Experimental investigation on reducing the solidification time of NFPCM by reducing sub cooling for different heat transfer fluid temperature for cooling applications

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Abstract. This study aims to investigate the solidification characteristics of water based nanofluid NFPCM (Nanofluid phase change material) with an aim to form an efficient CTES (Cool Thermal Energy Storage) system. Here we have taken base PCM as deionized water and Graphene is taken as nanoparticle because of its property of high thermal conductivity. The PCM was prepared by adding surfactant (0.2wt%) which is used to reduce the surface tension of the solution and then various concentration of graphene nanoparticle are added i.e. 0.2wt% and 0.4wt%, and the effect in solidification time and reduction of sub cooling is seen and studied. The enhanced heat transfer rate of NFPCM without sub cooling is advantageous for many CTES applications. So, finally it is constructed from experimental results that by embedding this technology with chiller systems which is used to cool large spaces can help us to conquer our motive to save energy and provide effective and efficient cooling.

1. Introduction
The increasing demand of energy in different sectors has led forward many researches on supply and demand of energy in effective and efficient manner. Among all sectors, building sectors contributes highest in consumption of energy. Renewable energy source is the best among other energy as it is sustainable and promising green technology. It includes solar energy, wind energy, biomass and geothermal energy. Solar energy and wind energy despite being more popular and efficient than other energy sources, the energy conversion and power generation is not consistent, as in night time no solar radiation is there and also during rainy season, the channel of receiving solar energy disrupts and bad weather conditions and off season includes wind energy system also [1]. The European Union (EU) has been working on framing and introducing new legislations for the reduction in energy consumption in all sectors and focusing on the concept of renewable energy. As building sector energy consumption is of total free energy which is 40% and same per cent of carbon dioxide emission as well [2].

Energy efficient heating and cooling systems can reduce CO₂ emissions by 2 GT and 710 MTOE of energy by 2050 [3]. Theory of energy efficient building states reduction in energy consumption without compromising thermal comfort and indoor environment of building. Regarding energy efficient buildings, many solutions have been introduced like passive cooling and heating strategies for reducing the energy consumption. Many research works has got commercialized and the solutions are

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available in markets. Among various strategies introduced above, Thermal Energy Storage is more popular, showing a good potential in improving the energy efficiency of building. For storing thermal energy, three concepts are generally used. 1. Sensible heat which is used in many applications but the drawback is low energy density and large variation in temperature during charging and discharging. 2. Latent heat, it is mostly preferred because of higher energy density and isothermal behavior during charging and discharging. 3. Hybrid storage system includes both sensible heat storage and latent heat storage [4].

Cool Thermal Energy Storage (CTES) system plays an important role in reducing the energy demand met by building air conditioning, food processing, industrial processes, cooling of electronics, etc in which large amount of heat is stored in a short duration of time [5]. It is good renewable means of way to improve refrigeration efficiency and reducing high electricity loads in buildings [6].

In regard to this, Phase Change Material (PCM) appears as a potential solution for energy efficient conditions as they can store more energy in the form of latent heat than other materials like bricks, clay, mortar, etc which stores sensible heat. There are various systems in which PCMs can be used as energy storage system as well as heat transfer fluid [7]. The PCM has major impact on thermal performance and efficiency of CTES system. Encapsulation of PCM includes the material properties and geometry, variation in volume during phase change and void volume of storage tank [8]. There are different geometries available for PCM encapsulation like cylinder and sphere but sphere is preferred mostly because it offers many advantages like favorable volume to surface area ratio of stored energy and heat transfer and it also has good porosity. Selection of PCM is very important as it affects heat transfer rate, solidification and need to be compatible with encapsulation material. The main characteristics required for good PCM are- 1. Thermo physical properties like, high latent heat of fusion per unit volume, high thermal conductivity, small volume during phase change, low vapour pressure during operating condition, high specific heat. 2. High nucleation rate and crystal growth. 3. Chemical properties include no corrosion, no degradation, non explosive, non toxic and non flammable [9]. Among various PCMs like organic paraffin and non paraffin, inorganic include salt hydrate and metallic, eutectic, water has many advantages over others. It has high thermal conductivity, high latent heat, abundant availability, no environment pollution, highly compatible with other refrigeration systems and high ratio of thermal conductivity to thermal diffusivity [10]. Use of pure water is not that beneficial as super cooling occurs during phase change.

The thermal energy is stored in PCM in the form of latent heat for better efficiency and it reutilized when it is needed. For energy storage, SHTES system requires larger vessel than LHTES systems [11]. In passive LHTES, PCM contributes to reduction in energy consumption, better thermal comfort and high building efficiency and this system can store 5-14 more heat energy per unit volume up to 50 kWh/m³ [12-13]. In sensible heat storage system, energy density is determined by specific heat capacity of storage medium and temperature difference. To increase energy storage density, latent heat is taken into consideration having phase change within temperature range of storage [14]. LHTES system finds application in thermal management in electronics and automobile engines [15].

The investigated of thermal performance of ice water cool storage in packed capsules was done and showed about 75% of energy was stored in water- ice as latent heat. They concluded that for practical applications, for achieving higher efficiency the sensible heat of ice should not be utilized due to low energy density and low cooling rate [16]. Hence, the proper understanding of solidification process inside TES system is important for designing of efficient storage system. When water is used as a PCM in spherical capsule, super cooling effect was observed at -5 °C and at that point no solidification occurred. On further reducing the temperature, same phenomena did not occur [17]. The super cooled water refers to state of metastable liquid even though the temperature of water is below its freezing temperature. This metastable state ends when ice nucleation occurs and thin plate like crystal of dendritic ice grows into super cooled region of water. During dendritic ice growth process, latent heat
released by dendritic ice gets consumed by super cooled water. If metastable state exists then thermal energy gets stored only in the form of sensible heat [18].

For the application of PCM and CTES system in building, the wall incorporated with PCM is able to capture large amount of solar radiation incident on walls of building [19]. High thermal mass of PCM walls leads to lower fluctuations in ambient temperature inside building. In Latent Heat Cool Thermal Energy Storage system (LHCTES) selection of PCM plays very important role in heat transfer by encapsulating suitable PCMs in walls and roof leads to enhancement in TES. The container should be designed in such a way that during phase change PCM volume changes and it should be able to absorb these volume changes and should also be compatible with PCM used. PCM is also increasingly used for food storage and transportation system.

2. Methods and methodology
In this experiment, Di water is used as a PCM which is dispersed with graphene nanoparticles and sodium lauryl sulphate as a surfactant. The factor which has led to selection of graphene for this study is its high in-plane thermal conductivity due to in-plane sp³ covalent bonding between carbon atoms and the coupling of weak Van der Waal forces at the outer plane. Another factor that favours the selection of graphene for conduction of heat in-plane is owing to its recurring assembly. Due to small in size, graphene nanoparticles has not caused any clogging in flow passages and their light weight enabled better stability Sodium lauryl Sulphate is commonly available synthetic detergent and surfactant. It is a white powder, has high pH value and manufactured from coconut oil. Its main function is to reduce surface tension at air liquid interface and it happens when we add graphene in solution which is collected on top and it resists mixing with the base PCM which is DI water.

The setup includes beaker filled with 180 ml of Di water, weighing SLS using digital lab weighing scale, further addition of measured sulphate in Di water, mixture formation using magnetic stirrer and repeat above steps with graphene nanoparticles. The volume of nanofluid required is 90% of the volume of spherical capsule and total four samples were prepared. The details of four samples are given in a table.

| Sample number | DI water used (ml) | GNP added (gm) | surfactant added (gm) |
|---------------|-------------------|---------------|----------------------|
| 1             | 180               | 0.00          | 0.00                 |
| 2             | 180               | 0.00          | 0.45                 |
| 3             | 180               | 0.45          | 0.45                 |
| 4             | 180               | 0.9           | 0.9                  |

Now the work is to investigate the solidification characteristics of NFPCM through the accumulation of nucleating agent at various temperatures to eliminate the subcooling. The procedure consists of filling of spherical capsule of 71 mm diameter with PCM, connect RTD with it and immerse it in an evaporator tank, connected RTD with capsule is also connected to data aggregation logger, varying the operating temperature, measuring the temperature and plotting curves to get the solidification time.
Figure 1. RTD sensor connection preparation.

Figure 2. Spherical ball filled and capped.
The experimental setup consists of constant temperature water bath which is made up of stainless steel coated with polyurethane to provide insulation and it has a capacity of 12 liters which contain 30% ethylene glycol and rest is water. This ensures that no freezing will occur at lower temperature near -20 °C. The bath is installed with evaporator that brings temperature of bath below 0 °C. The temperature of bath is constantly measured by RTD sensor and whenever the temperature reduces to required level, heating coil is activated which enables a constant temperature. The tank consists of stirrer which is mounted at the top of tank as it maintains the constant temperature of bath by stirring the water inside and prevents uneven cooling of ethylene glycol solution. A data logger is also used and all the RTD sensors are connected to it and it is further connected to the computer having software that monitors the temperature readings of whole setup.
3. Results and analysis

Figure 6. Freezing characteristics of DI water.

The above figure 6, it shows the freezing characteristics of DI water at different positions from the centre of shell. It has found that the solidification time for the centre of spherical shell is 4120 seconds, at 10 mm distance from center of shell is 3070 seconds and at 20 mm distance from center of shell is 1020 seconds. From further calculations it is concluded that the reduction in solidification time for the position of 10 mm from center of shell is 25.84% and for 20 mm distance from centre of shell is 72.82% with respect to centre of shell. From the figure we can observe that the subcooling for centre of spherical shell is found at 6.7 °C.
Figure 7. Freezing characteristics of DI water with 0.25% surfactant.

From the above figure 7, it is concluded that solidification time for the centre of spherical shell is 3800 seconds, at a distance of 10 mm from centre is 2820 seconds and at a distance of 20 mm from centre is 1360 seconds. The reduction in solidification time at a distance of 10 mm from centre is 25.65% and at a distance of 20 mm is 64.21% with respect to centre of shell. The above figure shows the subcooling for centre of spherical shell is at 2.08 ºC and after adding surfactant it is at 4.69 ºC.

Figure 8. Freezing characteristics of DI water with 0.25% GNP.

From the above figure 8, it is concluded that solidification time for center of shell is 3690 seconds, at a distance of 10 mm from centre is 2770 seconds and at a distance of 20 mm from the centre is 1280 seconds. The reduction in solidification time is found out with respect to the centre of shell so the reduction in solidification time at a distance of 10 mm from center is 24.93% and for 20 mm distance from centre it is 65.32%. The subcooling for centre of shell is at 0.82 ºC and after adding surfactant it is at 5.89 ºC.
4. Conclusion

- The percentage reduction in solidification time of DI water is observed to be increasing when graphene nanoparticles and surfactant are added in DI water.
- The subcooling of DI water is reduced up to the range of 5.5 °C.
- We conclude that the solidification time for DI water is reduced by the addition of surfactant and increasing the concentration of added graphene nanoparticles in DI water.
- We conclude that the subcooling in DI water is reduced by the addition of surfactant and increasing the concentration of added graphene nanoparticles in DI water.
- There was no sedimentation of prepared samples for a period of 4 weeks.
- As the solidification time reduces for different concentration of DI water, the overall energy consumption by the evaporator also reduces in air conditioning applications.

5. Reference

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