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A review on phase change cold storage in air-conditioning system: Materials and applications

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ABSTRACT

This paper reviews the previous work on phase change cold storage for air-conditioning systems focusing on two aspects including phase change materials (PCMs) and applications. Besides the studies on phase change cold storage devices, the typical air-conditioning systems with cold storage are also reviewed, namely the solar air-conditioning system with cold storage, latent cooling storage and transport system and mixed cold storage air-conditioning system. Moreover, the problems with respect to compatibility, heat transfer enhancement, phase change properties of composite PCMs, etc., are discussed for further investigation.

Contents

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1. Introduction

Cold storage plays an important role in conserving available energy, improving energy utilization efficiency and successful load shifting. The electrical energy consumption varies significantly during the day and night, especially in extremely cold climate areas where the major part of the variation is due to domestic space cooling. Therefore, cold storage air-conditioning, as an advocated energy-saving technology, offers a mean to alleviate the peak load on electricity grids and utilize power in the off peak period.

Ice storage is a frequently used cold storage method. However, the evaporating temperature of an ice storage air-conditioning system is lower than that of a conventional air-conditioning system by 8–10 °C, resulting in a decrease in the operating efficiency by 30%–40% [1]. Beside the ice storage, phase change cold storage method has been applied and gained popularity for many years. It employs phase change materials (PCMs) as the cold storage medium, and charges/discharges cooling capacity by the latent heat generated during the phase transition. Main advantages of the phase change cold storage can be summarized as: (1) the storage density of PCMs is 5–14 times higher than that of sensible heat storage materials [2]; (2) the phase change temperature can be adjusted according to the character of the air-conditioning system; (3) the refrigeration unit can operate under a single working condition instead of being integrated with a secondary refrigeration unit; (4) the system efficiency can be largely improved since a higher evaporating temperature is achieved; (5) the temperature swing of a phase change cold storage is much smaller compared with a sensible heat storage. However, there are always some practical difficulties in applying the phase change cold storage method owing to the properties of low thermal conductivity, density changes, poor stability under extended cycling, phase segregation and supercooling of the phase change materials [3].

Among diverse space cooling applications in buildings, this paper mainly focuses on water-cooled air-conditioning systems. The aim of this paper is to summarize some suitable PCMs for cold storage application and enhancements of the phase change behavior and heat transfer properties. Also, a review of optimization methods, including optimized structures of cold storage devices and air-conditioning systems that use a phase change cold storage to improve the energy utilization, is provided.

2. Phase change materials

Generally, PCMs for cold storage air-conditioning should have properties as follows: (1) phase change temperature corresponding to the practical range of the evaporating temperature; (2) large latent heat; (3) high thermal conductivity; (4) high freezing and melting rate; (5) large density; (6) small volumetric change between solid and liquid phase (7) freezing and melting congruently with minimum supercooling and without phase segregation, 8) stability in long term phase change behavior; (9) chemically stable, non-toxic and non-corrosive; and (10) low in cost. Based on this, optimization techniques for ideal phase change temperature, latent heat and thermal conductivity of PCMs have been widely studied. Current studies mainly concern tow aspects. For one thing, two or more kinds of PCMs are composited to achieve a required phase change temperature. For another, nanotechnology, microencapsulation and solvent absorption by solid are utilized to achieve appropriate thermophysical properties, especially better heat transfer efficiency.

2.1. Composite PCMs

The phase change temperature should correspond with the evaporating temperature of the air-conditioning system so that the working condition of the refrigeration unit and the cold storage unit can be concordant. Several classes of PCM are chosen and composited into binary or multiple mixtures for the purpose of obtaining a designed phase change temperature. According to the phase change temperature in concert with a certain functional air-conditioning system, the composite PCMs can be categorized as follows.

2.1.1. Composite PCMs for low temperature cooling systems

Cold air distribution is a familiar cooling supply application in which the supply air has a much lower temperature and smaller volume. Thus, its chilled water temperature is generally lower than that of a conventional air-conditioning system by 1.4–5 °C. Besides, the chilled water in many industrial air-conditioning systems has an even lower temperature. For example, food industries demand the chilled water at 2–4 °C and pharmaceutical industries generally require the solution temperature as low as −10 to −15 °C. There are many composite PCMs developed for low temperature cooling application in recent literatures, as listed in Table 1.

2.1.2. Composite PCMs for conventional air-conditioning systems

The chilled water temperature of a conventional air-conditioning system is usually about 7 °C, thus the PCM for cold storage should have a phase change temperature in the range of 5–10 °C. Some suitable composite PCMs are listed in Table 2.

It is reported that the COP of a refrigeration unit increases linearly with the increase of its evaporating temperature [14]. Thus, compared with conventional air-conditioning systems, the evaporating temperature of high temperature cooling systems, such as solar cooling systems and temperature and humidity independent control systems, is always higher in order to achieve a higher COP. Composite PCMs for cold storage of high temperature cooling application with a phase change temperature of 10–15 °C are listed in Table 3.

2.2. PCMs with special structures

2.2.1. Nano-composite PCMs

In order to improve the heat conduction, nano-scaled metal or metal oxide particles are added into the base fluid of PCM at

Table 1
Composite PCMs for low temperature cooling systems.

Ingredient	Type	Phase change temperature (°C)	Latent heat (kJ/kg)	Phase transition behavior		Reference
				Phase change band (°C)	Degree of supercooling (°C)	
Dodecanol–Caprylic acid (40.6:59.4 by quality)	Organic	7	178.6	/	2.5	[4]
Hexadecane–Tetradecane (2:3–0:1 by volume)	Organic	1.7–5.3	148.1 −211.5	≤ 3.2	1–2	[5,6]
Caprylic acid–Lauric acid (9:1 by mole)	Organic	3.77	151.5	8.23	/	[7]