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Performance enhancement of cold thermal energy storage system using nanofluid phase change materials: A review

Nor Azwadi Che Sidik[a,*], Tung Hao Kean[a], Hoong Kee Chow[b], Aravinthan Rajaandra[b], Saidur Rahman[c], Jesbains Kaur[c]

[a] *Malaysia – Japan International Institute of Technology (MJIIT), University Teknologi Malaysia Kuala Lumpur, Jalan Sultan Yahya Petra (Jalan Semarak), 54100 Kuala Lumpur, Malaysia*
[b] *Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia*
[c] *Research Centre for Nano-Materials and Energy Technology, School of Science and Technology, Sunway University, Bandar Sunway, 47500 Subang Jaya, Selangor, Malaysia*

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ABSTRACT

Cold thermal energy storage (CTES) plays a vital role in many industrial applications such as central air-conditioning in the large buildings, high powered electronic cooling applications, waste heat recovery, food processing, and restoring the electrical power imbalance between daytime need and night-time abundance. In addition, CTES system incorporating phase change materials (PCM) is proved as a viable option for achieving high energy efficiency by many systems. Due to the significance of this issue, many studies have been conducted on the applications of PCM in CTES system. The main aim of this article is to provide a comprehensive review, which summarizes recent research progress on PCM-CTES and an overview of numerical and experimental studies on the heat transfer performance of different base fluid of PCMs. This article also discusses several factors affecting the thermal conductivity of PCMs, such as nanoparticle enhanced PCMs, shape of encapsulated PCM materials, solid volume fraction and particle size. Observation and findings from past studies are discussed in detail. Recommendations based on research results, advantages and drawbacks of PCM-CTES are made for future research directions.

1. Introduction

Nowadays, township buildings are undergoing careful and detailed development by town planners. At the same time, building centralised air conditioning (AC) system such as District Cooling Plant, to serve the development of vicinity area has gained much consideration owing to its economic scale. According to Saidur [1], AC system is the biggest energy consumer of a building for temperate country like Malaysia, accounting 57% energy usage as shown in Fig. 1. Therefore, to reduce energy usage, cold thermal energy storage (CTES) is becoming viable in large centralised AC systems as latent energy storage.

CTES plays a vital role in many industrial applications such as central air-conditioning in large buildings, high powered electronic cooling applications, waste heat recovery, food processing, to restore the electrical power imbalance between daytime need and night-time abundance.

CTES stores cool energy via ice making during night time or off-peak period which is considered as unoccupied time since chiller is not required to cool down the temperature. On the other hand, it releases cool energy via ice melting to support the main chilling equipment during day time whereby it is considered as peak period since cooling is mainly needed for thermal comfort [2–5]. The maximum demand charge during daytime is minimised considerably while the installed capacity of chilling equipment could be reduced to half. The cooling load demand from peak hour is shifted to off-peak hour, making use of energy generated inefficiently by grid or power plant during night time to store ice [6,7] and hence, benefitting from lower electricity tariff rate and lower operating cost.

Fig. 2 is an illustration of estimated current cooling load demand profile from a typical development in city centre. The latent energy stored during charging at night time is released at day time for use. Note that the chiller is producing about 18,000RT as base load consistently during day time, far less from the peak load demand at an approximate of 29,500RT. The balance of 11,500RT (29,500RT − 18,000RT) will be topped from the ice melting, stored during night time. Hence, the electricity required during daytime is only equivalent to electrical energy of chiller plant to produce 18,000RT load and the balance of load demand has been shifted to

* Corresponding author.
E-mail address: azwadi@mail.fkm.utm.my (N.A.C. Sidik).

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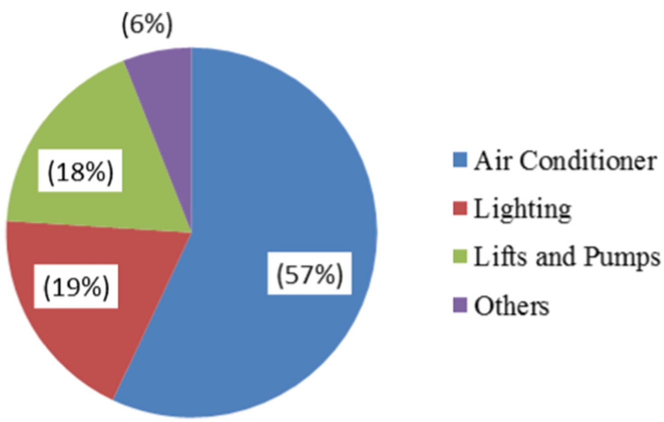

Fig. 1. Energy usage of office building (%).

night time.

The common type of CTES is ice on coil and ice ball system. For ice on coil, normally described as shell and tube construction, the coil is surrounded by heat transfer fluid (HTF) in a tank [8]. The outer surface of coil is in contact with the phase change material (PCM) where the cooling energy is transmitted from the coil at freezing point temperature, 0 °C during charging/icing and release back to the coil during discharging/melting process. For ice ball system, water and nucleating agent are filled in an encapsulated ball nodule, called ice ball. There are plenty amount of ice balls as PCM loaded in tank and immersed in HTF [9,10].

In early days, mixture of water and ethylene glycol of 25% concentration (EG25) is added in many applications. The purpose is to lower the freezing point of HTF so that it remains as flowing fluid at temperature below freezing point (0 °C to −12 °C) to circulate for heat transfer. This is for enabling charging and discharging process, mainly via convection to store or release cold energy. However, when EG25 is added, the average thermal conductivity of HTF is lowered [11]. As the specific heat capacity of the fluid is decreased, more circulating fluid is required to carry heat thus more pumping energy is needed to deliver higher flow rate. Therefore, improving the HTF thermal conductivity will enhance the CTES efficiency. One of the solutions is introducing foreign element of higher heat carrier capacity and thermal conductivity, known as nanoparticles which could improve the overall performance of HTF [12–14].

Recently, there have been few studies on the nanofluids performance CTES. For example, Qunzhi et al. [15] has observed that thermal response for water medium is slow due to its low thermal conductivity. By adding nanoparticles into water, the amount of cool energy stored increases. Meanwhile, Muhd Mustafizur Rahman [16] has conducted investigation on the fluid flow interaction during phase change process. The rate at which melting and solidification takes place with the influence of Grashof, Stefan and Prandtl is recorded.

It was also discovered by He et al. [17] that suspending a small amount of nanoparticles (1.13% by volume) in aqueous solution, the thermal conductivities of nanoparticle enhanced PCM was enhanced by 12.76% @ −5 °C and supercooling degree was reduced by 84.92%. Zhang et al. [18] used bio-organic nanofluid palmatic-stearic acid expanded graphite (PA-SA/EG) in their experiment, discovering good thermal stability and high thermal conductivities.

Teng [19] conducted experiments showing that combination of chitosan and nanoparticles to certain weightage has actually improved the thermal response and lower peak temperature for equivalent heat transfer. Chitosan is used to suspend the nanoparticles to achieve an even heat transfer in steel tank. However, putting too much chitosan will decrease the thermal conductivity of nanoparticles. He also pointed out that nanoparticles are favorable due to its nanoscale size as adding other additives in milliscale or microscale in size will cause blockage in piping thus increasing freezing temperature and reducing latent heat stored.

In a study by Wang et al. [20], they found that by using Cu-H_2O nanofluid, supercooling degree can be reduced and shorter freezing time was observed during cold storage process. Meanwhile, Ali et al. [21] conducted numerical investigation by lattice Boltzmann method demonstrated that introducing nanoparticles leads to enhancement of thermal conductivity of conventional PCMs.

Hence, there are many researches being performed for improving the thermal conductivity and overall efficiency of CTES. Most of the

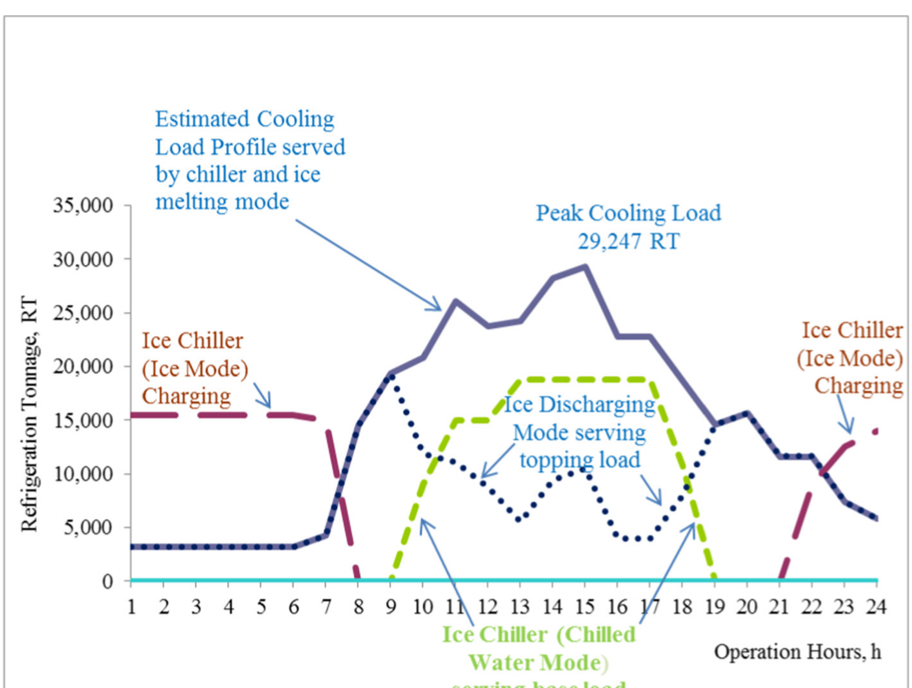

Fig. 2. Estimated cooling load of typical mixed development per day.