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Original Article

Thermophysical Properties of Paraffin Wax with Aluminum Oxide, Copper Oxide, and MWCNT: An Experimental Study

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Abstract - *Energy storage is crucial to conserve energy and strive to make the most of it. PCMs (phase change materials) in the past ten years, researchers have examined a range of materials with phase changes for thermal storage of energy during the last 10 years, and Latent Heat Storage (LHS) is an efficient method for thermal energy storage. As a result, the LHS approach shows significantly higher energy storage and a slight temperature difference between heat release and storage. However, their efforts produce minor results due to poor thermophysical characteristics. In the present study, paraffin wax with 0.1% volume fractions of a phase change material, pure paraffin wax, has been compared to aluminum oxide (Al_2O_3), copper oxide (CuO), and other nanoparticles. Paraffin wax has a better liquid thermal conductivity than pure paraffin wax with 0.1% volume fractions of Al_2O_3 and CuO nanoparticles added, which improves it by 95.5% and 75.5%, respectively. Additionally, it was discovered that combining MWCNT additions significantly increased the paraffin wax's thermo-physical properties. It is known that paraffin wax based on 0.02% MWCNTs has a solid-state heat capacity that is 36.54% more than that of pure paraffin wax. As a result, paraffin waxes based on nano additions can be used in TES systems. This will improve the TES system's thermal performance, making it more suitable for use in all climates and locations without endangering the environment. It will serve as an alternative to the process of heating and cooling using fossil fuels. While research drives the development of organic PCMs and NEPCMs, there is ample opportunity for innovative thinking in the areas of energy-efficient and cost-effective cool and heat thermal storage systems. Also, the present study is fruitful for researcher scholars or industrial persons for better selection of nanoparticle-based PCMs in TES systems.*

Keywords - *Paraffin wax, Nanoparticles, Multiwall carbon nanotubes, Thermal energy storage system, Thermophysical properties.*

1. Introduction

The system for thermal energy storage is one of the best methods available for energy storage. In materials undergoing phase transitions, the TES system either releases or stores thermal energy during the melting or solidification process. Researchers worked on TES systems based on organic, inorganic, and eutectic PCMs based on the PCM classification. Based on their stability in temperature of melting and latent heat of melting, organic PCMs like paraffin wax and fatty acids are most suited for latent heat storage. Through 450 thermal cycles, it was discovered that the fusion heat in the TES systems based on myristic acid, palmitic acid, and stearic acid had decreased by 10% and that their volume had increased by 10% from room temperature to 80°C [1]. Melts (HAM), which have been studied for their heat-accumulating capabilities, are the most common heat accumulators due to the fact they can store thermal energy through chemical reactions and latent heat of melting, as well as solid/liquid fusion. Based on the buildup of high-potential thermal energy, ionic compounds, alkali and alkaline-earth metal fluorides, chlorides, carbonates, and sulfates have the best thermal properties. However, due to melting enthalpy, salt eutectics require the most energy. The biggest drawback of this kind of material is, however, the high price of collected energy given the expensive cost of the HAM [2]. A few organic and inorganic PCMs in the TES systems conducted thermal cycle testing to determine their thermal stability. Through DSC, the heat of melting and the melting point of PCMs were studied. Particular inorganic substances, including ferric nitrate, barium hydroxide, di-sodium borate, and sodium hydroxide, were shown to have lower thermal stability during a few heat cycles, which made them less suitable in heat storage systems. However, the inorganic PCMs, such as paraffin wax, were discovered to be the PCM in the TES system that is most useful. Paraffin wax possesses a melting point of 54ºC and a latent heat of 184 kJ/kg. It has been discovered that there is only a small difference after 1500 thermal cycles in melting temperature (up to 3ºC) and latent heat (up to 18 kJ/kg). The high energy density of erythritol makes it a PCM that can store heat energy at greater temperatures [3]. According to the DSC test, organic PCMs' charging temperature and heat of melting rise after a predetermined number of heat cycles somewhat gradually [4].

Materials with phase changes may be useful for devices that store and use thermal energy. However, due to their poor thermal conductivity, their charging and discharging rates are slowed down. The thermo-physical characteristics of PCMs are a significant shortcoming of PCMs based on the literature review. Researchers are developing PCMs based on additives that have enhanced thermal characteristics, improved latent heat, shorter charging and discharging periods, and less super coiling issues. The pace of discharging and charging of the LHS can be accelerated by adding high-heat conductivity of the PCM with nanoparticles. The effective thermal conductivity of energy storage systems is increased thanks to this technology, which also speeds up charging and discharging. While developing the nano-enhanced PCM, each of these elements needs to be considered, including homogenous dispersion, longer stability of the nanoparticles, and low or no aggregation of the nanoparticles in the PCMs. Researchers have discovered two methods for making NEPCMs: one step and two steps. These techniques are used in PCM-based TES systems likes: It is shown that organic phase transition materials exhibit dramatically increased thermal conductivity upon the addition of graphene platelets. A 140% increase in heat conductivity was achieved by combining 4% graphene with 1-octadecanol [5]. Thermal conductivity improved by 6%, 6.7%, and 7.8% in paraffin PCM with 2%, 5%, and 10% of nanoparticles added by adding Paraffin to CuO [6]. There was an increase in heat conductivity by 0.25 to 2.7 with 10% nanoplatelets by adding paraffin to graphite nanoplatelets [7]. The latent heat was raised by 20% when the PCM's mass percentage of nanoparticles was raised by 10% by adding Paraffin to Fe_3O_4 [8]. 35% higher thermal conductivity when paraffin is added to Si3N4. [9]. Mesoporous silica nanoparticles added to n-octadecane resulted in a 5% and 6% increase in thermal conductivity relative to the 3% and 5% mass fraction of nanoparticles, respectively [10]. At a volumetric concentration of 2%, the highest melting rate would be achieved by the nanoparticles by adding Paraffin wax to Al_2O_3 nanoparticles [11]. PCM's thermal conductivity for weight fractions of nanoparticles of 0.5, 1.3, and 5%, in that order, jumped by 12.7, 20.6, 46.6, and 80% by adding Palmitic acid to TiO_2 [12]. Therminol 66 added to CuO would cut the charging/discharging duration by 20% at a concentration of 5% nanoparticles in the heat transfer fluid [13]. At first, the presence of CuO in coconut has little effect, but with time, the dispersion of CuO nanoparticles in coconut oil increases the PCM's melting rate by adding Coconut oil to CuO [14]. At 10% of nanoplatelets, enhancement in Ks:102.2% and Kl:97.7%, Cps:52% and Cpl:64%, αs :47% and αl :54%, by mixing methyl palmitate, lauric acid, and 2-hydroxypropyl ether cellulose with nano-graphene [15].

Additionally, the PCM's thermal physical properties were enhanced by the application of carbon nanotubes with one or more walls (SWCNT/MWCNT), which enhanced the thermal performance of the TES system. Findings from studies employing a PCM-based TES system and SWCNT/MWCNT include 5% of MWNTs-based PA; the thermal conductivity was improved by 26% by applying MWCNT-Palmitic acid [16]. The thermal conductivity of PCM based on MWCNTs and graphene is 31.8%, 55.4%, and 124% higher than that of applying MWCNT/Graphene-Paraffin wax, PCM based on graphene, and pure PCM in that sequence [17]. CuS-MWCNTs-6 mass percent/PW has a greater thermal conductivity than MWCNTs-4.1 mass percent/PW when CuS-MWCNTs-Paraffin wax is applied [18]. At one mass% of MWCNT, Stearic acid and polyethylene glycol both had increases in thermal conductivity of 16.83% and 16.57%, respectively, by applying MWCNT- Paraffin wax, Stearic acid, and Polyethylene glycol [19]. In comparison with pure PCM, the 0.10 mass percent MWCNT ternary eutectic PCM increases thermal conductivity and heat transfer rate by 34.4 and 67.28%, respectively, by applying MWCNT -ternary eutectic PCM [20]. The thermal and electrical conductivity is improved by applying MWCNT-Polyethylene/Paraffin wax [21]. It has shown a decrease in the heat of melting and melting point temperature decreased by 36.37%, by applying SWCNT-Sodium chloride (NaCl) [22].

It is clear from the literature study above that PCMs played an important role in any TES system. However, due to low thermophysical properties, it is less efficient for the TES system. The thermophysical properties of PCMs will be improved by the involvement of nano additives. Insufficient comparative and collective information on nano additives with volume/mass fraction; in particular, researchers have provided PCM. Also, a comparison examination of the thermophysical properties of nano additives-based PCMs applicable for waste heat recovery has not been discussed properly. In this present article, a comparative study has been done on the organic PCM (paraffin wax) with nano additives such as (Al_2O_3, CuO, and MWCNT). The findings of the study help many of the researchers who are working on TES systems for waste heat recovery.

2. Experiment Section

The NEPCM for paraffin wax that uses MWCNT, CuO, and Al_2O_3 nanoadditives was made in a single process. In this procedure, melted PCM was mixed with nano-additives at 75 °C, and there was a magnetic stirrer employed to ensure that the PCMs were evenly and steadily dispersed. At 75°C, the mixture was agitated for thirty minutes and an hour. Last but not least, Figure 1 illustrates that samples crystallized at room temperature. The testing setup is shown in Figure 2. Figures 3 and 4 also display samples (in liquid and solid) of 0.1% Al_2O_3, CuO, and NEPCMs based on paraffin wax and 0.02% MWCNTs, respectively.

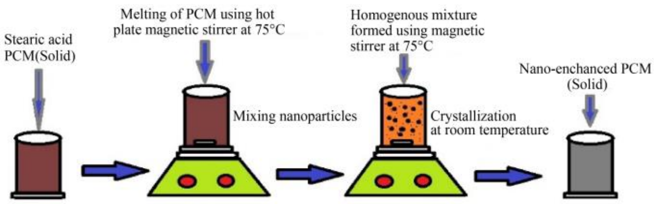

Fig. 1 Preparation steps of nano-additives based NEPCM

Fig. 2 Testing setup for nano-additives-based NEPCM

Fig. 4 Samples of NEPCMs (in liquid phase) (a) PW+0.1% Al_2O_3, (b) PW+ 0.1% CuO, and (c) PW+0.02% MWCNT.

PW+ 0.1% Al_2O_3 | **PW+ 0.1% CuO** | **PW+ 0.02% MWCNT**

Fig. 4 Samples of NEPCMs (in solid phase) (a) PW+0.1% Al_2O_3. (b) PW+ 0.1% CuO, and (c) PW+0.02% MWCNT.

3. Methodology

Using the latent heat of fusion was determined using PCM, with or without additives, and the T-History technique without sample stages, specific heat, or thermal conductivity (liquid/solid). A highly common, simple, rapid, inexpensive, and practical method for figuring out the thermophysical properties of any substance pure or dependent on additions is the T-History methodology. Common technologies that need very precise material sampling are heat analysis and differential scanning calorimetry (DSC and DTA, respectively), both of which are ability to assess modest volumes of information. The lumped capacity approach needs to satisfy the reference material (Bi<0.1). Two vertical test tubes are needed for this approach. Melted material filled the first test tube, which was maintained at a temperature above PCM's melting point. For comparison, the other test tube was poured with just pure water. After exiting the bath, the two test tubes were let to cool naturally. The test tubes around the contents were noted by the temperature profile of the temperature monitoring equipment.

Three zones can be seen in these temperature profiles: one for the PCM and one for the surrounding air. These zones are referred to as "liquid," "liquid-solid," and "solid". Likewise, these sites function as the PCM reference material. However, by entering the data, simple mathematical computation was used to derive the thermo-physical parameters. In the provided empirical equations.

The T-History approach expresses the solid-phase PCM/NEPCM's specific heat capacity [23].

$$c_{ps} = \frac{m_w c_{pw} + m_t c_{pt}}{m_{pcm}} \times \frac{A_3}{B_2} - \frac{m_t}{m_{pcm}} \times c_{pt} \tag{1}$$

The T-History approach expresses the liquid phase PCM/NEPCM specific heat capacity [23].

$$c_{pl} = \frac{m_w c_{pw} + m_t c_{pt}}{m_{pcm}} \times \frac{A_1}{B_1} - \frac{m_t}{m_{pcm}} \times c_{pt} \tag{2}$$

The T-History approach expresses the solid-phase PCM/NEPCMs' thermal conductivity [23].

$$k_s = \left[1 + \frac{c_{ps}}{h_{ls}} \times (T_m - T_w)\right] / 4 \left[\frac{t_f}{\rho_p R^2 h_{ls}} \times (T_m - T_w) - \frac{1}{h_w R}\right] \quad (3)$$

The expression for liquid phase PCM and NEPCM thermal conductivity using the T-History method [23].

$$k_l = \left[1 + \frac{c_{pl}}{h_{ls}} \times (T_m - T_w)\right] / 4 \left[\frac{t_f}{\rho_p R^2 h_{ls}} \times (T_m - T_w) - \frac{1}{h_w R}\right] \quad (4)$$

The T-History method's display of the latent heat (hls) of PCMs in their pure form [23]

$$h_{ls} = \frac{m_w c_{pw} + m_t c_{pt}}{m_{pcm}} \times \frac{A_2}{B_1} \times (T_o - T_s) \quad (5)$$

The NEPCMs' latent heat (h_{ls}) is displayed by [23]

$$h_{ls} = \frac{m_w c_{pw} + m_t c_{pt}}{m_{pcm}} \times \frac{A_2}{B_1} \times (T_o - T_s) - \frac{m_t c_{pt}}{m_{pcm}} \times \left(T_{f1} - T_{f2}\right) \quad (6)$$

4. Results and Discussion

The variation in the specific heat capacity of paraffin wax in its liquid and solid states with Al_2O_3 and CuO nano additives is depicted in Figures 5 and 6, respectively. When a substance is heated by 1 K (or 1°C), the amount of heat (J) absorbed per unit mass (kg) is the expression used to express its specific heat capacity. This number is expressed in J/(kg K) or J/(kg °C) units.

The liquid and solid stages of the mixture exhibited increases in specific heat capacities of 44.86% and 70.36%, respectively, over paraffin wax by the addition of 0.1% volume percentage of Al_2O_3. When a 0.1% vol. fraction of CuO was combined with paraffin wax, the specific heat capacities of the liquid and solid phases increased by 23.98% and 23.99%, respectively, above paraffin wax.

The disparity between paraffin wax's liquid and solid states' thermal conductivity with Al_2O_3 and CuO nano-additives is depicted in Figures 7 and 8. "Thermal conductivity," which is used to consider a typical description of a temperature gradient, is a unit area with a gradient of one degree per unit distance and the quantity of heat that goes through it in a unit of time; calculate the quantity of heat movement across a unit area per unit of time.

The thermal conductivity of paraffin wax was found to increase with 0.1% vol. percentage of Al_2O_3 nano-additives by 95.5% and 90.26%, respectively. Furthermore, CuO nano additives at a volume fraction of 0.1% were added, and paraffin wax's thermal conductivity was increased in both its liquid and solid forms by 75.5% and 72.11%, respectively.

The latent heat of fusion is one of a material's other crucial thermophysical characteristics. The amount of heat energy emitted when a substance melts at room temperature is defined as either absorbed or released. The difference in latent heat of paraffin wax with CuO nano and Al_2O_3 additions is shown in Figure 9; by incorporating CuO nano-additives and Al_2O_3 fractions of 0.1% vol, respectively, the latent heat of fusion of paraffin wax was seen to be lowered by 19.9% and 14.56% from paraffin wax.

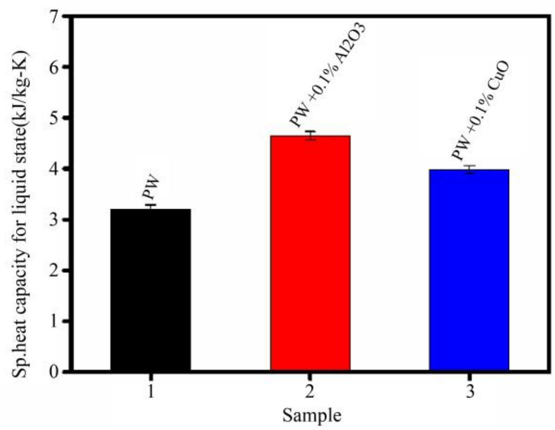

Fig. 5 Variation in Sp. heat capacity (liquid) of paraffin wax with Al_2O_3 and CuO nano-additives

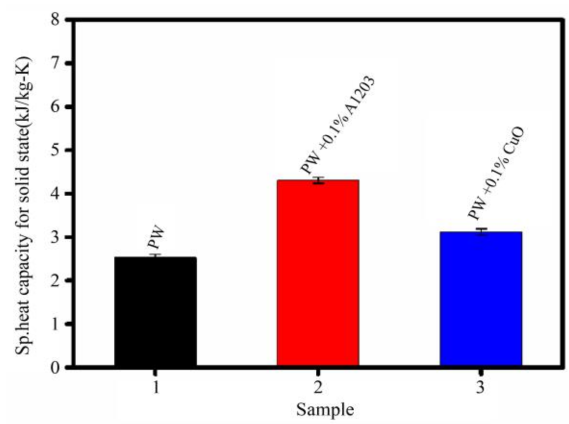

Fig. 6 Variation in Sp. heat capacity (solid) of paraffin wax with Al_2O_3 and CuO nano-additives

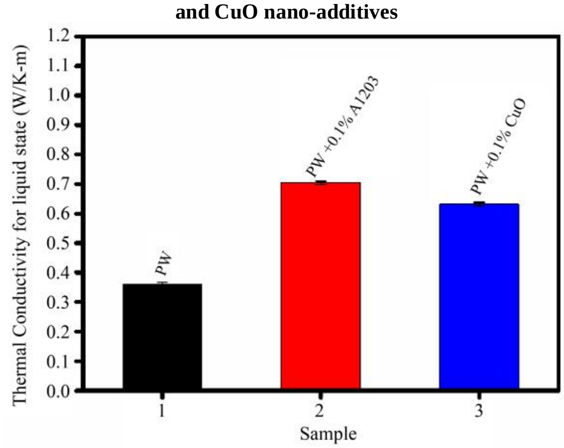

Fig. 7 Variation in thermal conductivity (liquid) of paraffin wax with Al_2O_3 and CuO nano-additives

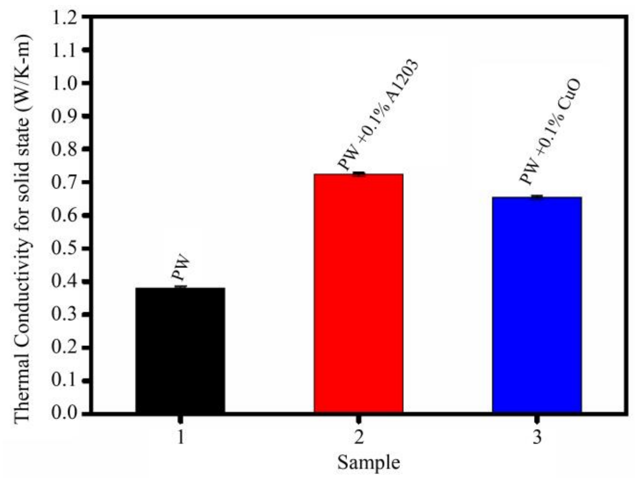

Fig. 8 Variation in thermal conductivity (solid) of paraffin wax with Al_2O_3 and CuO nano-additives

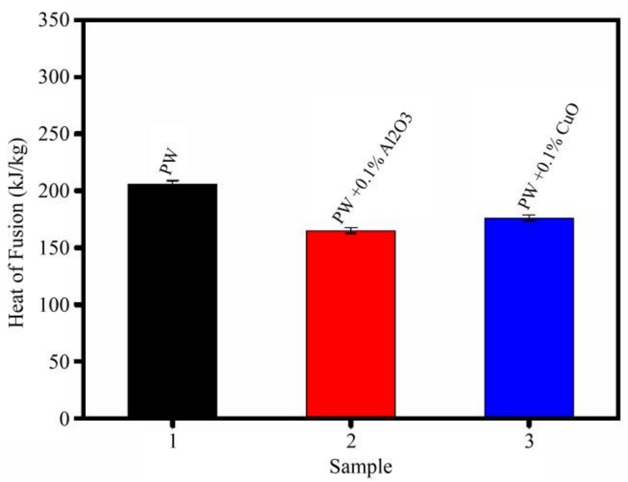

Fig. 9 Variation in latent heat of melting in paraffin wax with Al_2O_3 and CuO nano-additives

By combining MWCNT additions, it was discovered that paraffin wax's thermo-physical properties had significantly improved. As illustrated in Figure 10, it has been determined that PW composite PCMs have heat capacities for solid and liquid states with 0.02% MWCNT that were respectively 36.54% and 62.57% higher than PW phase-altering agents However, as Figure 11 shows, in comparison with pure PW PCMs, the thermal conductivity of 0.02% MWCNT in PW composite PCMs increased by 25.77% and 24.4%, respectively, in the liquid and solid stages. Additionally, the present study revealed, as illustrated in Figure 12, that the latent heat for PW composite PCMs containing 0.02% MWCNT was lowered by 35.95% in comparison to PW phase change materials that were pure. Due to a decrease in the fusion's latent heat, the TES system's operating performance was enhanced and required less time to charge. It was found that the MWCNT volume percentage in phase transition materials in PW composites ranged from 0 to 0.02%; the thermo-physical properties rose but decreased above this vol. fraction. It could happen when MWCNT particles settled out of PW composite phase change materials when they were present for 0.02% of the volume.

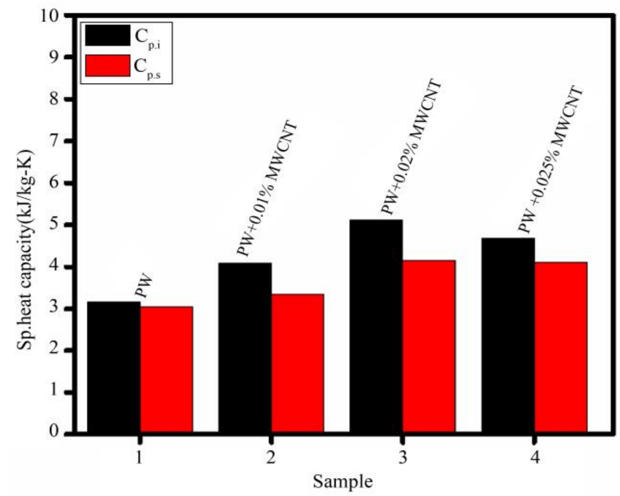

Fig. 10 Variation in specific heat capacity of paraffin wax with MWCNT

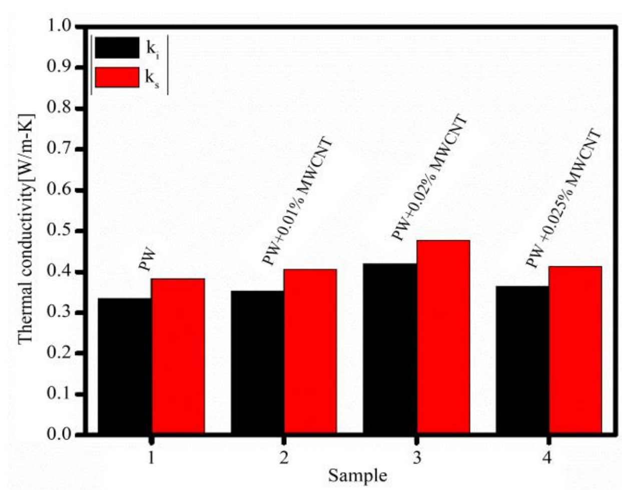

Fig. 11 Variation in thermal conductivity paraffin wax with MWCNT

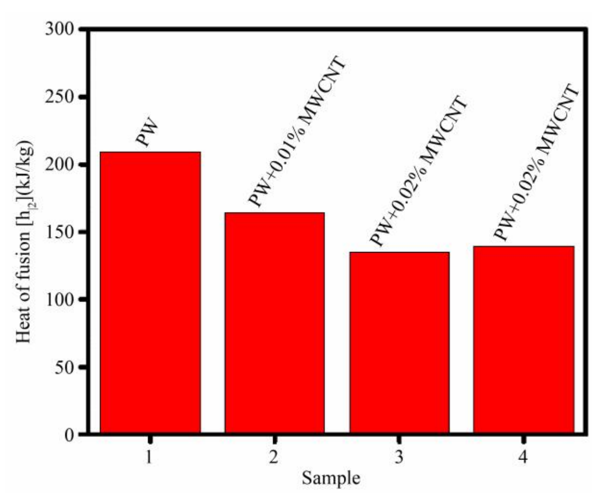

Fig. 12 Variation in latent heat of melting paraffin wax with MWCNT

5. Conclusion

This study found that paraffin wax with the optimal amount of nano additions in the vol. fraction significantly improved in terms of its thermo-physical characteristics. The conclusions are as follows:

- The liquid and solid's respective specific heat capacities of paraffin wax have improved by 44.86% and 70.36%, respectively, over pure paraffin wax because 0.1% vol. portion of Al_2O_3 was added.
- Paraffin wax's thermal conductivity increases by 95.5% and 90.26 percent in the liquid and solid states when CuO nano-additives are applied in a volume fraction of 0.1%, respectively, over pure paraffin wax.
- The addition of CuO nano additions and Al_2O_3 at a volume fraction of 0.1% to paraffin wax reduces the latent heat of fusion by 14.56% and 19.9%, respectively. The addition of 0.02% volume percentage of MWCNT to paraffin wax resulted in a 25.77% and 24.4% increase in terms of both liquid and solid-state thermal conductivity, respectively, compared to pure paraffin wax.
- MWCNT in paraffin wax, at 0.02% by volume, has better thermophysical properties than pure paraffin wax.

The results stated above indicate that adding nanoparticles is essential to improving paraffin wax's thermophysical properties. To apply Thermal Energy Storage (TES) technology for waste heat recovery, its thermal performance will be enhanced.

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