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Research Paper

Experimental study on the characteristics of ethanol solution's vacuum flash under adsorption condition

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HIGHLIGHTS

- The adsorption chamber combined with condenser coil is proposed for the vapor trapping.
- Explore the effect of ethanol solution flow rate and concentration on the vacuum ice making process.
- Adsorption condition can effectively reduce the peak pressure of ice slurry generator at initial moment of flash vapor.
- Low concentration of ethanol solution is favorable for ice slurry formation.

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ABSTRACT

Characteristics of ethanol solution's vacuum flash under adsorption condition were investigated experimentally. The temperature of cooling medium, ethanol solution flow velocity, and ethanol solution concentration were varied as experimental parameters. Explore the effects of these parameters on ice making process via controlling a single parameter. As results showed, adsorption condition can effectively reduce the peak pressure of ice slurry generator at initial flash moment. This peak pressure just reaches the minimum (800 Pa) when the cooling medium temperature in adsorption chamber is at 30 °C. The larger ethanol solution velocity of flow, the higher pressure when the whole system is stable in the same ethanol solution concentration. When the ethanol solution flow rate (velocity of flow) is at 5 L/h, the ethanol solution temperature can be reduced to −9 °C, which is more conducive to the production of ice crystals, but it may have ice blocking phenomenon. Ethanol additives can promote the solution to cool the temperature below 0 °C, and the higher the concentration is, the lower the temperature is. But for this ice preparation system, when the solution concentration is at 5%, it is more favorable to produce ice crystals. Through the analysis of all experimental conditions, 10 L/h of ethanol solution flow rate with ethanol concentration of 5% is the best ice production condition under the adsorption conditions.

1. Introduction

Ice slurry, also known as "fluid ice", refers to the solid liquid two phase solution, in which floating a large number of crystals particles average size does not exceed 1 mm [1]. Ice slurry has excellent heat transfer performance, high cooling, high latent heat value and reasonable energy consumption, which make it achieves the very high refrigeration efficiency and has good application prospects in mine cooling, medical protection, fire fighting and other fields. So the ice slurry has attracted more attention in the field of ice preparation at home and abroad [2–5]. Currently, there are mainly some basic types in ice slurry preparation. (Super cooled type, Scraper type, Ejector system, Vacuum type, falling film type.) The traditional refrigerants were used in addition to the vacuum process above all the methods, which was contrary to the domestic and international attention to the of the ozone layer. Vacuum ice preparation has many advantages: preparation process without the use of CFC or HCFC refrigerant, high thermal efficiency, simple structure and convenient operation. Domestic and foreign scholars studied extensively on the vacuum ice making [6–9].

However, there is a lot of water vapor in the process of producing ice slurry by vacuum evaporation, and the key problem is how to effectively capture and deal with this water vapor to maintain vacuum. Kim [10] adopted 7 wt% ethylene glycol solution to prepare the ice slurry device, and used two ways to maintain the vacuum degree, one was the combination of two stage booster and vacuum pump, the other one was combination of Liquid nitrogen and vacuum pump. Although the operation effect was very perfect, the cost of system was a little bit high by these two ways. Xu [11]

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designed a kind of vacuum flash chamber with a sandwich layer in which circulate low temperature refrigerant, and can trap water vapor, but the cost was high when the volume of the flash chamber was big. So find the economical way to removal of water vapor is the key of the ice making in vacuum.

Considering the use of waste heat and solar energy, the absorption or adsorption is the good choice to trap the water vapor. We have achieved some research results by absorbing water vapor to maintain vacuum requirement. Wu [12] developed numerical diffusion-control partial differential equations to describe droplet behavior at different chamber parameters. Results showed that low relative humidity can significantly reduce the droplet flash time. However, solid adsorption has not been used in ice slurry preparation by vacuum type. At present, based on adsorption mechanism, the use of solid adsorption system of ice with the characteristics of the energy saving and environmental protection payed the attention of the experts at home and abroad. Tamainot-Telto [13] established the adsorption experiment model of activated carbon-ammonia Based on the equilibrium equation and the heat convection equation, and the driving temperature of the whole experimental device was changed between 80 and 200 °C. Professor Wang, Shanghai Jiao Tong University, made a large number of experiments and obtained amount of research results on adsorption refrigeration [14–17]. Li [18] adopted solar energy as a solid adsorption refrigeration driven heat source, and developed a solar adsorption type ice making machine. These studies showed that the solid adsorbent can effectively trap the refrigerant vapor to realize the refrigeration. So adsorption bed used in vacuum ice slurry making system has great energy-saving significance.

In addition, ethanol can restrain the growth and recrystallization of ice crystals, and reduce the adhesion of ice crystals, it can make the ice slurry have good fluidity [19]. Tang [20] selected several kinds of alcohol additives to explore the effect on the growth of ice crystals. The experiment found that the alcohol additive could hinder the growth of ice crystals to some extent. So, select ethanol solution as experimental material to solve the recrystallization problem in experiment.

The main idea of this paper is that a single adsorption bed combined with condenser coil is used to trap vapor to maintain vacuum, and then explore the effect of adsorption on vapor capture and the characteristics of ethanol solution's vacuum ice slurry preparation.

2. Experimental apparatus and procedure

2.1. Experimental apparatus

As shown in Fig. 1(a), according to the experimental requirements, the experimental system was set up, including (1) vacuum creation equipment with vacuum pump; (2) vacuum maintenance equipment with pressure tank, adsorption chamber and condensation chamber. In condensation chamber, there is the condenser coil which is a part of the refrigerating unit (3) Agilent data acquisition and processing equipment; (4) ethanol solution supply control equipment with water tank, flow pump, flow valve; (5) ice slurry generator, in which ethanol solution is evaporated; (6) thermostatic bath, which is used to circulating the cooling medium.

Fig. 1(b1) shows structure diagram of the adsorption chamber. The adsorption chamber is cylinder, whose height and diameter are respectively 0.4 m and 0.2 m. It has inside a cooling medium coil circulating the cooling medium. There is a hollow tube that is vapor diffusion channel in the center of adsorption chamber. Its maximum loading capacity of 13× zeolite is 10 kg. The 13× zeolite are spherical particle, and water adsorption capacity of zeolite

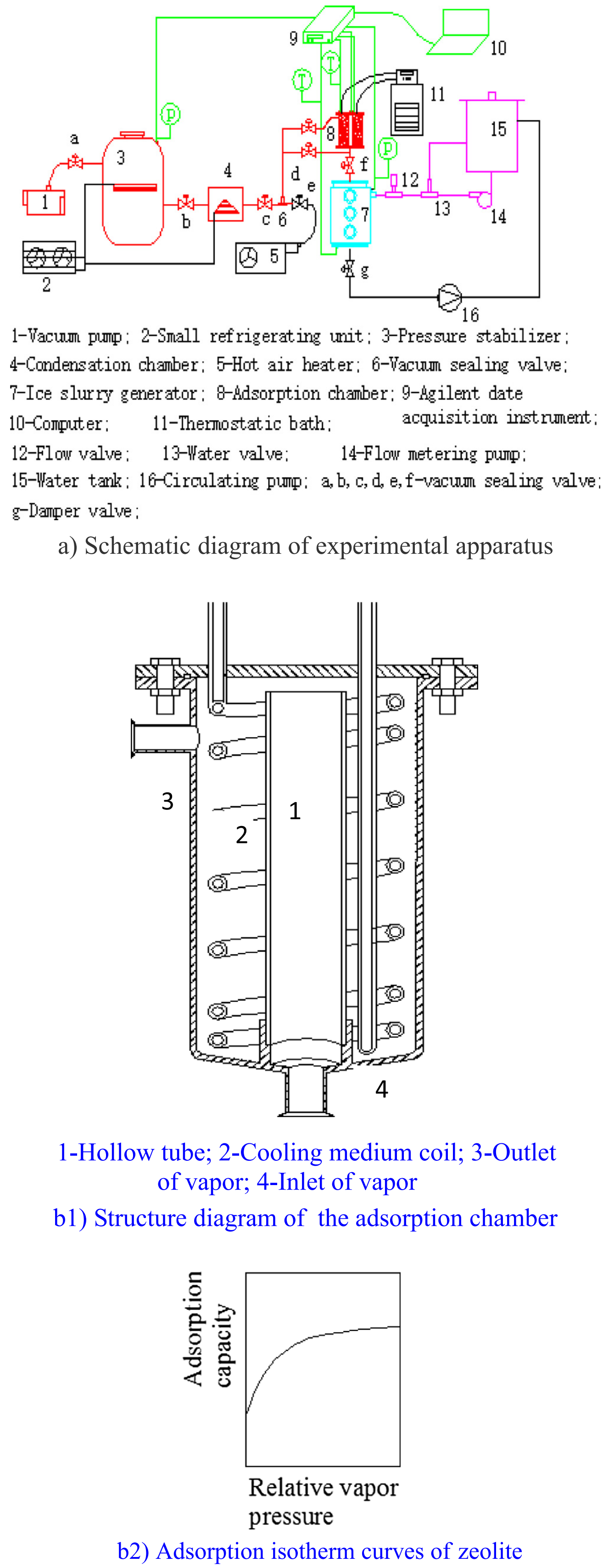

Fig. 1. (a) Schematic diagram of experimental apparatus. (b1) Structure diagram of the adsorption chamber. (b2) Adsorption isotherm curves of zeolite. (c) Structure diagram of the ice slurry generator.