Experimental analysis of Thermal Efficiency of functionalized Graphene (COOH) reinforced PCM for thermal energy storage system

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Abstract. In this work, the emphasis is on the thermal conductivity of paraffin wax and nano material which is functionalized graphene (COOH). Firstly COOH graphene is combined in various concentrations with paraffin wax to achieve higher thermal conductivity and then it is analysed for thermal conductivity having flow rate of heat transfer fluid (HTF) as 50ml at 8 second. When COOH functionalized graphene is used in this experiment, the thermal conductivity of paraffin wax increases. This study included experiments on varying concentrations of functionalized graphene (COOH) and inlet HTF temperatures for thermal properties, density, specific heat and nanofluid properties. The graphene is combined by stirring it with the paraffin wax. Graphene concentrations are 0.25 volume%, 0.5 volume% and 0.75 volume% for the flow rate of 50 ml in 8 second. Thermal conductivity increases with increase in the concentration of graphene. In the winter season, where environmental losses are higher than the summer season and the air temperature is 18°C, while it is above 29°C in the summer season, it also reduces PCM charging time around 30 to 50 percent with the use of functionalized graphene. In all concentrations, HTF temperature varies from 80°C to 90°C, with observed input energy, environmental losses, charging time, charging rate and performance. All values are noted after a 10 minute interval, till the cylinder is fully charged.

Keywords: Thermal Energy Storage system, HTF, Carboxyl Functionalized Graphene, Paraffin Wax.

1. Introduction

Solar energy, light from the Sun that emits heat, induces chemical reactions and creates electricity. The cumulative volume of solar events on Earth is considerably more than the actual and projected energy needs of the planet. This strongly diffused source has the potential to meet all possible energy needs if suitably harnessed. As a clean energy source, solar energy is projected to become highly desirable in the 21st century because of its limitless availability of energy. The Sun is an incredibly strong source of energy, and sunlight is by far the greatest source of energy that the solar system provides, but its surface strength is currently very tiny. This is primarily due to the massive radial expansion of radiation from the distant Sun. The Earth's atmosphere and clouds, which absorb or spread as much as 54 percent of the incoming sunlight, account for comparatively small additional
losses. Almost 50 percent of the sunshine that hits the ground is cleared. Latent heat thermal energy storage (LHTES) systems, however, have cited more concern than sensible heat thermal energy storage (TES) because of the greater storage space, smoother running and thermal energy storage (TES) systems [1]. Present literature indicates that substantial research work has been carried out in various thermal device groups where phase change material (PCM), TES, and LHTES are used. The analysis paper by Soares et al. [2], for instance, summarized the uses of LHTES thermal control and energy conservation systems. The study on the application of TES to the solar thermal power plant was reviewed by Kumar and Shukla [3] et al. Soroush Ebad et al. observed that by using copper wire mesh with porosities of 87% and 75%, the maximum improvement in charging times could be 17 percent and 24 percent [4]. Pramod Kumar et al. [5] found that a thermal energy storage unit to test thermal efficiency doped with PCM (Paraffin wax) in the presence of carboxyl functionalized [6] graphene [7, 8] (-COOH) to increase PCM thermal conductivity. Volume concentrations ranged from 0.25 to 1% with a 0.25% increase. The charging time at different flow rates as defined in the graphs is considered in this novel work and an increase in thermal conductivity and flow rate contributes to a decrease in charging timing. Compared to sensible heat storage and chemical heat storage, latent heat storage is the safest heat storage strategy. There are several research involving different facets of organic PCMs. Alpha nano alumina [9], silver nanowire [10] and carbon nanotubes [11], etc., have improved the thermal conductivity of organic PCMs. Fatty acid [12], paraffin wax [13] and beeswax [14] thermal efficiency have been studied and improved. In addition, organic PCMs have been added to gypsum boards [15] too. The novelty of this work is that at lesser flow rate of 50 ml in 8 second or at 6.25 ml/second the concentrations of graphene is varied from 0.25 volume% to 0.75 volume%. In steps of 0.25 volume% and charging rate along with energy and environmental losses, energy accumulated and charging efficiency is found out for the PCM nanocomposite.

2. Materials and Methods

2.1 Selection of PCM, nanoparticles and its procurement

Paraffin wax acquired from Ecosense Sustainable Solutions Private Limited having properties such as high fusion heat and high potential for heat storage. The functionalized graphene group Carboxylic (COOH) was purchased from Platonic nanotech private limited that was used in doping paraffin wax (PCM). The nano particle and PCMs are procured as per reference [5].

2.2 Making of nanoparticle based PCM.

Graphene nanoparticles based on carboxyl (COOH) are mixed/doped in varying volume quantities of 0.25%, 0.5%, 0.75% with PCM paraffin wax. Next with the help of electrical heaters, the paraffin wax is heated until the PCM is fully melted. Nano material is added and combined/stirred as the PCM continues to simmer, resulting in a composite PCM. The manufacturing of the nano composite based PCM is as discussed in reference [5].

3. Experimental setup

In a cold HTF tank, the Thermal energy storage system (TESS) is packaged with water. The water is then delivered from the cool HTF tank to the HTF tank at the top of the device via a pump. The pump is allowed to close when there is an overflow condition, and the electric heater is turned on to provide the heat exchangers with warm water. The water flows through the heat exchanger by way of appropriate tubes as the water gets sufficiently heated. The hot water dissipates the heat through convection and conduction when flowing through the heat exchanger and the solid PCM melts to complete the charging process by absorbing heat from the HTF, which is stored in HTF water. The HTF used is stored in the used HTF tank and the HTF flows continually until the PCM is completely loaded and melted. The multiple thermocouples are mounted on specific cylinders nodes to provide temperature data such as PCM inlet and PCM outlet temperature that is used in energy. The schematic diagram of TES with different parts and experimental setup is as per reference [5].

4. Charging period analysis
\[ E_{\text{in,chg}} = m\, \text{HTF} \, C_{\text{HTF}}(T_{\text{HTF,chg}} - T_{\text{amb}}) \times \text{time}_{\text{chg}} \]  \hspace{1cm} (1)

\[ E_{\text{loss,chg}} = q \times L_{\text{ins}} \times \text{time}_{\text{chg}} \]  \hspace{1cm} (2)

\[ E_{\text{acc,chg}} = E_{\text{in,chg}} - (E_{\text{loss,chg} (i+ii)} \)  \hspace{1cm} (3)

\[ E_{\text{loss,chg} ii} = m\, \text{HTF} \, C_{\text{HTF}}(T_{\text{HTF,chg}} - T_{\text{amb}}) \times \text{time}_{\text{chg}} \]  \hspace{1cm} (4)

- \( E_{\text{in,chg}} \) = input energy
- \( E_{\text{loss,chg}} \) = environmental losses
- \( E_{\text{acc,chg}} \) = energy accumulated
- \( E_{\text{loss,chg}} \) = energy loss without absorption
- \( C_{\text{HTF}} \) = specific heat capacity of water
- \( m\, \text{HTF} \) = mass flow rate of HTF
- \( T_{\text{HTF,chg}} \) = PCM inlet temperature during charging
- \( \text{time}_{\text{chg}} \) = charging time
- \( T_{\text{amb}} \) = ambient temperature
- \( T_{\text{HTF,chg}} \) = PCM inlet temperature during charging
- \( q_1 \) = Rate of heat transfer for HTF per unit length (W/m)
- \( L_{\text{ins}} \) = length of insulation

the formulas for analysis as well as the mathematical model is as per the earlier published paper of the author [5].

5. Result and discussion

Charging time in this experiment reduces with the help of graphene with the given flow rate and increasing volume percentage of functionalized graphene. In all observations, input capacity, losses, performance and charge rates are critical variables. The following concentration outcome becomes greater than the prior concentration. The primary focus is on energy inputs, energy conservation, and energy losses. The charging rates in this experiment are dependent on PCM input energy and absorption capability which in turn is based on environmental losses. Figure 1 in this experiment indicates a drop in the charge rate with an increase in graphene concentration.
Figure 1: Charging rate (temperature v/s time)

Figure 1 shows simply how to minimize charging time as the amount of graphene increases. The flow rate of HTF which is water is 50 ml in 8 second (6.25 ml/second), while the concentration of COOH-based graphene reading is taken in the winter season for each volume percentage. At 57°C in the summer season, paraffin wax melts completely in 5 hours. But in the winter season, paraffin wax with nano particles takes more time to charge the cylinder at 0.25% capacity. In order to charge the cylinder, 0.5% and 0.75% of volume need even less time. The PCM temperature reaches approximately 70°C in 2-3 hours.

Figure 2: Input energy v/s Time

Figure 2 indicates the input energy given by HTF, the dependence of input energy on HTF temperature when HTF temperature decreases, so the amount of input energy also decreases.
Based on Figure 3, energy environmental losses often released from device surfaces such as HTF tank surface, tubes, surfaces of insulation material. Such losses automatically rise in the winter season due to lower ambient temperatures.

Figure 4 shows the energy loss without absorption with respect of time. A significant volume of heat is not consumed in this process, which is completely lost. With the support of electrical motors for energy consumption, the hot water comes back to the HTF tank after the process. It depends on the input energy and PCM absorption capacity.
Figure 5: Accumulated energy (energy absorbed by PCM)
Figure 5 indicates the accumulation of energy. Accumulation of energy is the energy consumed by PCM which is used for charging of cylinder. In this case, PCM absorption capacity decreases with increasing cylinder charging temperature. But graphene concentration increase PCM charging rate and controls the absorbing capacity. At 0.75 volume% as shown in the graph energy accumulation is decrease steadily.

Figure 6: Charging efficiency of PCM
Figure 6 indicates the efficiency of PCM charging, the charging efficiency is also reduced with increasing PCM temperature and the temperature difference between PCM and HTF and is dependent on charging performance. With declining PCM energy absorption power, charging efficiency
decreases and in the winter season, environmental losses are rising, so energy losses are higher than summer season in the winter. As compared to others the charging efficiency of 0.75 volume% decreases very slowly due to rising PCM thermal conductivity of nanomaterial.

6.0 Conclusions

We found in this experiment that when the PCM temperature becomes 40°C, the PCM thermal conductivity is enabled or activated. The particles of graphene continuously oscillates to transfer heat at given flow rate which is 50 ml in 8 seconds or (6.25ml/sec), then the PCM thermal conductivity increase and charging rate suddenly increases itself due to high thermal conductivity of graphene. Along with the PCM energy absorption power, energy losses depend on the input energy. Such losses can be prevented to a certain limit, but cannot be avoided. PCM's energy storage ability also declines with a rise in PCM temperature due to the heat transfer from higher temperature to lower temperature. With the increase in the concentration (volume %) of Graphene, charging time decreases. Paraffin wax was used as PCM, and it takes 150 minutes for the PCM temperature to increase from 40°C to 57°C while the ambient temperature is elevated in the summer season. In the case of 0.75 volume% of Graphene doped PCM, the temperature rise from 18 to 70°C and it takes 150 minutes for charging. This kind of studies have been done for various applications like getting hot water in winter nights, solar cooker and solar greenhouse where the energy absorbed in charging during sunny days can be used to discharge during the night. These phase change materials also serves its purpose in battery thermal management system where the stored energy during charging can be discharged at the time of need.

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