Applied Thermal Engineering 98 (2016) 246–255

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Parametric study of ice thermal storage system with thin layer ring by Taguchi method

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HIGHLIGHTS

- Thin layer ring has been studied statistically by Taguchi method.
- Material has the greatest impact on ice increased area.
- Arrangement has the second place of effect on ice increased area.
- Thickness has the trifling effect on ice increased area.
- The optimal condition (A3B2C1) of thin layer ring has been found.

ARTICLE INFO

Article history:
Received 9 September 2015
Accepted 4 December 2015
Available online 22 December 2015

Keywords:
Numerical
Ice formation
Ice thermal storage
Thin layer ring
Heat transfer enhancement
Taguchi method

ABSTRACT

A numerical study of material, thickness and arrangement of thin layer ring has been comparatively conducted to achieve heat transfer enhancement in the building thermal storage system. The parameters of thin layer ring from three perspectives have been numerically investigated and optimized by the Taguchi method to find the optimal combination. Nine combinations of model are carried out by combining different levels of each factor, and ice generated area of each combination has been statistically analysed. The results show that material and arrangement of thin layer ring have the most significant impact on the ice formation, but the thickness of thin layer ring has trifling effects on the ice formation. From this study, the optimal combination (A3B2C1) is acquired, and the reproducibility of the results is verified by two analytical results.

1. Introduction

Nowadays, ice thermal storage (ITS) system with a standard chiller has been widely used to store energy during off-peak hours and release energy during on-peak hours in order to reduce not only energy consumption but also the demand charges during peak hours [1], since thermal conditioning systems such as AC and other refrigeration systems take a share of 16–50% of the energy consumption among all the energy used in the building sector [2], while people spend around 90% of their time in buildings [3]. Using thermal storage system is a cycling process for energy transfer and conservation and provides a comfortable environment for people. Even through energy conservation is widely studied, peak demand conservation was not properly addressed until recently [4–6]. On the electricity bill, peak demand is accounted for 30% of total charges, so it is the most important because utility companies always require supplying sufficient energy to accommodate the expected increase in peak demand. Due to varying structures of electricity rates and the offered incentives, ITS system has been regarded as the most advanced and cost effective peak demand management method for space cooling [7–10] in different building applications that are mainly occupied during the operating hours, such as office buildings [11], hospitals [12], schools [13] [14], and churches and mosques [15]. The offset in electricity demand after using ITS system is accompanied by an improved system performance [16] and reduced total cost [17]. Therefore, technical performance of ITS system has a large impact on continuously improving the energy efficiency and reducing the environmental impact of industrial facilities. Nowadays, water or ice are the most attractive storage materials for HVAC field and have been widely used as phase change material (PCM) [18], since these materials are inexpensive, abundant and safe [19]. However, in the current ITS systems, the solidification of ice is not well developed which not only affects the cooling performance of the system but also wastes energy. In particular, there are some blind areas between the refrigerant cylinders with incomplete ice formation due to inefficient heat transfer which lowers the thermal storage capacity of the system. The duration of ice formation depends on three major heat transfer processes as shown on the top of Fig. 1:

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http://dx.doi.org/10.1016/j.applthermaleng.2015.12.038
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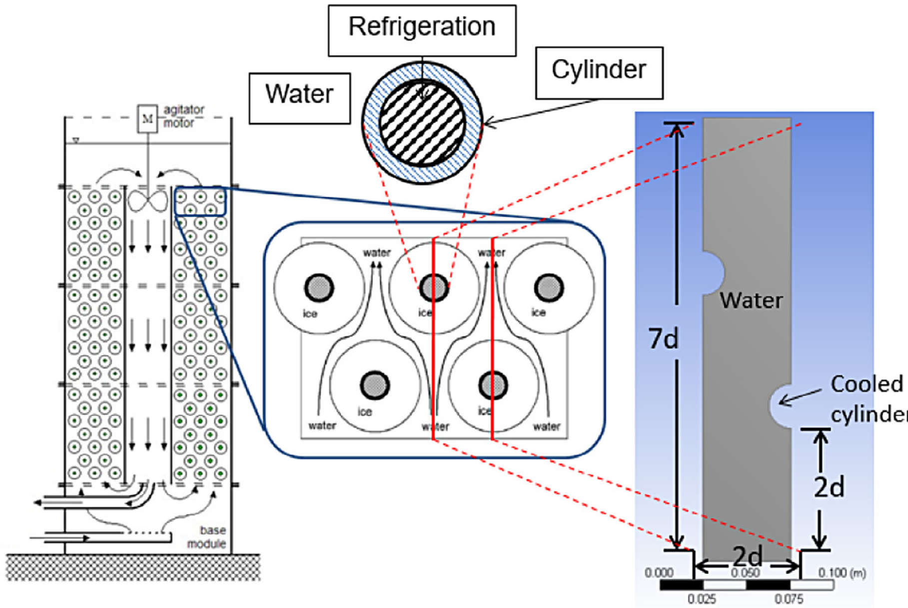

Fig. 1. Geometry of the ITS tank (left) [20] and the position of analysed rectangular space in the tank (right) [21]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

convection from the heat transfer fluid (refrigerant) to the refrigerant cylinder; conduction within the cylinder; and heat transfer from cylinder to the phase change material (PCM) such as water through conduction and/or convection. In the solidification process, the solid layer generated by PCM on the cylinder surface shortens the heat transfer duration [22].

There are many applications to improve heat transfer in the thermal storage system, but less in the ITS system [23–28]. Among them, the new application of thin layer ring structure has been demonstrated as an effective way [29]. The results show that ice generated area can be increased when using the thin layer ring structure during the same charging period, since energy can be transferred from water to the cooled cylinder through the thin layer ring more efficiently. The novel thin layer ring is used as extended fin to induce energy from not completely cooled region to the cooled cylinder. The mechanism of enhanced heat transfer is illustrated in detail in the previous work of Xie and Yuan [29]. In Fig. 1, the cross-section of ice tank is shown on the left side [20] and the investigated rectangular area is on the right side [21]. The three-dimension geometry of thin layer ring is shown in Fig. 2 from a construction point of view. However, this novel technology has not been analysed in details during the ice formation process, many different parameters could impact its performance on the solidification of water. Usually, the change in thermal conductivity of material would vary the rate of heat transfer. Meanwhile, the distance of transferring also affects conductive heat transfer within the transferring material. Because of the phase change occurring in an ITS system, it always happens firstly near the cooling source, the strategy or arrangement of transferring material also plays an important role, which needs to be taken into account.

The study focuses on the effect of material, thickness and arrangement of thin layer ring structure on the ice formation enhancement. It has been shown that the heat transfer performance of the thin layer ring is dependent on its material, thickness, and arrangement [29]. The ice formation with novel thin layer ring can be improved by increasing the thermal conductivity of a material. Copper, aluminium and stainless steel were tested in our previous study [29]. Thickness effect was studied from 0.5 mm to 2 mm, and the arrangement effect was investigated for the staggered arrangement and parallel arrangement. But these tests were limited by the number of factorial level.

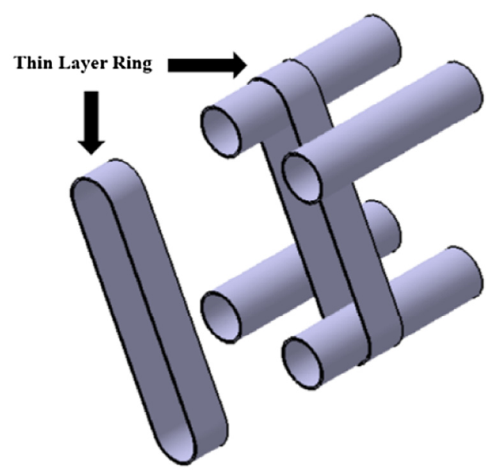

Fig. 2. Three dimension thin layer ring attached on the surface of refrigerant tubes.

In this study, the influence of various design parameters on the heat transfer enhancement with thin layer ring is analysed using numerical method in the rectangular space. The Taguchi method [30–32] is introduced into this study. The method is used to demonstrate a systematic procedure of using Taguchi parameter design in product design of thin layer ring applied in ITS system. It is also adopted to demonstrate a use of the Taguchi parameter design in order to identify the optimum thin layer ring performance with a particular combination of parameters in the ITS system application.

2. Numerical simulation of thin layer ring in ITS

2.1. Physical model

In the study, the cooled cylinder in the fixed rectangular space is considered as the investigated area for this numerical study. The