Heat Transfer Analysis of Graphene Reinforced PCM for Thermal Energy Storage

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Abstract. In this experiment, the charging rate of PCM is compared in the summer and winter seasons, while PCM does not charge effectively in winter season due to lower atmospheric temperature but such effects are not seen in summer season. The key objective of this analysis is to increase the thermal efficiency and charging rate by using different nano material concentrations (COOH) varying from 0.25 volume % to 0.75 volume %. This work also includes testing of thermal conductivity, density, specific heat and Nano fluid properties at varying functionalized graphene (COOH) concentrations and temperatures at the heat transfer fluid (HTF) inlet. Paraffin wax is implemented as a PCM in this process and carboxylic group (COOH) based graphene is the nano material used. The present research's outcome is that the PCM charging time decreases with increasing carboxylic (COOH) graphene concentration in terms of volume percentage. The charging time decreases with the mixing of carboxylic group (COOH) graphene concentration in this experiment in the winter season. The charging rate increases with graphene concentration, as opposed to without the nanomaterial PCM. In this experiment, In the short period of the process time, the significant volume of energy can be retained as charging period is decreased by 25% to 60% by the implementation the carboxylic group (COOH) based nano powder in PCM.

Keywords: COOH Graphene, Paraffin Wax, Nanofluid, Thermal Energy Storage Device, hot water used as HTF (Heat Transfer Fluid)

1. Introduction

Solar energy is energy which is translated by the sun into thermal or electric energy. The cleanest and most available potential renewable energy source is solar energy, and the U.S. has some of the world's richest solar electricity. This energy can be harnessed by solar technologies for a wide spectrum of technologies, including the generation of electricity, the supply of light or a suitable indoor climate, and the heating of commercial, industrial or residential water. Solar power is an extremely scalable electricity technology, it can be installed at the central station either as a distributed generation device or as a solar power plant (like traditional power plants). Using leading edge solar plus storage systems, each of these approaches can also retain the energy they generate for delivery after the sun sets. Thermal energy storage (TES) have been developed with the objective of being the efficient storage / release of thermal energy. The TES will be effective to climate change issues since, by effectively extracting heat energy from sustainable and clean energy sources, less fossil fuel can be used,
minimizing greenhouse gas emissions in the long run. The main category of TES systems are Thermal Energy Recovery of Sensible Heat. Inherent intermittency of the capital of renewable energies (such as Wind and solar power) raises the requirement for thermal energy approaches for storage (TES). For equilibrium in the imbalance between demand and supply for energy [1]. There are typically three types of different focus of TES technologies on energy storage media materials like logical heat storage, latent heat storage and thermo-chemical heat storage. Among the three energy storage methods[2, 3], As the storage medium has become a promising and desirable alternative, within a limited temperature range, latent heat storage using a phase change material (PCM) will release / retain a significant amount of energy. Zou et al.[4] suggested that the thermal reaction rate could be promoted by the injection into the shell content of high thermally conductive particles. In addition, during the use of the bulk PCM, the encapsulation technique is an important way to address issues such as leakage, corrosion and volume expansion. In order to position a slurry with improved energy storage ability and capacity of heat transfer, the particle size allows it to be quickly applied to the carrier fluid [5]. Qiu and Lin [6] observed that by increasing the micro encapsulated phase change material (MEPCM) concentration, the laminar energy transfer of the MEPCM slurry was constantly improved. To make solid composites, MEPCM particles can also be mixed with other compounds. Incorporated with MEPCM particles, owing to the decreased freeze-thaw periods by the latent heat of PCM [7], the MEPCM-concrete slab obtained a longer operating life. ShZh Zhenyu et al. [8] observed that in MEPCM-composite pavements, latent heat decreased temperature fluctuation and the risk of thermal cracking was smaller. Harish kumar Sharma et al. [9] observed that the charging time of phase change material (PCM) by using a combination of hybrid nanofluid (Zinc Cobalt Iron Oxide) and water as heat transfer fluid (HTF) increases the efficiency of the thermal energy storage system. Pramod kumar et al. [10] observed that in presence of carboxyl functionalized[11] graphene[12, 13] (-COOH) doped with PCM (Paraffin wax) to improve PCM thermal conductivity With a rise of 0.25%, volume concentrations ranging from 0.25 to 1 percent. Sujit kumar verma et al.[14] reviewed on fundamental structural improvements to further increase the thermal performance of solar collectors. In this work the charging time at various flow rates and various volume percent of carboxylic functionalized graphene as mentioned in the graphs are considered and analyzed. An increase in thermal conductivity or amount of functionalized graphene in volume percentage and increase in flow rate leads to decrease in charging time and increase in charging rate and this defines the novelty of the work. The reading for pristine paraffin wax was taken in summer and for various volume percent of carboxylic group functionalized graphene was taken in winter season.

2. Materials

2.1 Nanoparticles and PCM:
Properties such as high fusion heat and high capacity for heat storage are present in paraffin wax acquired from Ecosense Sustainable Solutions Pvt. Ltd Ltd. Carboxyl (COOH) group functionalized graphene was purchased from platonic nanotech private limited which was used in doping paraffin wax (PCM). The properties of paraffin wax (PCM) is shown in table 1.

| Properties         | Values                      |
|--------------------|-----------------------------|
| Solubility of water| ~1ml/L                      |
| Boiling point      | >370°C                      |
| Odour              | Odourless                   |
| Oil presence       | >0.23                       |
| Chemical formulation | C_{n}H_{2n+2}            |
| Melting point      | 45°C to 60°C               |
| Flash point        | 200°C -240°C               |
| Density            | ~ 0.9g/cm^3                |
2.2 PCM Composite preparation

Carboxyl (COOH) based graphene[15] nanoparticles[16] are mixed / doped with PCM paraffin wax in different volume amounts of 0.25%, 0.5%, 0.75%. First, the paraffin wax is melted with the support of electrical heaters until the PCM is fully melted. As the PCM starts to boil, nano content is applied and mixed / stirred, resulting in a PCM composite [17, 18], as shown in Figure 1, Figure 2 and Figure 3.

Figure 1. Before melting paraffin wax

Figure 2. Carboxylic graphene

Figure 3. After stirring and melting process
3. Experimental set up

As seen in Figure 4, the TES schematic diagram is packed with water in a cold HTF tank. Then the water is delivered by pump from the cool HTF tank to the HTF tank at the top of the unit. If there is a state of overflow, the pump is allowed to close and the electric heater is switched on to supply warm water to the heat exchangers. The water flows through the heat exchanger as the water gets sufficiently heated by means of electrical heaters and it runs through the spiral heat exchanger, the hot water dissipates the heat by convection and conduction, and the solid PCM melts by extracting heat from the HTF, which is water, to complete the charging process. In the used HTF reservoir, the used HTF is collected and the HTF flows constantly until the PCM is fully filled and melted. To have information of the temperature such as PCM inlet and PCM outlet temperature that is used in various energy calculation, the different thermocouples are placed on different cylinders.

4. Results and discussions

In this experiment, the PCM charging time will be reduced by increasing the cylinder charging rate. In PCM, the decrease in charging time is dependent on seasonal effects and nano graphene (COOH) concentration. We charged the cylinder containing paraffin wax in 5 to 6 hours in accordance with the seasonal impact in the summer season, but it was not possible in the winter season at that time. In this case we also have two forms in this situation, first the increasing thermal conductivity and second the HTF flow rate. The flow rate increment is the easiest way to reduce the charge time. After that case, when using higher thermal conductivity nano material, we increase PCM thermal conductivity, so the PCM charging rate increases due to high conductivity material. The reduction in charging time in this experiment is a contrast between the summer and winter seasons. Easily PCM (paraffin wax) is used in the summer season, while PCM cylinders containing nanomaterial of varying volume percentage accounts to the winter season. Our goal in this experiment is to reduce cylinder charging time in the winter season as opposed to the summer season. The air temperature during the winter season is nearly low at about 16 to 20°C under seasonal conditions. The air temperature is around 27°C or higher in summer season, however, the temperature of the PCM depends on the atmospheric temperature and thus the more time it takes to charge than in the winter than in the summer season. The melting point
of the PCM is from 58°C to 68°C. So, during the summer season, charging process of the cylinder is very convenient. Below mentioned graphs display every seasonal and flow rate effect.

Figure 5. Flow rate 50ml in 8sec

In figure 5, in every summer and winter season the flow rate of 50 ml in 8 seconds is assigned, while for every volume percent concentration of COOH based graphene reading is taken in the winter season. Paraffin wax melts fully in 5 hours at 57°C in the summer season. Although paraffin wax with nano particles takes more time to charge the cylinder at 0.25 percent volume in the winter season. For 0.5 and 0.75 percent of volume require much less time to charge the cylinder. In 2-3 hours, the PCM temperature reaches about 70°C.
In figure 6, the charging rate in this experiment explains the PCM temperature increase with nano concentration and time. Each state is compared with the basic charge rate of paraffin wax in summer season when there was no nano concentration in the PCM. The PCM temperature raises the ambient temperature in this flow rate to 57°C in 2-3 hours of charging time. Although the ambient temperature in the winter season is almost very lower relative to summer, the nano content PCM reached 80°C in 3 hours.

In figure 7, the rapid flow rate of 50 ml in 2 seconds is plotted for various concentration of functionalized (COOH) graphene and pristine paraffin wax. Though at a very high speed, higher temperature HTF flows. In summer season, the PCM temp rises 40°C (ambient temp) to 60°C in 100 minutes while we get 90°C temperature in winter season with 0.75 volume percent nano concentrations at the same time.

5. Conclusion:

In this experiment, PCM thermal conductivity does not enable or activate until the PCM temperature exceeds 40°C. At 40°C, PCM’s the physical transition i.e. melting and conversion to semi-solid state begins. During each experiment, with rising thermal conductivity, the temperature very easily overcomes the lowest atmospheric temperature in the winter season and at different flow rate like 50 ml in 2 seconds is mostly suitable for this process. According to statistics, as the time increases, maximizing the length of the operation, the large quantity of energy becomes waste, and hence, one should focus on the reduction of the charging time and then reducing energy loss. We can reduce the cylinder charging interval in any situation in which we can charge the cylinder in the winter season in less time by increasing the nano particle(COOH) based PCM concentration. We have an ideal time span for the same concentration in all graphs obtained. The desired result is 50 ml in 2 seconds with 0.75 volume percent, in which the cylinder stores energy and reaches 90 °C in 90 minutes. In this experiment, the PCM charge rate increases with increasing flow rate and graphene concentration. Graphene does not play any part in the rate of discharge. We noticed that when the PCM temperature
increases 40°C and reaches liquid state, then graphene thermal conductivity is activated. The cylinder is charged in 90 minutes at high temperatures due to increase in graphene concentration.

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