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Review

Review of cold storage materials for air conditioning application

Gang Li, Yunho Hwang*, Reinhard Radermacher

Center for Environmental Energy Engineering, Department of Mechanical Engineering, University of Maryland, 4164 Glenn L. Martin Hall Bldg., College Park, MD 20742, USA

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ABSTRACT

This paper reviews the recent development of available cold storage materials for air conditioning application. According to the type of storage media and the way a storage medium is used, water and ice, salt hydrates and eutectics, paraffin waxes and fatty acids, refrigerant hydrates, microencapsulated phase change materials/slurries and phase change emulsions are separately introduced as suitable energy storage or secondary loop media. Water storage and static ice storage, which are already well-established technologies, have little need for further study. Dynamic ice slurry application is discussed especially for its generation method, relating to the efficiency and reliability of converting water or aqueous solution to ice crystals or ice slurry. Thermal and physicochemical properties of different phase change materials have been summarized including latent heat, thermal conductivity, phase separation, supercooling, and corrosion. Moreover, corresponding solutions for issues of different materials are also discussed. Thermal and hydraulic characteristics of phase change slurries (mainly about clathrate slurries, microencapsulated phase change slurries, and phase change emulsions) are discussed and summarized. In addition, the principle of the sorption cold storage is described and different kinds of working pairs are introduced. Relevant perspectives for commercialization of storage materials are discussed.

Matériaux à accumulation thermique pour les applications de conditionnement d'air : état de l'art

Motsclés : Accumulation thermique ; Matériau à changement de phase ; Microencapsulation ; Sorption

1. Introduction

Cold storage, which primarily involves adding cold energy to a storage medium, and removing it from that medium for use at a later time, has wide applications for air conditioning use in buildings, vehicles, and other conditioned spaces. By separating the maximum cooling and power demands in time, it can offer cooling while reducing or eliminating the peak

* *Corresponding author*. Tel.: +1 301 405 5247; fax: +1 301 405 2025.
E-mail address: yhhwang@umd.edu (Y. Hwang).
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electric power load of the buildings, and has benefits such as waste heat recovery and renewable energy utilization.

Cold storage technologies in air conditioning applications can be classified according to the type of a storage medium and the manner in which the storage medium is used. Previous research has provided summaries and reasonable analyses for most of the common storage media such as water and ice. Saito (2002) suggested that water storage and static-type ice, which are based on established technologies, have little need for further study. More topics have surfaced in recent years for promising phase change material (PCM) storage, in which the storage media options can include materials such as salt hydrates and eutectics, paraffin waxes and fatty acids, refrigerant hydrates including clathrate slurries, microencapsulated phase change materials (MPCMs) or slurries, and phase change emulsions. Moreover, utilizing sorption technologies for cold storage purpose has been developed recently. In this paper, a brief introduction is provided for water storage and ice storage technologies, while more detailed description is provided for more promising cold storage materials in air conditioning application.

2. Chilled water and ice slurries

Chilled water storage, which utilizes the sensible heat (4.184 kJ kg^{-1} K^{-1}) to store cooling, needs a relatively large storage tank as compared to other storage systems that have a larger latent heat of fusion. However, it has wide application because of its suitable cold storage temperature (4–6 °C). This characteristic enables it to be directly compatible with conventional water chillers and distribution systems, and provides good unit efficiency with a low investment. Ice storage uses the high fusion heat of water (335 kJ kg^{-1}), which can make storage tank much smaller. However, it stores cooling in the form of ice, which means that the refrigeration equipment must operate at temperatures well below its normal operating range for air conditioning application. Therefore, either special ice making equipment is used, or refrigeration chillers are selected for low temperature service.

2.1. *Chilled water storage*

Water is most dense at 4 °C and becomes less dense at both higher and lower temperatures. Because of this density–temperature relationship, this kind of storage system has the phenomenon of a stratified temperature distribution in a storage tank. Effective chilled water storage requires that some form of separation should be maintained between the stored cold water and the warmer return water. The mixing of two water streams at different temperatures, which is caused by the inlet diffuser during charge and discharge processes, significantly affects the temperature distribution in the tank. Here the two diffuser types most commonly used in today's commercial chilled water storage tanks are shown in Fig. 1 (Bahnfleth et al., 2003). Most studies related to this stratification tried to enhance the chilled water storage in terms of performance, simplicity, cost, and reliability. In a single stratified tank that stores both hot and cold water, diffusers are located at the top and bottom of the tank. Various physical methods, such as membranes, internal weirs, baffles, labyrinths, series tank, empty tanks, and thermally stratified systems, have been used to create the temperature stratification necessary for a high efficient storage (Mackie and Reeves, 1988; Dorgan and Elleson, 1993).

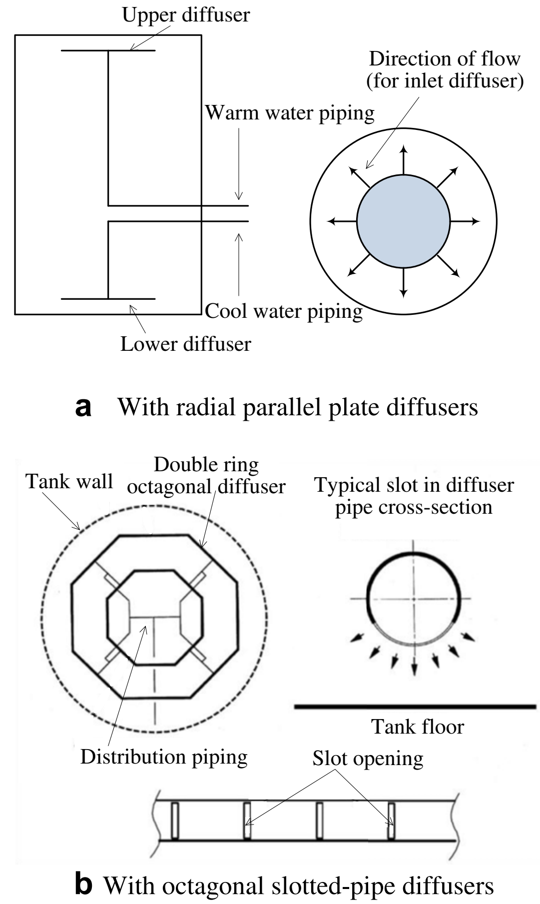

Fig. 1 – Stratified storage tank (Bahnfleth et al., 2003).

More attention has been paid to the numerical simulation for the transient behavior of the thermocline formation process in the thermal storage tank. Initially, one-dimensional simulation was developed. Cole and Bellinger (1982) developed a model based on tests performed in a scale model tank with a side inlet. Mixing was accounted for by a constant empirical mixing parameter, which is a function of the Fourier and Richardson numbers. They reported that their simulation results agreed with their experimental results both in the interior of the tank and at the tank outlet. The primary deficiency observed in this model was that it under-predicted the temperature below the thermocline. Truman and Wildin (1989) developed a model, which was found to be reasonable in predicting the tank storage performance. Other models such as an effective diffusivity model to quantify the inlet mixing effect caused by various inlet geometries were also developed (Zurigat et al., 1991; Ghajar and Zurigat, 1991; Caldwell and Bahnfleth, 1998). Later, many two-dimensional studies have attempted to simulate the thermocline formation process and were able to predict it reasonably. A steady state model was developed by Stewart et al. (1992) to study the effects of a submerged, downward-impinging flow from a slot in a chilled water storage tank. The flow was modeled