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Solidification behaviour of water-NaCl based graphene nanofluid PCM

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Abstract

This study aimed to investigate the solidification behavior of water-NaCl based graphene nanofluid PCM during solidification. The nanofluid phase change materials (NFPCMs) with graphene mass concentration of 0.30 %, 0.60 %, 0.90 % and 1.20 % were prepared and their respective solidification time was measured. The reduction in solidification time increases with the increased graphene nanoparticles volume fraction. For the NFPCM of 1.20% volume fraction, there is an appreciable reduction in the solidification duration of 33.33%.

Keywords: Subcooling, Solidification, Cool thermal energy storage, Nanofluid phase change material, Graphene nanoparticles.

1. Introduction

To achieve an energy efficient cooling for various applications is the most technical challenges in many industries such as refrigeration, air-conditioning, chemical, electronic cooling and manufacturing industries. Among the various energy consuming industries, the building sector consumes nearly 40 % of the world's energy consumption and there is a persistent interest among the researchers on conservation of energy and utilization of alternative energy sources. Moreover, the energy needs for several applications are time dependent as well as in a different phase and pattern, mainly in the building cooling applications. This imbalance between energy demand and supply has made the requirement of the thermal energy storage (TES) systems (Zalba et al., 2003), to store the hot or cool thermal energy either in the form of latent heat or sensible heat by using a suitable storage medium. Electric cost reduces through the integration of cool thermal energy storage (CTES) system by shifting the off-peak times during a day, particularly in the large building central air conditioning, refrigeration in supermarkets and various other places like base stations, telecommunication, where the cooling requirement is highly discontinuous.

The phase change material (PCM) in CTES system possesses number of advantages than the sensible storage for cooling applications, due to high storage capacity and phase transition in an isothermal manner. The review (Kumaresan V. et al., 2013) articles have been described on the heat transfer, materials and encapsulation geometry in the field of CTES applications. Because of high thermal transport properties of water, most of the CTES systems commonly use water as the storage medium. Only limited systems use the PCMs other than water like hydrated salts, eutectic mixtures and brine solutions. However, its high degree of subcooling which demands

the evaporator's operation at a temperature kept below the phase change temperature of water is the major problem of using water as the PCM in the refrigerator system. It is the well-known fact that with 1°C decrease in evaporator temperature, the specific energy consumption increases by 3 % to 4 %. The various techniques have already been suggested to minimize the energy consumption by decreasing the subcooling of water in the CTES system.

Due to advancements in the field of nanotechnology, a new concept of dissolving high conductive nanoparticles in the phase change material have been developed to boost up the thermal performance during charging/discharging process in the TES applications. (Kumaresan et al. 2012) conducted an experiment to study the heat transfer properties by enhancement of Nanofluid phase change material (NFPCM) during freezing. The dispersed Multi-walled carbon nanotubes (MWCNT) in paraffin (RT 21) at four different volume fractions. They noticed that the thermal conductivity increases with the increased concentrations of MWCNT and K is not depending on temperature. Also they observed that the MWCNT not only decreases; the solidification duration but also suppress the subcooling effect. They found that the heat transfer enhancement offered by NFPCM will improve the major problems that have been confronted in the conventional phase change material. The phase change properties of different PCMs like paraffin with various phase change temperature (Kumaresan et al., 2012), barium chloride, stearic acid and oleic acid have already been investigated and reported. Generally, their results discovered that the addition of nanoparticles leads to enhancement in the reduction in solidification/melting period and thermal conductivity compared to that of base PCM. It is also described that the effect of addition of nanomaterial on the latent heat of the PCM depends on the concentration of the nanoparticle. In addition, for CTES applications with the addition of alumina, copper oxide, copper and multiwall carbon nanotubes (MWCNT) subcooling in the PCMs is

the major problem is considerably reduced, mainly in water (P. Chandrasekaran et al., 2013). Recently, due to excellent thermal and electrical transport properties in number of potential applications, two-dimensional crystalline allotrope of carbon, graphene, receives much attention amongst the researchers (A.Sathishkumar et al 2016). Considering thermal properties of graphene nanoparticles and need to develop an energy efficient CTES system, the present study aims to investigate solidification performance of water-NaCl based graphene nanofluid PCM in a rectangular test module during their solidification at -15°C brine temperature.

2. Preparation of nanofluid PCM

The preparation of Phase change material (PCM) and nanofluid phase change material (NFPCM) is very important in the TES applications, due to phase change during charging and discharging process. The continuous thermal cycling increases the flocculation of the nanoparticles in the base PCM. A two-step method was used to prepare the water-NaCl based NFPCM. The materials, mixture of deionized water and NaCl as the base PCM, graphene nanoparticles as the nanomaterial were used to prepare the NFPCMs. Base PCM is prepared by proper mixing of 10% NaCl in deionised water. The graphene has 2–3 layers with an average thickness of 3–8 nm and particle size of 5–10 μm with a surface area of $\sim 250 \text{ m}^2 \text{ g}^{-1}$. The TEM image of the graphene nanoparticles is shown in Fig. 1. Before the graphene were dispersed in the base PCM, the ultrasonication of the graphene nanoparticles was carried out in water bath for a period of 40 min under dry condition. The GNPs were then mixed with the solution and the shear mixing was continued for 15 min and the mixture was transferred to the ultrasonicator. To disperse the graphene uniformly in the base PCM, the mixture was sonicated continuously for duration of 90 min. Four different sets of NFPCM having mass concentration of 0.30%, 0.60 %, 0.90 % and 1.20 % were prepared by using the same procedure. By using the scanning electron microscope (SEM), analysis of the size of dispersed graphene in the base PCM have been done. The thickness range of graphene is about 3–8 nm is shown in fig. 2. After ensuring the thickness of the graphene less than 200 nm, their corresponding solidification time was measured.

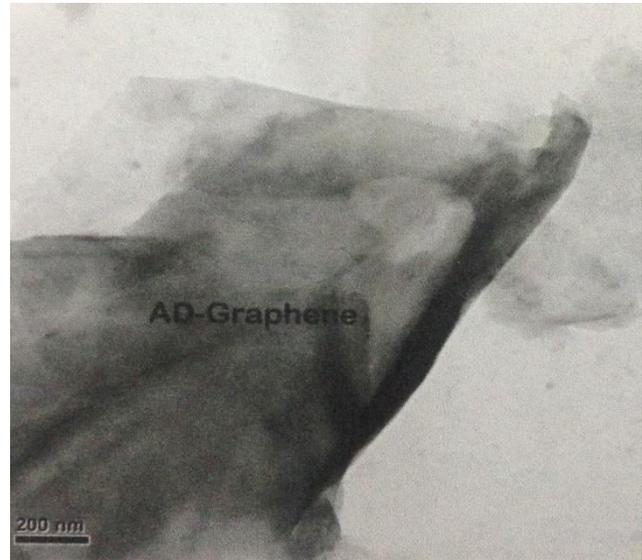


Fig.1 TEM image of the graphene nanoplatelets
(Source: Ad-Nano Technologies Private Limited, India)

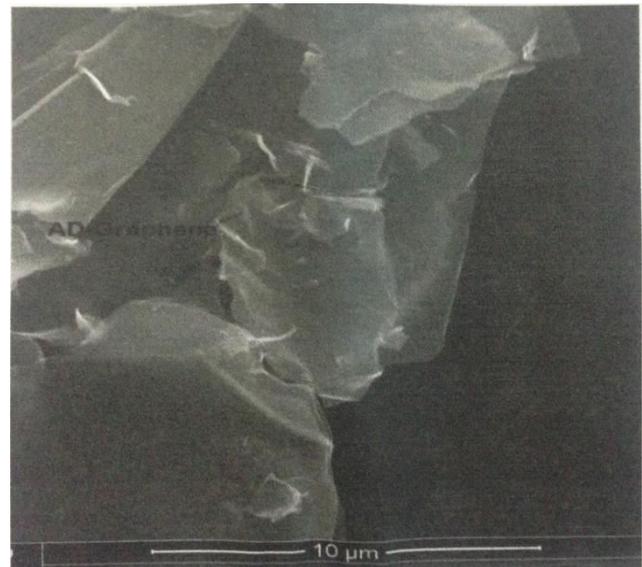


Fig.2 SEM image of the dispersed Graphene

3. Experimental setup

The Fig.3 shows of the schematic of experimental setup to investigate solidification behaviour of the water-NaCl based graphene nanofluid PCM. It consists of a stainless steel tank of capacity 18G which is thermally insulated and was fitted with a heating coil having capacity of 1800 W. Vapour compression refrigeration system consisting of compressor (C), condenser, expansion valve (EV) and evaporator (E). A mixture of ethylene glycol and water (50:50 by volume) was used as the the secondary refrigerant. By using proportionate temperature differential controller (PTDC) which regulates the output of the heating coil based on the temperature of the surrounding HTF, the desired experimental temperatures of the HTF was achieved. The required quantity of the NFPCM was measured using standard volumetric flask of class 'B' and it was transferred to rectangular test module made up of fibre having length height and wall thickness of 14.4cm, 21 cm, 2cm respectively. The rectangular test

module was filled up to its 75 % of total volume with NFPCM; in order to accommodate the increase in volume during the solidification of water-NaCl based PCM. Thermocouples were attached to the rectangular test module as shown in the Fig.3. The module filled with the NFPCM was placed in the bath which is maintained at a temperature of -15°C . The temperature variation of the NFPCM was continuously monitored. Readings were taken for every 30 s using a data logger until the temperature of the NFPCM attained the thermal equilibrium with the brine temperature.

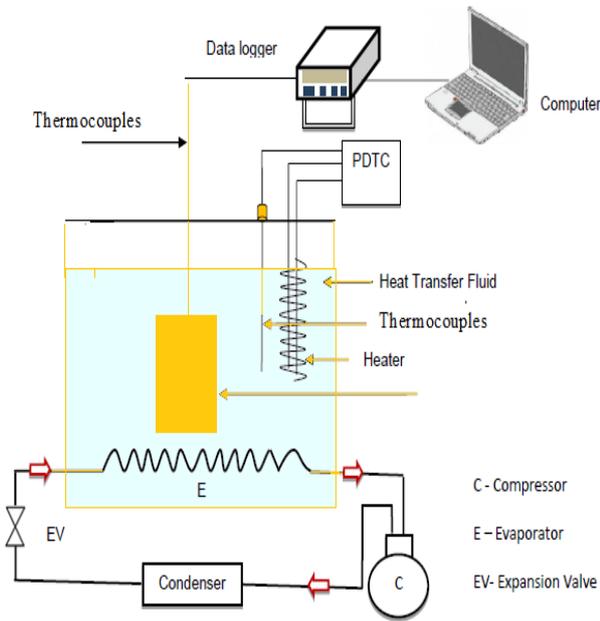


Fig. 3 Schematic of the experimental setup



Fig. 4 Actual experimental setup

5. Results and discussions

The effects of different concentrations of graphene on the solidification behavior of water-NaCl based PCM are discussed in this section. Fig. 4(a) shows the transient temperature variation of the NFPCM with different concentrations of graphene, throughout the

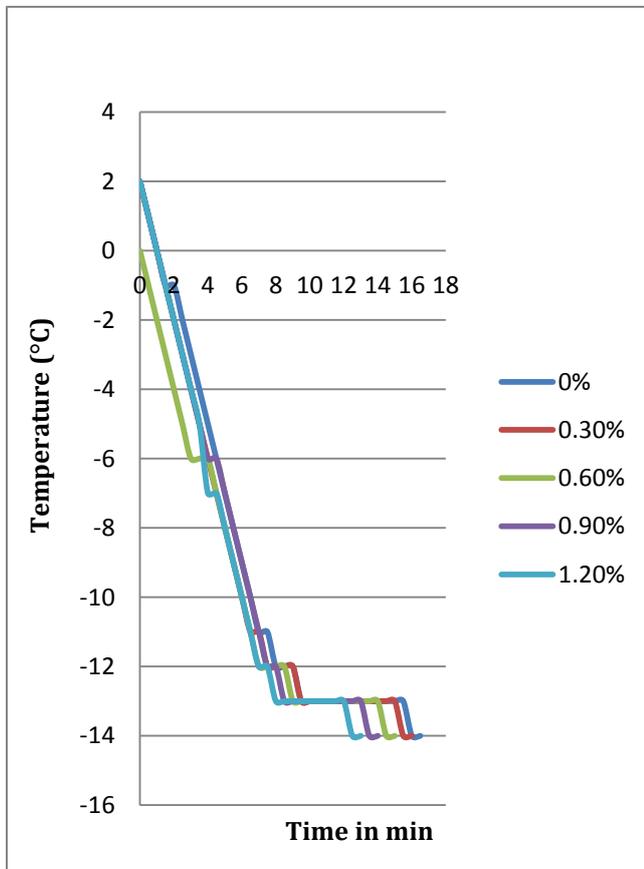
experimentation at the center of rectangular test module, when the surrounding bath/brine temperature was maintained at -15°C . It is observed from graph that the solidification duration was significantly reduced for the NFPCM containing maximum concentration of the graphene and increased with decrease in the concentration of graphene.

The experimental outcomes showed a remarkable deduction in the solidification period in case of all NFPCM compared to that of the water-NaCl base PCM.

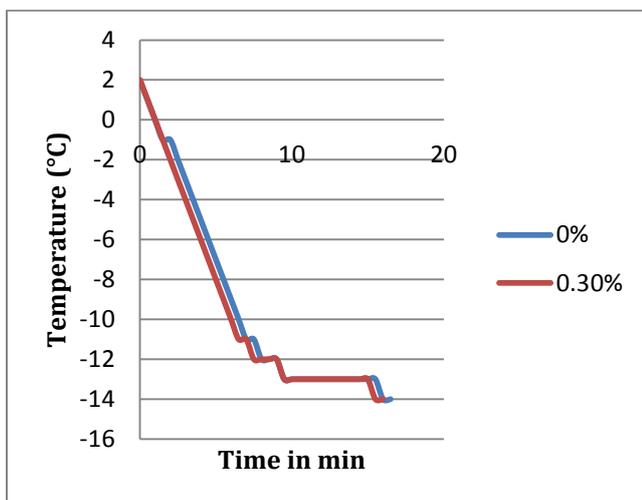
33.33 % of maximum reduction in the solidification period was observed in the NFPCM having 1.20 wt. % of graphene. The heat transfer rate enhances due to the presence of high conductive graphene layers with the large surface area in the NFPCMs.

Fig 4 (b) shows the exploded view of effect of NFPCM having 0.30% graphene. From experimental results, with the addition of 0.30% graphene in base fluid, 8.33% reduction in solidification duration has been observed. A significant reduction of 16.67 % and 25 % in the solidification duration was accomplished by increasing the graphene concentration in the base PCM from 0.60% and 0.90% respectively.

A relatively higher reduction in solidification duration was reported with addition of nano particles in the PCM other than water-NaCl based PCM. Mostly, the investigators used nanoparticles in water or in water-NaCl based PCM for cold thermal energy storage application with the objective of decreasing subcooling/solidification duration and enhancing thermal performance during solidification. It is understood from the above discussions that the degree of subcooling decreases with increase in the concentration of graphene nanoparticles in base PCM. This reduction in subcooling and enhanced thermal performance characteristics of the NFPCM will play an important role in the development of energy efficient refrigerator based cold thermal energy storage systems suitable for various industrial and domestic cooling applications.



(a)



(b)

Fig.4 Temperature - time history of water during (a) entire period of experimentation (b) exploded view ($T_{surr} = -15^{\circ}\text{C}$).

Conclusions

The solidification behavior of water-NaCl based graphene nanofluid PCM was investigated experimentally by varying the concentration of nanoparticles. The conclusions have been arrived from the present experimental results are as follows,

- 1) The solidification duration was considerably reduced by 8.33%, 16.67%, 25%, 33.33%, with the NFPCM containing 0.30%, 0.60%, 0.90% and

1.20% graphene nanoparticles compared to the water-NaCl PCM at the surrounding of -15°C respectively due to its enhanced heat transport properties.

- 2) The subcooling was significantly decreased for the NFPCM containing maximum concentration of the graphene and the subcooling increased with decrease in the concentration of graphene.
- 3) The presence of high conductive graphene acted as a nucleating agent to initiate the solidification in advance to that of water-NaCl PCM.
- 4) The pioneering advancements in the field of nanotechnology will play an important role in design and development of an energy efficient cool thermal energy storage system suitable for various industrial and domestic cooling applications.

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