles in ice slurry during long-term storage. Okawa et al. (2003, 2004) reported that the permeability of the ice/water mixture was increased by 24 h of storage due to variation of the shape of the ice particle. For "transfer and melting", Lee et al. (2006) and Knodel et al. (2000) measured the pressure drop and heat transfer coefficient of ice slurry flow in order to evaluate the effect of the existence of ice particles in the flow. Niezgoda-Zelasko and Zalewski (2006) considered the effect of a transition between laminar and turbulent flow types. For "production", a variety of methods have been investigated (Stamatiou et al., 2005). Matsumoto et al. (2004) and Oda et al. (2004) cooled and stirred a fluid consisting of an oil-water mixture with a small amount of additive. Yamada et al. (2002) oscillated a cooled plate in ethylene glycol solution to remove the ice produced at the surface. Hirata et al. (2003) produced ice around a cylinder and removed it using its own buoyancy. Tanino and Kozawa (2001) utilized the release of a super-cooling state of water to generate ice slurry. Watanabe et al. (1995) sprayed coolant drops onto water to produce ice within.

Authors have investigated a vacuum freezing type ice slurry production method using ethanol solution (Asaoka et al., 2006). Although the method was already introduced in the first report, the minimum explanation of the method will be repeated below for the discussion of this paper. In this method, ethanol solution, as the thermal storage material, is evaporated under a low-pressure condition, and the remaining solution is cooled and frozen as a consequence of the latent heat of evaporation. A circulating system to produce ice slurry is shown in Fig. 1. The system consists of an evaporator, a vacuum pump and a condenser. Ethanol solution, having been supplied to the evaporator, is then evaporated so that ice forms within. The vapor produced in the evaporator is transferred by a vacuum pump to a condenser. Condensed liquid is diluted in a concentration control unit and returned to the evaporator for re-use. Since no refrigerator is used in the vacuum freezing type system, loss of performance caused by ice sticking to the cooling surface is avoided. Using this circulating system, it is anticipated that ice slurry can be produced efficiently and continuously. Although some methods using other materials in the same way have been investigated, the system using ethanol solution has some advantages.

In the first report of this paper, the vapor-liquid equilibrium of ethanol solution was measured, which is necessary to estimate the ideal COP of the system. In this second report, ice slurry was produced using the vacuum freezing method and observations were made of the ice formation process along with measurements of the pressure and the concentration of vapor. Here, the words "concentration of vapor" and

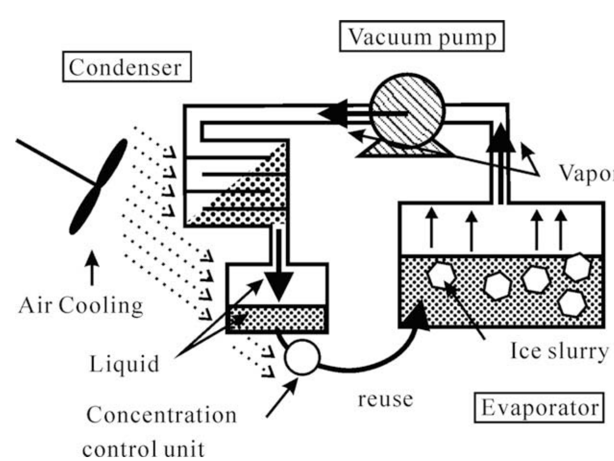

Fig. 1 – Schematic diagram of a system to produce ice slurry.