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Recycling of Waste Paraffin Wax by the Addition of SiO₂ Nano-Powders to Improve Thermal Conductivity

Abstract-Paraffin wax is an important material used in thermal energy storage (TES) systems. The thermal conductivity of the material is an important parameter that decides the degree of exploitation of the paraffin wax in TES systems. The thermal conductivity is improved by the addition of silicon oxide nanoparticles (1%, 2%, 4%, and 6%) to the paraffin wax. The average size of the SiO₂ particles is equal to 38 nm. The addition of SiO₂ nano-particles at very small ratios was found to enhance the thermal conductivity of the paraffin wax considerably. SiO₂ nanoparticles, add to paraffin wax, have a significant effect in enhancing the thermal storage characteristics of paraffin

Keywords :Thermal conductivity, waste Paraffin wax, SiO₂ nano powders

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1. Introduction

Ceramic nano-particles are potential candidates in the development of nanocomposites for many technological applications in mechanical, electric sciences, etc. [1-6]. Nano-powders have been used effectively to enhance thermal conductivity regarding the composite material [7]. Polymer composites of nano-elements may exhibit thermal conductivity at low levels, low thermal conductivity portrays paraffin wax as other PCMS. This character limits the absorption and energy release rate. [8]. Previous works have focused on different techniques for the enhancement of thermal conductivity of the polymer composites by adding metallic and nonmetallic nanoparticles that are known to have advantageous thermal properties [9,10].

Thermal energy storage (TES) systems are systems that utilize a certain amount of material (like salt hydrates, paraffin, and organic compounds) to store thermal energy at low or high temperature regarding other systems. They are used to store the excess of energy to be utilized in later times and purposes [11,12]. TES systems could be classified as latent heat, practical heat and thermo-chemical energy storage systems based on the energy exchange of the system. It is worth mentioning that some materials used in TES systems may exhibit disadvantageous properties such as low thermal conductivity and insufficient melting and solidification rates that reduce their applicability to certain requirements [13]. Waste paraffin wax is a by-product of the high-pressure olefin polymerization process [14]. Paraffin wax is an important TES material favorable to energy

storage applications for being environmentally friendly and because of its availability at a low cost. Paraffin wax can decompose by certain bacteria or grown biologically. It's melting point lays in the temperature range 54 – 66 Celsius, and that makes it appropriate for TES in flat solar collectors [15]. In the field of industrial uses, it is generally suitable for modifying the crystal characteristics related to paraffin wax, usually through the addition of branching to the presented carbon backbone chain. Typically, the modification is achieved with additives, like forms of polyethylene, microcrystalline wax, or EVA copolymers. The branched characteristics will lead to modified paraffin with modified functional features, smaller crystalline structure, and higher viscosity. Pure wax of paraffin is infrequently utilized to carve original models for the casting of metals and other materials in the lost-wax process, since it is quite brittle at room temperature and shows the risk of breakage and chipping when worked. Pliable and soft waxes, such as bee-wax, could be ideal for this type of sculptures, however, the "investment casting waxes," generally paraffin-based, are specifically formulated for the intention. Concerning a pathology lab, the paraffin wax is applied for the impregnation of tissue before the sectioning tissue's thin samples. The water will be eliminated from tissue by ascending alcohol strengths (75% to absolute), the tissue will be cleared in organic solvent like xylene, after that, the tissue will be placed in paraffin wax for a few hours, at that point it will be set in a mold with wax in order to cool and solidify; microtome will be used to cut the sections [16]. The direct-

synthesis method was used to produce nanocomposites materials by adding nano-silica (SiO_2) to paraffin. To demonstrate the feasibility of using nanocomposites materials in thermal storage systems, both the heat conduction and differential scanning calorimeter (DSC) experiments were used to assess the characteristics of nanocomposites materials and paraffin.

2. Experimental Section

Silicon dioxide (SiO_2) nanoparticles were added into the waste paraffin wax after being melted. The volume fractions of SiO_2 particles to the wax were fixed at (0%, 1%, 2%, 4%, and 6%) such additions are expected to be less than 10% to be cost effectuated and results into the requirement enhancement [17]. The mixture of the SiO_2 particles-molten wax was subjected to ultra-sonic mixing for 25 minutes at 65°C to achieve homogeneity of the distribution of the particles within the wax medium. the added nano-particle, then the photon spectrum will be different in these two materials. Besides, several frequency photon vibration modes are due to van der Waals interaction between paraffin and nano-particle, which are available to carry heat energy. At the melting point, the combined effect of photon mismatch and weak coupling with the matrix, the occurrence of high photon scattering results in high thermal interface resistance which reduces the capability of nanocomposites in transferring heat [18]. Figure 1 shows the specimens of the SiO_2 nanoparticle/wax composites. Before to specimens' preparations, dry SiO_2 nano-powders were analyzed by Fourier transformation infrared (FTIR) spectroscopy using 27- TENSOR/ Bruker FTIR spectrometer. X-ray diffraction patterns were recorded using XRD-6000 Shimadzu X-ray diffractometer utilizing $\text{Cu K}\alpha$ X-ray 40 kV applied voltage and 100 mA current. The thermal properties of specimens, in addition to the melting temperature were measured through the use of differential scanning calorimetry (DSC). The coefficient of the thermal conductivity of composite material under investigation was measured by Lee disk method which is appropriate for thermal conductivity measurement of poor thermal conductors. The coefficient of thermal conductivity k in W/m.K is determined from the following equation by placing the specimen between the two discs of the apparatus[19]

$$k = \frac{msd(dT/dt)}{A(T_1 - T_2)} \quad (1)$$

Where m , s , d are the mass, specific capacity and thickness of the lower disc in the Lees' apparatus. T_1 and T_2 are the temperatures of the upper and lower discs respectively. The details of the measurements are described elsewhere [19].

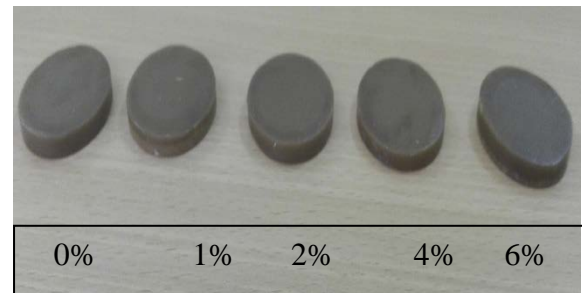


Figure 1: Specimens of the SiO_2 nanoparticles/paraffin wax composites.

3. Results and Discussion

SiO_2 nano-powder having a purity of 99.5%, density of 2.7 gm/cm^3 , the specific surface area of $170\text{-}200 \text{ m}^2/\text{g}$ and the PH value of 6.6 was used in this work [20]. This powder was characterized by atomic force microscopy which showed that the particles within the investigated specimens have sizes range (20- 55) nm while the average particle size calculated from the size distribution measurement, was about 38 nm. Figure 2 shows the atomic force micrograph and the associated size distribution measurement which was found reproducible over the investigated specimens.

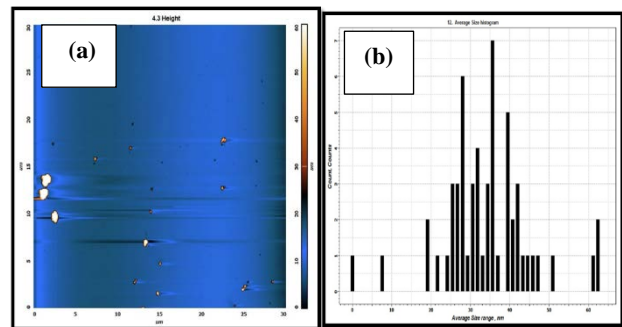


Figure 2: (a) Atomic force micrograph of the SiO_2 nano-powder (b). The corresponding size distribution measurement.

Figure 3 shows the X-ray diffraction pattern for the SiO_2 nano-powder in the 2θ range 10 – 70 degrees. Two sharp peaks were observed in this pattern that could be indexed to cubic silicon oxide structure [21]. The high peaks intensities at relatively low step-size of the measurements indicate that the synthesized powder is highly crystalline.

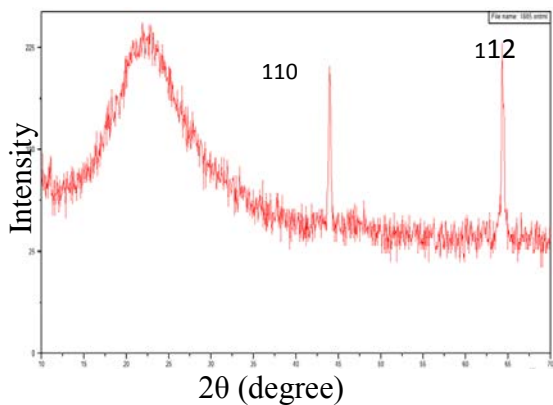


Figure 3: X- ray diffraction pattern of SiO₂ powder

Figure 4 shows the FTIR spectrum of the SiO₂ nano-powder. FTIR spectrum exhibited similar features to those observed by other researchers [22]. i.e. the infra-red band at 1632 cm⁻¹ and 3437 cm⁻¹ (which relate to stretching vibrations of H₂O), shoulder at 3246 cm⁻¹ (which relates to stretching vibration the Si-OH bonds). The broad and strong IR band at 1111 cm⁻¹ with the shoulder at 1188 cm⁻¹ is typically allocated to Si-O-Si asymmetric stretching vibrations. While infra-red band at 474 cm⁻¹ is due to O-Si-O bending vibrations [22].

FTIR result of paraffin wax, the characteristic peaks related to paraffin wax could be detected after 200, 400, 600, 800 and 1,000 cycles, see Figure 5. Peaks around 2960–2850 cm⁻¹ and 1465 cm⁻¹ indicate carbon-hydrogen stretching and bending absorptions. Symmetric C–H bending absorption that is related to CH₃ group at 1381 cm⁻¹ and the CH₂ rocking absorption band at 729 cm⁻¹ prove the linear saturated aliphatic structure regarding paraffin wax [23].

While in Figure 6 (paraffin wax /SiO₂) composite was determined after 2800 - 3000cm⁻¹. The peaks around 2848.29-295.62cm⁻¹ show carbon hydrogen stretching and bending absorption. The C–H bending absorption related to the CH₃ group at 1381 cm⁻¹ and the CH₂ rocking absorption band at 729 cm⁻¹ prove the linear saturated aliphatic structure regarding paraffin wax.

Through the FTIR analytic the addition of nano SiO₂ powder to the waste paraffin led to increasing of absorbance from the same region (2800-3000) cm⁻¹ as carbon-hydrogen stretching and bending bonds. So that be useful to increase the thermal properties of paraffin wax for energy storage applications.

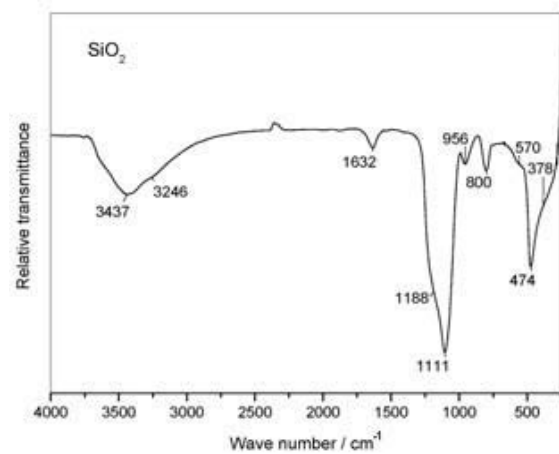


Figure 4: FTIR spectrum of the SiO₂ particles

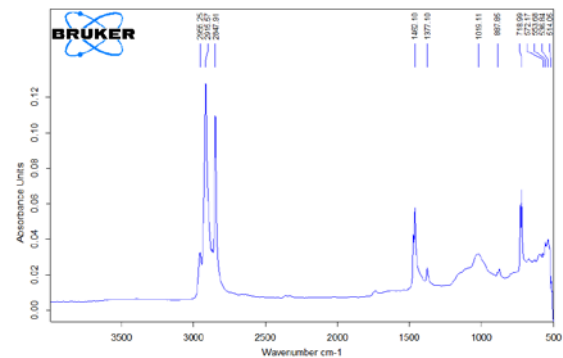


Figure 5: FTIR spectrum of the wax paraffin

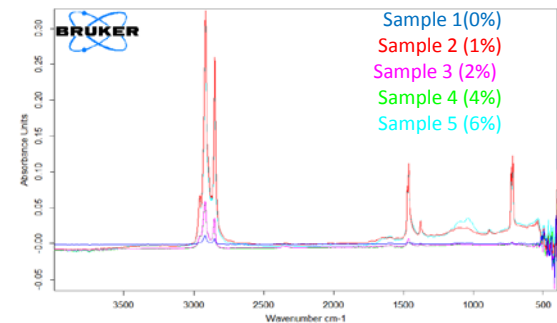


Figure 6: FTIR spectrum of the (nano SiO₂/wax paraffin) composites

The paraffin wax response to the thermal effect is shown in Figure 7, the differential scanning calorimetry (DSC). The DSC curve, in the temperature range 10 – 200 °C, shows that melting of the material occurs at 63 °C. The endothermic peak associated with the material melting exhibits a gradual increase at the low-temperature region where the rate of heat flow into the specimen is lower than that associated with the high-temperature region (i.e. the region where melting completes) [24–27].

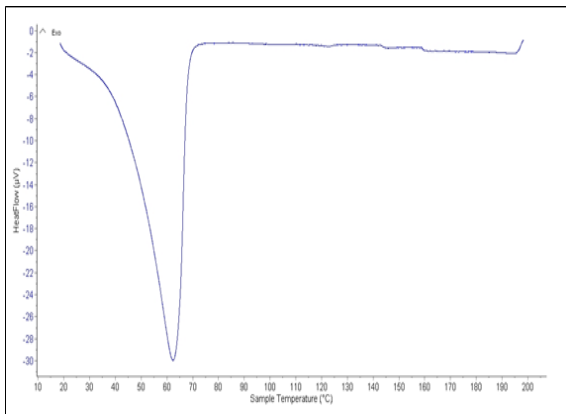


Figure 7: Differential scanning calorimetry of the pure paraffin wax.

Figure 8 display thermal conductivity behavior of SiO_2 /paraffin wax composite at different concentrations of SiO_2 nanoparticles. The thermal conductivity of the composites increases with the increase of SiO_2 nanoparticles. Because the SiO_2 nano particles have higher thermal conductivity than paraffin wax in other words SiO_2 nanoparticle behave like nano centers that assist thermal conductivity throw the composite materials and this effect increases with increase nano centers.

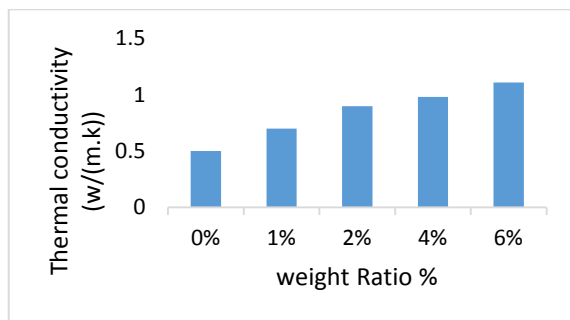


Figure 8: Thermal conductivity of SiO_2 / paraffin wax composite

4. Conclusions

Silicon dioxide nano-powder was utilized to enhance the thermal conductivity of paraffin wax used for thermal energy storage applications. The SiO_2 powder exhibited an average particle size of 38 nm. The SiO_2 nanoparticles were added into the melting paraffin wax to make SiO_2 / paraffin composites. The FTIR analysis revealed that the addition of SiO_2 nanoparticles led to the increase of absorption exhibited as carbon-hydrogen stretching and bending bonds. Increase thermal conductivity by increasing SiO_2 nanopowders to the paraffin wax. This study emphasizes that the addition of SiO_2 nano-particles is advantageous to the thermal properties of paraffin wax for energy storage applications.

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